Geospatial Mapping as a Guide for Resource Allocation Among Burn Centers in India

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Timely treatment is essential for optimal outcomes after burn injury, but the method of resource distribution to ensure access to proper care in developing countries remains unclear. We therefore sought to examine access to burn care and the presence/absence of resources for burn care in India. We surveyed all eligible burn centers (n = 67) in India to evaluate burn care resources at each facility. We then performed a cross-sectional geospatial analysis using geocoding software (ArcGIS 10.3) and publicly available hospital-level data (WorldStreetMap, WorldPop database) to predict the time required to access care at the nearest burn center. Our primary outcome was the time required to reach a burn facility within India. Descriptive statistics were used to present our results. Of the 67 burn centers that completed the survey, 45% were government funded. More than 1 billion (75.1%) Indian citizens live within 2 hours of a burn center, but only 221.9 million (15.9%) live within 2 hours of a burn center with both an intensive care unit (ICU) and a skin bank. Burn units are staffed primarily by plastic surgeons (n = 62, 93%) with an average of 5.8 physicians per unit. Most burn units (n = 53, 79%) have access to hemodialysis. While many Indian citizens live within 2 hours of a burn center, most centers do not offer ICU and skin bank services that are essential for modern burn care. Reallocation of resources to improve transportation and availability of ICU and skin bank services is necessary to improve burn care in India.

Improving access to surgical care has moved to the forefront of the global health agenda. As part of the United Nation's Sustainable Development Goals, a specific focus has been directed toward achieving universal access to safe surgical care in a secure, affordable, and effective manner.[1,2] Thermal injuries account for 77% of preventable deaths among surgically treatable causes of mortality around the world.[2] These injuries disproportionately affect young patients resulting in significant annual losses in gross domestic product for low- and middle-income countries.[1,2] With this in mind, immediate intervention is necessary to prevent continued and increasing burden of disease.[1]

Surgical interventions required for the treatment of thermal injuries represent essential procedures as defined by the Lancet Commission on Global Surgery and World Health Organization.[3–5] The global standardization of burn care and international implementation of Advanced Trauma Life Support and Advanced Burn Life Support programs have led to improved outcomes for patients presenting with burn injuries. Additionally, it is indisputable that timely access to care is critical in these situations.[6] One of the most significant indicators of survival in any injury is the time to intervention.[7–12] In this manner, emergency transportation systems, distance to district hospitals, and access to optimal burn care resources have a direct impact on outcomes among local patient populations.

As the second most populous country in the world with one of the fastest growing economies, India presents an important public health challenge from the perspective of burn care delivery.[13–16] More than 1 million patients suffer burn injuries in India each year; of these patients more than 700,000 require treatment or hospitalization, imposing an immense burden on both public and private hospitals and across both medical and surgical subspecialties.[15,17] Importantly, more than 90% of these injuries are thought to be preventable. With only 50 physicians per 100,000 people and even fewer surgeons, the majority of health care originates in the private sector leading to catastrophic expenditures among patients with burns in India.[15,17]

The goal of the current study was to define the current state of access to burn care in India, accounting for those factors known to affect outcomes among patients with burn injuries including access to skin banks and intensive care units (ICUs). Understanding limitations in access to burn care in India has the potential to inform future approaches focused on increasing access to care. The juxtaposition of extreme wealth alongside visible poverty, striking degree of urbanization adjacent to traditional rural populations, and overburdened, yet

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Conflict of interest statement. I.B.M. is a co-founder and CEO of Redivis Inc. whose software was used to perform the geospatial analysis presented in this article. The remaining authors have no conflicts of interest to disclose.

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resourceful healthcare systems in both these findings have the potential to apply to low- and high-income countries alike given the breadth of economic and social barriers that must be overcome to improve access to care in a country as diverse as India.

METHODS

Burn centers in India were identified by the All India Institute of Medical Sciences and National Academy of Burns-India using data from the official website of National Academy of Burns-India (http://thenabi.org/bcp.php).[18] Centers that were part of the National Academy of Burns-India were included. Each identified institution was surveyed regarding structure and resource availability. The retrieved data included location and type of hospital, type of funding (government or private), human resources (eg, type and number of surgical and hospital personnel), capacity (eg, number of burn unit and ICU beds), and supplies (eg, availability of skin bank facilities, laboratory services, physiotherapy, ventilator support, and dialysis).

We analyzed time and distance to all burn centers, as well as the proportion of the population living within 2 hours of a burn center. The location of each burn center was defined using geographic coordinates of latitude and longitude. These data were geocoded in ArcGIS 10.3 and subsequently analyzed in Redivis (Redivis Inc.).[19] Redivis is a Stanford-based online visualization platform that allows for greater accuracy in determining the population that resides within this 2-hour threshold. Rather than using Euclidean (straight-line) distance, Redivis uses road network information, including road type and corresponding speed limit (sourced from OpenStreetMap [https://www.openstreetmap.org/]) to implement a time–distance algorithm (http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-the-cost-distance-tools-work.htm) to predict the time it would take for individuals to access care throughout the country. We combined multiple geospatial layers of geographic and population data for India with our geocoded burn unit statistics using OpenStreetMap (OpenStreetMap Foundation) and the WorldPop database (GeoData Institute).[20] OpenStreetMap is an online mapping system that uses GPS technology, aerial mapping, and field maps to visualize road-specific composition and resultant speed data.[20] The WorldPop database (GeoData Institute; [http://www.worldpop.org.uk/]) is a high-resolution mapping system constructed using peer-reviewed methodologies.[21–23] In this system, spatial demographic datasets are created to map the world's population density per square meter.

To calculate distance and time, we used Manhattan distance (distance based on road infrastructure) to present our findings based on maximum travel times using standard travel routes.[23] The 2-hour distance was estimated using established speed limits for roads and highways and average walking speed where no roads were present. This 2-hour time period was specifically established to account for the Lancet Commission of Global Surgery's recommendation that emergency procedures become available within 2 hours to improve access to safe surgical care.[24]

By combining these data visualization strategies for each burn center alongside country-specific data regarding road infrastructure, we were able to calculate the time and distance to all burn centers as a function of the population living within 2 hours of a burn center as previously described.[25] Finally, based on established guidelines used by the American Burn Association in the United States, we identified a minimum set of resource criteria (eg, presence of an ICU and a skin bank) that if met by an individual facility, indicated that the burn center had the potential to provide surgical care to patients requiring operative intervention after thermal injury.[26]

RESULTS

A total of 67 inpatient hospital burn care facilities were identified within India as provided in Table 1. Of these, 30 (44.8%) were funded by the local, state, or central government, while 37 (55.2%) were private institutions. The majority of units were staffed by plastic surgeons (n = 62), with an average of 5.8 physicians per unit. A total of 1339 inpatient beds were available for patients with burns across the entire country (0.1 beds per 100,000 population). Although many institutions included an ICU specifically for burn patients (n = 51; 76%), there were a total of only 297 burn-specific ICU beds available within these units. Of these facilities, 53 (79%) had access to hemodialysis facilities.

Approximately 75.1% of the population was estimated to live within 2 hours of a designated burn center (Figure 1). Most of the population was located within 2 hours of a burn facility staffed by 1 to 10 physicians, while a minority of patients (8.1%) were able to receive care at institutions with 20 to 30 physicians (Figure 2). With regard to the availability of specific resources within these burn centers, 64.4% of the population lived within 2 hours of a burn-specific ICU, while only 21.8% had access to a center with a skin bank. Only 15.9% of the population lived within 2 hours of facilities that had access to both an ICU and a skin bank. Regions lacking access to an American Burn Association type facility in India and the United States are compared in Figure 3.

DISCUSSION

Thermal injury is a major source of global mortality that is particularly prevalent in the developing world. In fact, recent demographic data suggest that more than 90% of all mortality secondary to thermal injury occurs in low- and middle-income countries.[4] The scope of this problem is effectively demonstrated in countries like India where approximately 1,000,000 thermal injuries occur annually and are one of the leading causes of disability.[14] In this article, we focused on defining the current state of access to burn care facilities in India as this is a large developing country particularly plagued by the burden of this specific disease process. In doing so our goal was to identify barriers to accessing adequate care and opportunities for targeted improvements in care for patients with thermal injuries.

India is a huge country with a total population of 1.36 billion distributed in 29 states and 7 union territories. The results of our study suggest that the majority (75.1%) of the population in India lives within 2 hours of a designated burn

Table 1. List of burn care hospitals in India

Site Number	Hospital Name	City	Funding
1	King George Hospital and Andhra Medical College	Visakhapatnam	Government
2	NRI Medical College	Vijaywada	Private
3	Guwahati Medical College and Hospital	Guwahati	Government
4	Assam Medical College	Dibrugarh	Government
5	Nemcare Hospital	Guwahati	Private
6	Burn Hospital, Pandasarai	Darbhanga	Private
7	Apollo Burn Hospital	Patna	Private
8	Patna Medical College and Hospital	Patna	Government
9	Kalda Burn & Plastic Surgery Center	Raipur	Private
10	JLNHRC	Bhilai	Private
11	Burn & Trauma Research Center	Bilaspur	Private
12	UCMS and GTB hospital	Delhi	Government
13	Lok Nayak hospital	Delhi	Government
14	Safdarjung Hospital	Delhi	Government
15	PGIMER & Dr RML Hospital	Delhi	Government
16	Jaipur Golden Hospital	Delhi	Private
17	Jai Prakash Narayan Apex Trauma Centre, AIIMS	Delhi	Government
18	Gujarat Burns Hospital and Research Centre	Ahmedabad	Private
19	Solace Hospital	Vadodara	Private
20	BAPS—SM hospital	Vadodara	Private
21	PGIMER	Rohtak	Government
22	RPGMC	Tanda	Government
23	Sher-I-Kashmir Institute of Medical Sciences	Srinagar	Government
24	SMHS Hospital Govt Medical College	Srinagar	Government
25	MGM Medical College Hospital	Jamshedpur	Government
26	Tata Main Hospital	Jamshedpur	Private
27	Devkamal Hospital and Research Centre	Ranchi	Private
28	KLES Dr Prabhkar Kore Hospital & MRC	Belagavi	Private
29	AJ Institute of Medical Sciences	Mangalore	Private
30	St Johns Medical College and Hospital	Bangalore	Private
31	Elite Mission Hospital	Thrissur	Private
32	Jubilee Mission Medical College	Thrissur	Private
33	Ernakulum Medical College	Ernakulum	Private
34	Kamla Nehru Hospital Building Hamidia Hospital	Bhopal	Government
35	Choithram Hospital and Research Center	Indore	Private
36	Sir Aurobindo Institute Medical Sciences	Indore	Private
37	Lake City Hospital	Bhopal	Private
38	NSCB Medical College	Jabalpur	Government
39	Lahane Hospital	Latur	Private
40	Pravara Institute of Medical Sciences	Loni	Private
41	K.E.M hospital	Mumbai	Government
42	Vedant Hospital	Nashik	Private
43	Shriram Hospital	Akola	Private
44	BJ Wadia hospital	Mumbai	Government
45	Masina Hospital	Mumbai	Private
46	National Burns Center, Airoli	Navi Mumbai	Private
47	Lokmanya Tilak College and Hospital	Mumbai	Government
48	Bembde Hospital	Aurangabad	Private
49	SCB Medical College	Cuttack	Government
50	Institute of Medical Sciences	Bhubaneswar	Private
51	Dayanand Medical College & Hospital	Ludhiana	Private
52	Fortis Hospital	Ludhiana	Private
53	Christian Medical College and Hospital	Ludhiana	Private
54	Amandeep Hospital	Amritsar	Private
55	SMS Medical College	Jaipur	Government
56	Mahatma Gandhi Hospital	Jodhpur	Government
57	Government district hospital	Kumbakonam	Government

Table 1. Continued

Site Number	Hospital Name	City	Funding
58	Ganga Medical Centre and Hospitals	Coimbatore	Private
59	Kilpauk Medical College and Hospital	Chennai	Government
60	Gandhi Medical College	Secunderabad	Government
61	Vinayak Hospital	Noida	Private
62	JN Medical College	Aligarh	Government
63	SIPS Hospital	Lucknow	Government
64	Sanjay Gandhi Postgraduate Institute of Medical Sciences	Lucknow	Government
65	Sir Sunderlal Hospital, Institute of Medical Sciences	Varanasi	Government
66	Anandaloke Hospital and Neurosciences Centre	Siliguri	Private
67	IPGMER and SSKM Hospital	Kolkata	Government

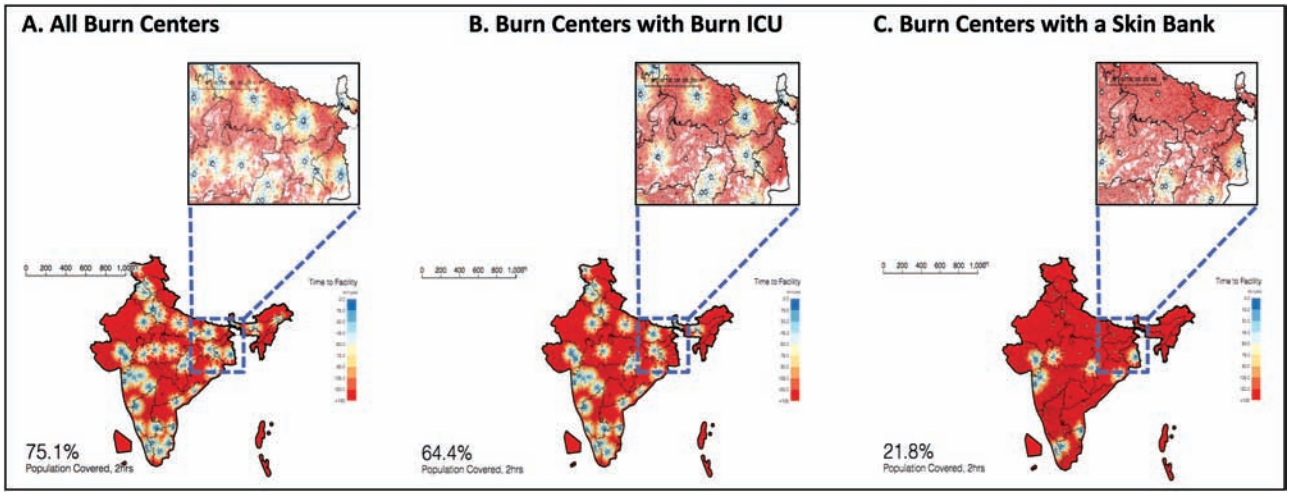

Figure 1. Population of India within a two-hour travel time of burn centers. (A) Population (75.1%) within two-hour travel time from all burn centers (gray dots) in India. (B) Population (64.4%) within two-hour travel time from burn centers with a burn ICU. (C) population (21.8%) within two-hour travel time from burn centers with a skin bank facility. Insets indicate partial map of India depicting higher population densities (> 300 people/m2) with highlighted dots: If outside of the 2-hour travel time to burn centers with a particular facility, the population densities are dark gray. If they are within this travel time, the population densities are light gray. The circles with a black outline indicate locations of burn centers.

center. In theory, this proportion of the population should be able to access basic services at burn care in a timely manner. However, not all of these centers provide access to the same resources necessary for complete care of the burned patient. Specifically, only 64.4% of the population can access an ICU and only 21.8% of the population has timely access to a burn center with a skin bank. Even more concerning is that only 15.9% of the population lives within 2 hours of a burn center that houses both an ICU and a skin bank; both ICU and skin banks are generally required to adequately care for patients with severe thermal injuries. Finally, only 8.1% of the population had timely access to centers with 20 to 30 physicians, suggesting a potential lack of access to specialty services when needed. Taken together, these data argue that not all burn centers in India provide the same level of care for patients and that the vast majority of patients are unable to access centers that are equipped to provide complex care to their patients. This is supported by an article by Shanmugakrishnan et al, who found that no patients with burns greater than 55% TBSA survived in a study of 150 patients treated at an Indian burn center.[27] However, mortality rates for patients with less than 30% TBSA burns were low, suggesting that the burn center could adequately care for patients with burns requiring less complex care but was unable to adequately support those patients in more critical condition.

While 75% of the Indian population can theoretically access a burn care center within 2 hours, it is important to remember that the remaining 25% of the country represents a largely underserved population with limited access to even basic burn care. There are certainly many systems-level issues present that limit the effectiveness of burn care in India. Transportation infrastructure limits the ability of patients to reach medical care. Inadequate staffing and availability of critical care services limit the scope of care available for patients with thermal injury. Limited access to nonphysician healthcare providers reduces the ability of the system to triage care and offload simple cases from overworked physicians. Affordability of care constraints or may even prohibit the care that patients are able to seek or receive. However, each of these factors presents unique opportunities to improve the care that Indian hospitals can provide for their patients with thermal injuries.

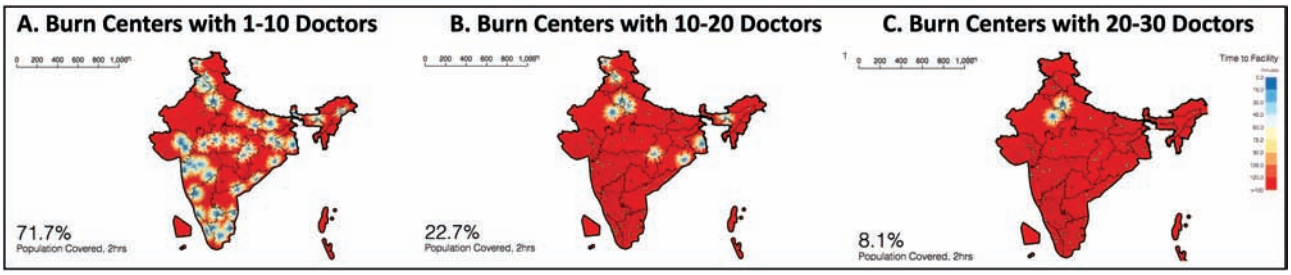

Figure 2. Distance analyses of population-level spatial access to burn doctors. (A) Population (71.7%) within two-hour travel time from burn centers (gray dots) in India with 1 to 10 doctors. (B) Population (22.7%) within two-hour travel time from burn centers in India with 10 to 20 doctors. (C) Population (8.1%) within two-hour travel time from burn centers in India with 20 to 30 doctors.

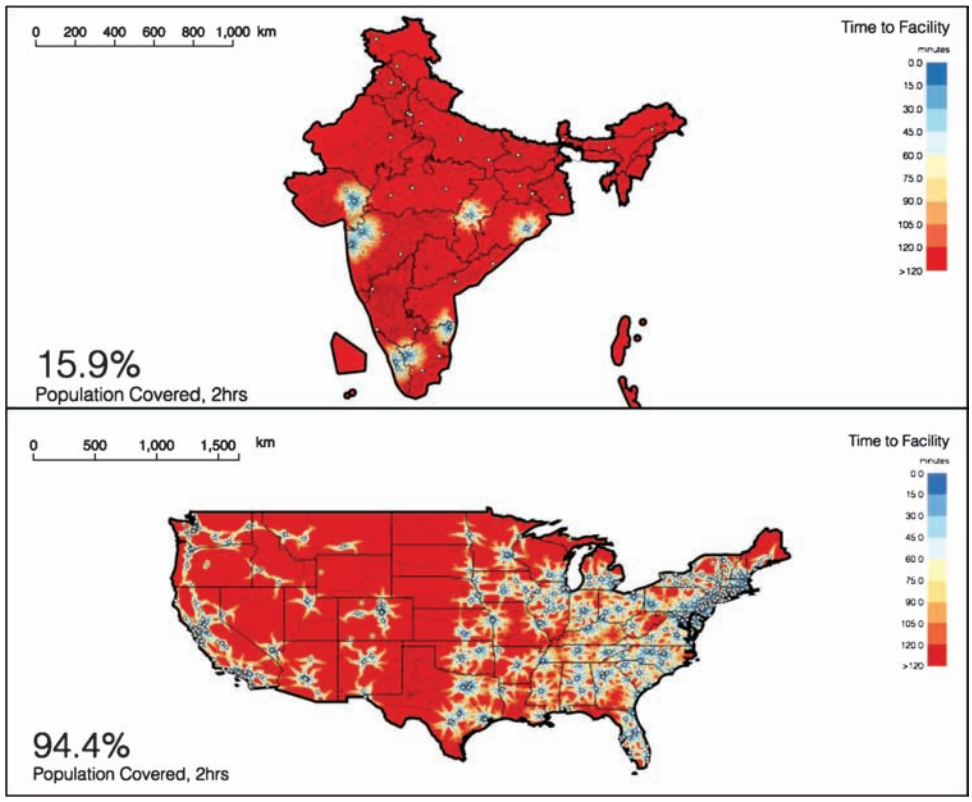

Figure 3. Population of India vs United States within a two-hour travel time of burn centers with ICU and skin bank. (A) Population (15.9%) within two-hour travel time from burn centers (gray dots) in India with a burn ICU and skin bank. (B) Population (94.4%) within two-hour travel time from burn centers in the United States with ABA verification.[29]

In an effort to improve care for patients with thermal injury in India, we advocate for prioritizing efforts toward improving infrastructure within existing hospitals as our results suggest that existing centers provide accessible care for the majority of the population. Scaling up services within existing centers avoids overhead costs associated with real estate and construction and may supplement resources available to invest in improving burn-specific infrastructure and workforce. Improvements to existing centers such as increasing burn-specific ICU beds, skin banks, and surgical services would greatly improve these hospitals' ability to provide care for patients with both simple and complex injuries. Another focus for systems-based improvement is an emphasis on task shifting, which has already been demonstrated as a valid concept in the surgical setting by the Aravind Eye Care System in India.[28] Task shifting is defined as the designation of specific duties to capable trainees who have limited specialty training or education in a certain field. With regard to burn care, it would be entirely feasible for trained workers to evaluate and address minor burns in an effort to triage care and reduce the overwhelming volume that often floods burn care centers in India. This care can also be transferred to community workers who can evaluate patients closer to home in rural villages and potentially mitigate the time and financial requirements necessary to receive burn care in the current system. As such, areas identified in our current geospatial study as being located further than 2 hours from a burn center may be the ideal site for initiation of such training programs.

The model that we describe in this article uses geospatial imaging to combine population density and public map data

to estimate the time it would take an individual to access a burn center in India. This is a creative strategy that allows us to make broad estimates of an otherwise complicated calculation. However, this technique creates its own limitations that should be considered when interpreting the data. First and foremost, it assumes that an individual has the capability to travel at the speed limit of a given road. In India many individuals do not have access to reliable transportation; the time they would require to either acquire a ride or make the trip by some alternative mode of transportation may be much longer than our model estimates. Adverse road conditions may also contribute to longer travel times. If this were the case our results would likely underestimate the time it would take an average Indian to access specialty burn care. In addition, the cost of travel may be a significant barrier that prevents some patients from accessing care. In this case, one's ability to seek care at a burn center would not depend on proximity at all but rather on the financial ability to afford care and the associated travel costs. In India, alternative forms of medicine such as Ayurveda are an important part of the healthcare system and it may be possible that patients have better access to these therapeutic methods than to the conventional burn care system. Access to these alternative therapy options is not reflected in our study. We also do not account for resources available from neighboring pharmacies or other hospitals. Importantly, though, access to surgical care remains a critical aspect of proper burn care and cannot be provided by alternative strategies. Additionally, as our analysis focuses on the resources within burn centers documented by the National Burns India registry, it is possible that our results underestimate the availability of burn care as there are facilities particularly in the private sector that were not included in our analysis.

Ultimately, investment in both existing and new systems will be required to serve the diverse population and high volume of thermal injuries that occur within India. Given the scarcity of existing resources, we believe that attention must first be directed toward improving the quality of care and resource availability within existing centers while simultaneously developing innovative solutions to serve those with limited access to any form of care. Improving access to burn care represents an important challenge that must be approached and overcome in a stepwise fashion to address the serious impact that these injuries continue to have on healthcare systems and economic growth within developing nations.

CONCLUSION

In conclusion, this study demonstrates that nearly 75% of the population lives within 2 hours of a designated burn center. However, there exists substantial state and regional variation in geographic access to these centers. While the optimal distribution of burn centers relative to population and area is yet to be determined, these data provide important information about population access that may be used to guide resource allocation in burn care in India.

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