Basic Seismic Response Capability of Hospitals in Lima, Peru

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ABSTRACT

Objective: The objective of the study was to research the basic seismic response capability (BSRC) of hospitals in Lima Metropolitana. A large number of wounded could be registered in case of an earthquake; therefore, operational hospitals are necessary to cure the injured. The study focused on the operational performance of the hospitals, autonomies of essential resources such as power, water, medical gases, and medicine, in addition to the availability of emergency communication system and ambulances.

Methods: Data by a probabilistic seismic risk analysis have been used to assess the operational level of the hospitals. Subsequently, availability of an essential resource has been combined with the immediately operational hospitals to evaluate the BSRC of the health facilities.

Results: Forty-one of Lima's hospitals have been analyzed for a seismic event with 72-100 years of a return period. Three hospitals (7.3%) were capable to work in a self-sufficient manner for 72 hours, another three (7.3%) for 24 hours, and one (2.4%) for 12 hours.

Conclusion: Results showed a low performance of the hospitals in case of an earthquake. The issue is due to the high seismic vulnerability of the existing structures. Given the importance of Lima city in Peru, structural and nonstructural retrofitting plans should be implemented to improve the preparedness of the health system in case of an emergency. (*Disaster Med Public Health Preparedness*. 2019;13:138-143)

Key Words: disasters, earthquakes, emergency preparedness, hospitals, risk assessment

Peru is one of the high seismic risk countries in the world with a long history of destructive earthquakes.[1] The major cause of this phenomenon is the subduction process between the Nazca and South American plates. The most destructive earthquakes registered were the 1746 Lima earthquake (8.4 Mw), the 1970 Ancash earthquake (7.8 Mw), the 2001 Arequipa earthquake (6.9 Mw), and the 2007 Pisco earthquake (8.0 Mw).[2] After the Arequipa and Pisco earthquakes, several hospitals suffered heavy damage or collapses and, because of that, limited hospital service was provided.[3,4,5]

According to the Centre for Studies and Prevention of Disasters (PREDES; Lima, Peru), an 8.0-Mw earthquake in front of coastal Peruvian areas around Lima with tsunami consequences is expected to occur.[6] As reported by PREDES, 316,029 houses could be affected, 779,338 people may be injured, and 68,000 could die based on a seismic scenario of 8.0 Mw.[6] Intensive treatment and surgery would be required for the injured.[7,8] Furthermore, a high level of vulnerability is expected in Lima's hospitals in case of earthquakes, as stated in the work done by the Pontifical Catholic University of Peru (PUCP, Lima, Peru).[9] Given the previsions, the major challenge remains to determine whether the hospitals in Lima are capable to provide medical care to the expected injured.

Some work has been done in Peru to assess economic losses, structural, nonstructural, and organizational vulnerability, patient demand and performance of the hospitals in Lima in case of earthquakes, but not many prediction studies of the response capability in case of earthquakes have been developed.[9,10,11] Therefore, the development of models capable to determine which hospitals can face an emergency is very important.

Post-earthquake results showed that medical service was affected by structural and nonstructural damages, loss of electricity, water, and communication.[12,13] The Chilean experience after a 2010 earthquake showed that even a well-prepared country, such as Chile, suffered an interruption of hospital service.[14,15] After the 2011 Christchurch earthquake, hospital performance suffered due to damages to lifelines rather than structural components.[16] Although more components can affect the functionality of a hospital after an earthquake, the structural and nonstructural ones remain essential for the operational level of hospitals.

The capacity of the hospitals to provide health service in case of an emergency depends on several variables, and it has been assessed with different approaches. Risks, available clinical services, utilities, supplies, building integrity, telecommunication and transportation systems, key staff, operating theaters, and beds are the most common variables taken into account in preparedness guidelines.[17] In regards to the approaches, hospital treatment capacity (HTC) was assessed focusing on functional operating rooms and physical, human, and organizational aspects.[18,19] The impact of facility damages on hospital capacities was evaluated considering net damage coefficient, beds, operating rooms, laboratories, emergency department capacities, and waiting time.[20] Finally, national hospital preparedness was assessed considering the local hazards, the compliance of the pavilions with the building code and resources such as electricity, water, communication tools, and transportation system.[21]

Though several variables and models have been considered in past research to estimate performance of hospitals in case of earthquakes, the combination of seismic hazard, building damages, and lack of supplies has not been assessed fully. Thus, the final goal of the study was to determine which hospitals were capable of providing medical care in case of a seismic event. Taking into account the aforementioned variables, a model capable to determine the seismic response capability of hospitals in Lima was developed.

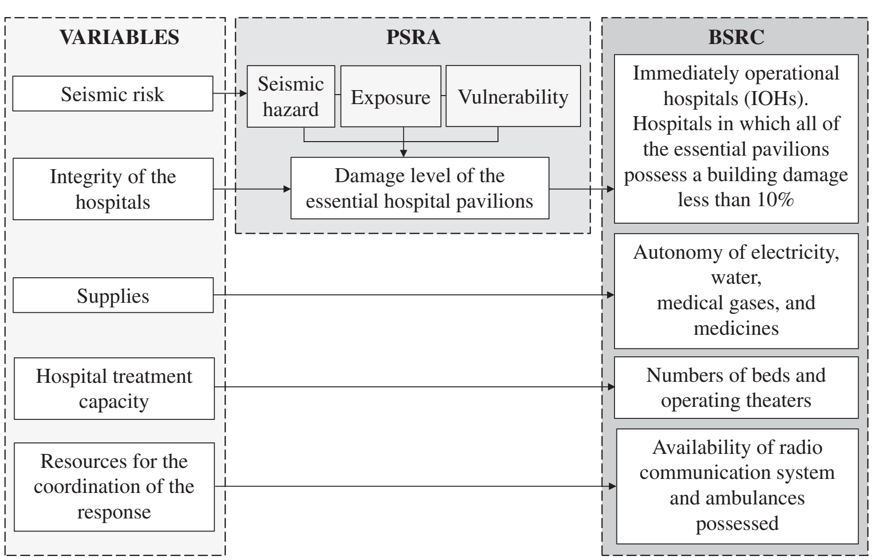
METHODOLOGY

This study aimed to assess the seismic response capability of the health facilities in Lima Metropolitana in case of a seismic event. Lima is a city with more than 10 million inhabitants in which the health system is composed of public (Ministry of Health), semipublic (Social Security), and private (clinics) sectors. According to a database created in 2012 by PUCP (Lima, Peru), about 41 hospitals with their 737 pavilions belonging to public and semipublic sectors were used to achieve the goal of the study.[9] Hospitals were selected considering the importance of the services provided in case of an emergency, the presence of beds, and operating theaters.

Following the results observed in past earthquakes and the principles provided by preparedness guidelines, the seismic response capability of the hospitals was assessed considering variables such as the seismic risk, the integrity of the hospitals, supplies, HTC, and resources for the coordination of the emergency response, as shown in Figure 1.[13,14,17] In the present study, given the lack of abundant data and the complexity of considering the relationship among the variables in a unique model, it has only been possible to determine a basic seismic response capability (BSRC), as illustrated in Figure 1. The BSRC was conceived as the set of the considered and measured variables, which could ensure the functionality of the hospitals after the impact of an earthquake. The seismic risk allowed quantifying not only the expected seismic damage to the essential hospital pavilions, but also the immediately operational hospitals (IOHs) after the impact of an earthquake. Supplies such as electric power, water, medical gases and medicine, and their related autonomies permitted to define the amount of hours that hospitals can remain functional in case of an

FIGURE 1

Scheme of the Basic Seismic Response Capability Assessment



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emergency. The HTC made it possible to quantify the number of beds and operating theaters possessed by the hospitals. Last, the resources for the coordination of the emergency allowed the establishment of the availability of redundant emergency communications system (radio) and the ambulances owned, hence the capacity of the hospitals to manage the response.

Immediately Operational Hospital

Probabilistic seismic risk analysis (PSRA) data about 41 hospitals carried out by PUCP were used to assess the damage level of the hospital buildings.[9] The PSRA allowed the assessment of the seismic hazard, the exposures, the vulnerability, and the damage of the analyzed hospital pavilions.[9] Regarding the seismic hazard, a seismic scenario with 72-100 years return period and peak ground acceleration of about 0.25 g was considered in the study. As soon as the damage was known, the performance of the hospital pavilions and the IOHs was evaluated. Because the study is focused on an emergency situation, only essential hospital pavilions which house important activities and services for caring for the injured were taken into account to assess the IOHs, as illustrated in Figure 2.[22] According to the Federal Emergency Management Agency (FEMA) and the investigated seismic return period, hospital buildings have to respect the immediate occupancy building performance, which provides a global damage to the building less than 10%.[23] Therefore, if a hospital possessed all of the essential pavilions with an expected level of seismic damage less than 10%, it was considered as an IOH, as shown in Figure 2.

Basic Seismic Response Capability

To evaluate the BSRC, data about supplies (autonomy of electric power, water, medical gases, and medicines), number of beds, number of operating theaters, availability of radio communication system and ambulances owned and collected during the development of the Health Contingency Plan of Lima and Callao hospitals in 2016 were used in the present study, as shown in Table 1.[22]

Taking into account the IOHs, the supplies, the number of beds, the number of operating theaters, the availability of radio communication system and ambulances owned, the BSRC frame was achieved, as shown in Table 1. In detail, if a hospital possessed all of the aforementioned supplies at the same time, and at least for 72 hours, 48 hours, 24 hours, and 12 hours, it was defined as a hospital capable to work in a self-sufficient manner for 72 hours, 48 hours, 24 hours, and 12 hours, respectively. Of course, only the hospitals capable to continue working for 72 hours and with all of the essential resources to face an emergency can be classified as safe hospitals.[24]

RESULTS

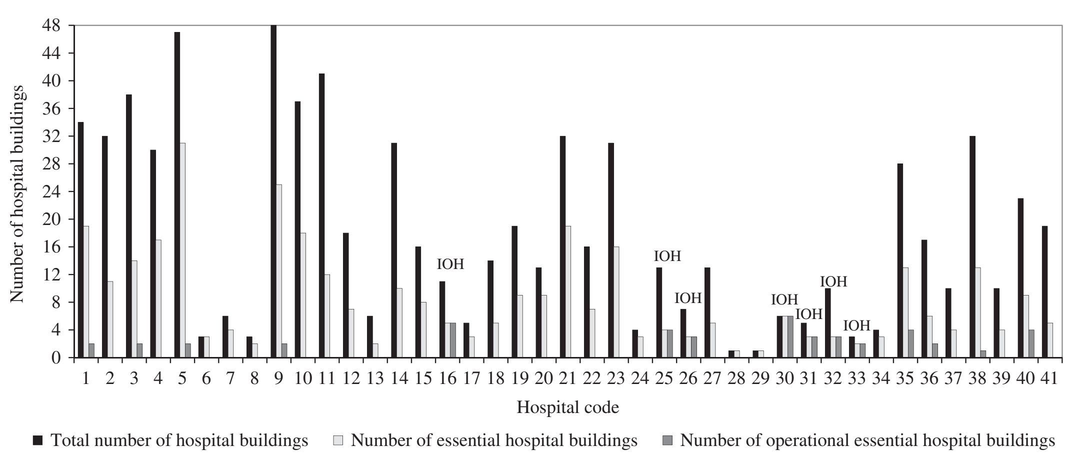
A total of 41 hospitals and 737 pavilions belonging to the public (Ministry of Health) and semipublic (social security) sectors have been evaluated. From the 737 pavilions, 344 (46.7%) have been classified as essential in case of a seismic event, as shown in Figure 2.

Immediately Operational Hospitals

Looking at the 344 essential hospital buildings, a damage level less than 10% was observed on 121 (35.2%) essential buildings for the seismic event analyzed (see Figure 2), whereas, focusing on the 41 hospitals, only 7 (17.1%) of them have been considered IOHs (see Figure 2).

FIGURE 2

Immediately Operational Hospitals (IOHs)



Abbreviation: IOH, immediately operational hospital.

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TABLE 1

Summary of the Basic Seismic Response Capability Measures by Hospitals

Hospital Code and IOHs	Electricity Supply (h)	Water Supply (h)	Gases and Medicines Supplies (h)	Number of Beds	Number of Operating Theaters	Radio Availability	Ambulances Availability
1	72	72	72	477	7	Y	3
2	72	12	24	451	5	Y	3
3	48	72	168	656	5	Y	3
4	48	120	168	697	13	Y	5
5	24	72	168	822	10	N	5
6	72	48	168	57	2	N	3
7	48	48	168	89	3	Y	2
8	12	72	168	241	5	Y	3
9	24	120	168	476	8	Y	3
10	48	120	168	344	6	N	2
11	48	72	168	590	0	N	2
12	72	72	120	70	2	N	4
13	48	12	12	71	3	N	2
14	48	72	168	230	0	Y	2
15	12	72	168	217	3	N	3
16*	72†	72	72	91	3	Y	2
17	12	12	12	79	2	N	2
18	12	24	24	38	1	N	1
19	24	24	48	105	2	Y	2
20	72	120	168	219	6	Y	3
21	48	168	168	430	10	N	N
22	24	120	168	1638	21	N	N
23	72	48	168	886	21	N	N
24	12	120	24	235	6	N	N
25*	72†	168	168	102	6	N	N
26*	72†	168	168	109	2	N	N
27	120	168	168	15	2	N	N
28	12	24	24	68	3	N	N
29	24	24	24	88	4	N	N
30*	72	24†	24	53	2	N	N
31*	72	24†	24	60	2	N	N
32*	48	24†	24	154	0	N	N
33*	12†	120	24	55	4	N	N
34	24	24	24	43	2	N	N
35	72	72	168	511	12	N	N
36	72	72	168	455	9	Y	6
37	24	24	12	0	0	N	N
38	72	120	168	224	2	Y	4
39	48	120	168	87	0	Y	2
40	72	24	24	11	3	N	3
41	72	72	168	387	9	Y	2

*Immediately Operational Hospital (IOH).
†Maximum hospital autonomy considering the availability of all supplies.

Supplies

Taking into account only the autonomy condition for which the hospital could be able to operate in a self-sufficient manner in case of an emergency, the hospital distribution autonomies for 120 hours, 72 hours, 48 hours, 24 hours, and 12 hours are respectively 1 (2.4%), 10 (24.4%), 10 (24.4%), 10 (24.4%), 10 (24.4%) (see Table 1).

Basic Seismic Response Capability

The BSRC of the hospitals for the seismic return period analyzed is shown in Table 1. Among the IOHs, the capacity to operate in a self-sufficient manner was 72 hours for 3 hospitals (7.3%), 24 hours for 3 hospitals (7.3%), and 12 hours for 1 hospital (2.4%). Furthermore, all of the hospitals except 1 possess beds, and only 5 hospitals do not possess operating theaters. At last, only 1 hospital has a radio tool and availability of owned ambulances.

DISCUSSION

Based on the expected scenario in Lima Metropolitana, an exploratory work to assess a BSRC of hospitals is presented. On a sample of 41 hospitals, 7 (17%) of them resulted as

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being able to continue working in a self-sufficient manner in case of an earthquake. Among the latter, only 3 hospitals (7%) possess supplies for 72 hours. In any case, they cannot be considered safe hospitals because they do not have essential equipment like radio and owned ambulances. Past earthquake experiences have denoted the importance of a redundant communication system for the medical response coordination capability.[25] For example, the communications infrastructure was severely damaged in a Japan 2011 earthquake.[26] As a consequence, it was difficult to use mobile and landline phones or computers with Internet service.[26] Instead, the presence of an alternative communications system, such as satellite data transmissions and radio, became crucial for the response to natural disasters.[2,25,27]

Despite the presence of a minimum backup of supplies possessed by the hospitals analyzed, the major factor that influences the BSRC is certainly connected to the vulnerability and the antiquity of the hospital buildings as already denoted in a past study on economic losses in Peru.[9] Low performance and response capacity of existing hospitals have been denoted in many past earthquake experiences. Achour et al., in a study on 34 hospitals and 9 past earthquakes, showed that hospital performance and the continuity of operation were affected by moderate or heavy structural damages and malfunction of power, water, gas, and telecommunication lines.[28] Thus, improvements of structural and nonstructural performance are essential to improve the functionality of the hospitals.

According to a model developed about the expected number of persons injured in Lima, between 4,666 and 121,303 injured could need treatment through inpatient care.[10] Comparing the results obtained by BSRC, it is possible to say that such patient demand should be faced by IOHs only, which corresponds to 17% of the hospitals analyzed. It is evident that, in case of an emergency, external aids such as the private sector and field hospitals are necessary.

Some simulation models to assess the seismic performance of health facilities have been developed, highlighting the importance of building integrity for a good response capability, especially in areas with a high level of seismic hazard. For example, Paul et al. proposed a methodology to predict the seismic response of hospitals combining and assessing capacities depending on the intactness of the buildings and the availability of operating rooms, laboratory, emergency departments, and beds.[20] Lupoi et al. and Miniati et al. developed an HTC index for 1 or more hospitals, focusing on functional operating theaters and considering structural and nonstructural damages, trained key stuff, and organizational aspects such as the presence of an emergency plan.[18,19] Although some models and capacities have been analyzed in the past, the present work took into account the availability of supplies for a certain amount of time (12 hours, 24 hours, 48 hours, and 72 hours) and the operability of the hospital, which have not been considered simultaneously until now.

The major limitations of the study lie in different aspects. First, variables such as the seismic risk, the integrity of the hospitals, supplies, HTC, and resources for the coordination of the emergency response belonging to the response capability were considered in the study. Additional aspects of preparedness and recovery capability can influence the health systems in case of earthquakes. The damage that the structures have been subject to has been evaluated considering the whole pavilion, with no regard to its local damage distribution. Together with this, the damage to lifelines and utility systems has not been considered. Concerning the HTC, the study was limited to considering only the maximum number of beds rather than the effective availability of beds. No evaluation on the quality of emergency contingency plans and training of key medical staff has been performed, and, last, due to the complexity of surveying new hospitals given their privacy regulations and the difficulty of getting permission, only the available hospital sample of 41 facilities was analyzed.

CONCLUSION

A BSRC of 41 existing hospitals belonging to public and semipublic health sectors in the Lima metropolitan area was evaluated. Physical damage to the structures, backup of power, water, gases and medicines, and availability of radio equipment and ambulances were selected as the measures of the BSRC. Even considering the exploratory nature of the study, a low response capability was found after the analysis, mainly due to the building vulnerability of the existing hospitals. Thus, an improvement of hospital preparedness starting from structural and nonstructural retrofitting plans on the existing hospitals should be considered by decision-makers for the future.

The methodology presented represents a way to assess the BSRC of hospitals in case of earthquakes. It is evident how the interconnections of all of the components are essential for their correct evaluation. Future research is necessary to study the relationships among the components and how they can be used as measures of the seismic response capability. Furthermore, capabilities such as medical readiness, medical response coordination, continuity of health care service delivery, and medical surge should be investigated. Finally, a study on a larger sample of hospitals can certainly help assess an effective and more realistic response of the health sector in Lima Metropolitana during the aftermath of an earthquake.

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