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Design Criteria of Shelter Hospitals in Response to Biological Accidents: A Systematic Review

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Abstract

Background: The appropriate response to mass causality biological events requires well-established preparedness and providing a surge capacity. In such a situation, a practical solution is to convert large public venues into shelter hospitals. Due to the lack of a guideline for the transformation of a large public center into a hospital, the present study collected the design criteria for the transformation of public buildings into shelter hospitals in response to biological events such as epidemics or mass causality biological accidents.

Methods: The keywords were searched in Scopus, Web of Science, and PubMed databases until November 2021. This systematic review was conducted using terms related to mass causality biological accidents, shelter hospitals, and design criteria.

Results: Of 1802 extracted articles, duplicates (n = 280) and unrelated publications (n = 1342) were left out in the initial evaluation. Among 180 remained papers, 29 records satisfied our criteria after reviewing abstracts and full texts. Most of the included studies were related to the transformation of public venues into hospitals in response to the coronavirus disease 2019 (COVID-19) pandemic. The investigated themes included site selection, layout and structure, waste and wastewater management, ventilation, communication, food and medicine delivery, humanitarians and social supports, post-treatment care, and Management measures.

Conclusions: In summary, large public venues are highly recommended alternatives for surge capacity in response to mass causality biological accidents. However, the main challenges for using these centers are the provision of basic requirements such as water and electricity, ventilation, and available space.

Preparedness against disasters is a challenging issue for health systems. For example, the coronavirus disease 2019 (COVID-19) pandemic (as a mass causality unintentional biological accident) brought about many health challenges. Based on the past updates, during the pandemic, more than 554 million people were infected and more than 6 million people died.[1–3] In this situation, policy-makers found that the preparedness of the health-care system was not acceptable. Challenges such as the lack of personal protective equipment, regulating quarantine and social distancing, making decisions in new emergency conditions, and most importantly the provision of hospital beds discovered deficiencies in health systems.[4–7]

Different solutions are offered to create additional hospital capacity in response to mass causality disasters, however, 1 of the most practical methods is the establishment of hospital shelters. To be more detailed, the shelters are large-scale buildings/venues Author: Please provide highest academic degree for each author. Also, please confirm spelling and order of names. Thank you.

into hospitals used to treat patients and accommodate survivors. The role of the shelter hospital during and after a mass causality biological accident is to reduce the admission load of permanent hospitals by providing patients with medical care and life-saving conditions. On the other hand, by accepting mild-to-middle-symptom patients, shelter hospitals can reduce the likelihood of the spread of disease in society.[8,9] The establishment of shelter hospitals in response to different disasters is a historical approach, through which public buildings such as schools, sports complexes, theaters, and large exhibition halls were converted into temporary hospitals. Large space and short-time conversion are 2 main characteristics of shelter hospitals.[9–11]

Ansary et al. (2010) acknowledged that public buildings such as schools, religious facilities, and social centers can be used as shelters during disasters, although the vulnerability of these buildings should be evaluated in advance.[12] To exemplify, after the typhoid epidemic in Montreal, Canada (1910), and the influenza epidemic in Spain (1918), public buildings and

large industrial centers were used as shelter hospitals to increase the number of hospital beds.[13] Also, a recent successful experience in the transformation of public venues into shelter hospitals was performed in response to the COVID-19 outbreak, especially in China. Several Fangcang hospitals provided surge capacity for patients with mild-to-moderate levels of disease. These temporary hospitals increased the number of hospital beds. The Fangcang hospitals had an undeniable role in the collapse of the epidemic in highly infected areas of China.[4,9,14–16]

Several earlier publications evaluated alternative solutions to create additional hospital capacity in response to man-made and natural accidents as well as wars[17–20]; however, information about intentional and unintentional biological accidents is very limited. Also, the nature of biological accidents is different from that of chemical, nuclear and radioactive ones.[21,22] During biological accidents (intentional accidents like mass causality biological attacks and unintentional accidents like an epidemic), it is necessary to separate infected patients from society to reduce the spread of disease. In addition, providing surged hospital capacity and its related solutions is very important.[23–26] Therefore, the present study examines the main design criteria and necessary standards for transforming public buildings into temporary medical centers and shelter hospitals for the treatment and temporary accommodation of patients in response to mass causality biological accidents and epidemics.

Methods

The present study is a qualitative systematic review aimed to collect design criteria for temporary shelter hospitals in response to mass causality intentional and unintentional biological accidents. To find the main keywords, 10 related articles from high-ranking journals were studied, accompanied by pieces of advice from experts. The keywords were searched in databases including PubMed, Web of Science, and Scopus by a search strategy described in Table 1.

The inclusion criteria were the relevancy of the articles to the research question (design criteria for the transformation of public buildings to shelter hospitals in response to mass causality intentional and unintentional biological accidents), the types of included documents were original articles, reviews, letters to the editor, reports, practice, health policy and commentary published until November 2021. Also, the exclusion criteria are as follows:

1. Articles dealing with chemical, nuclear, and radioactive accidents; wars; and natural disasters like floods and earthquakes.
2. Articles focused on the design criteria of permanent hospitals.
3. Articles whose full text was not accessible.
4. Non-English language articles.

After the systematic search, duplicates were removed. Then, the articles were evaluated based on the inclusion and exclusion criteria. In the initial screening, the title and abstract were assessed. The articles related to the research subject were fully evaluated in terms of content. The remaining articles were used to extract the design criteria for shelter hospitals in response to intentional and unintentional biological events. The PRISMA flowchart is presented in Figure 1. All the steps of the study, including selection, evaluation, and data extraction, were carried out by 2 researchers, separately. In each phase of data extraction, any controversy between the 2 researchers was discussed by a research team to reach a common idea, and then the next stage began.

To extract the design criteria, a researcher-made checklist (as an Excel file) was used. The main extracted items were the title of the article, publication year, the type of biological accident or epidemic studied, the type of public building, the name of the shelter or temporary hospital, the capacity of the hospital, the number of admitted and recovered patients, and the design and establishment criteria of a shelter hospital in response to biologic disaster; because this study was a qualitative systematic review, the last step was the extraction of articles related to qualitative synthesis, in which the articles were read completely by the research team. Finally, the criteria for converting large public places into shelter hospitals in response to mass causality biological accidents were extracted.

Table 1. Search strategy and keywords

#1 AND #2 AND #3	Strategy
"biologic disaster" OR "biologic emergency" OR "bioterrorism" OR "biologic attack" OR "biologic event" OR "biologic threats" OR "biologic crisis" OR "biologic risk" OR "biologic hazards" OR "biologic catastrophe" OR "biologic incident" OR "Biohazard Release" OR "Biowarfare" OR "biologic accident" OR "Biological" OR "CBRN" OR "CBRNe" OR "Biohazard" OR "Mass Casualty Incidents" OR "Biological Terrorism" OR "agent" "Bioterrorism" OR "Pandemic" OR "Epidemic" OR "Outbreak" OR "Disaster" OR OR "Incident" OR "Emergency" OR "Accidents" OR "Event" OR "Threat" OR "Agent" OR "tragedy" OR "Mass Casualty Incidents" OR Pandemic	#1
"Field Hospitals" OR "Mobile Hospital" OR "temporary health–care facility" OR "shelter hospital" OR "settlement hospital" OR "settlement health–care facility" OR "primary health–care facility" OR "Fangcang Hospital" OR "Fangcang shelter hospitals" OR "peripheral health–care centers" OR "makeshift emergency hospital" OR "settlement health–care"	#2
Design and Construction OR Renovations OR Design parameter OR Design building OR construction building OR surge capacity OR Medical Countermeasure OR design criteria OR design consideration OR reconstruction OR standard OR criteria OR practice OR development	#3

Results

The total number of included articles was 1802, after removing the duplicates (n = 280) and initially screened articles (n = 1342), 180 related articles remained for content assessment. Twenty-nine articles were finally selected for extraction of the criteria (Figure 1).

Most of the final extracted articles were published by Asian researchers and studied temporary hospitals in China. Of the final articles (n = 29) entered into the study, 17 publications were carried out in Asia, 5 studies in North America, 4 studies in Europe, and 2 articles in Africa. Only 1 study was conducted with a global approach (Table 2). Almost all the articles described the design criteria for converting public centers into temporary hospitals in response to the epidemic of COVID-19 and Ebola. Most of the public buildings converted into shelter hospitals were sports stadiums.

Table 3 describes the criteria to establish a shelter hospital in response to a biological disaster. The important factors were classified into 9 themes including location, layout, waste management, ventilation, information technology (IT) and communication, supplementation (drug and food), humanitarian supports, post-curing acts, and management measures. Each theme has some subthemes through which we defined the criteria.

Discussion

The present study was a qualitative systematic review in which authors collected principal design criteria for converting large

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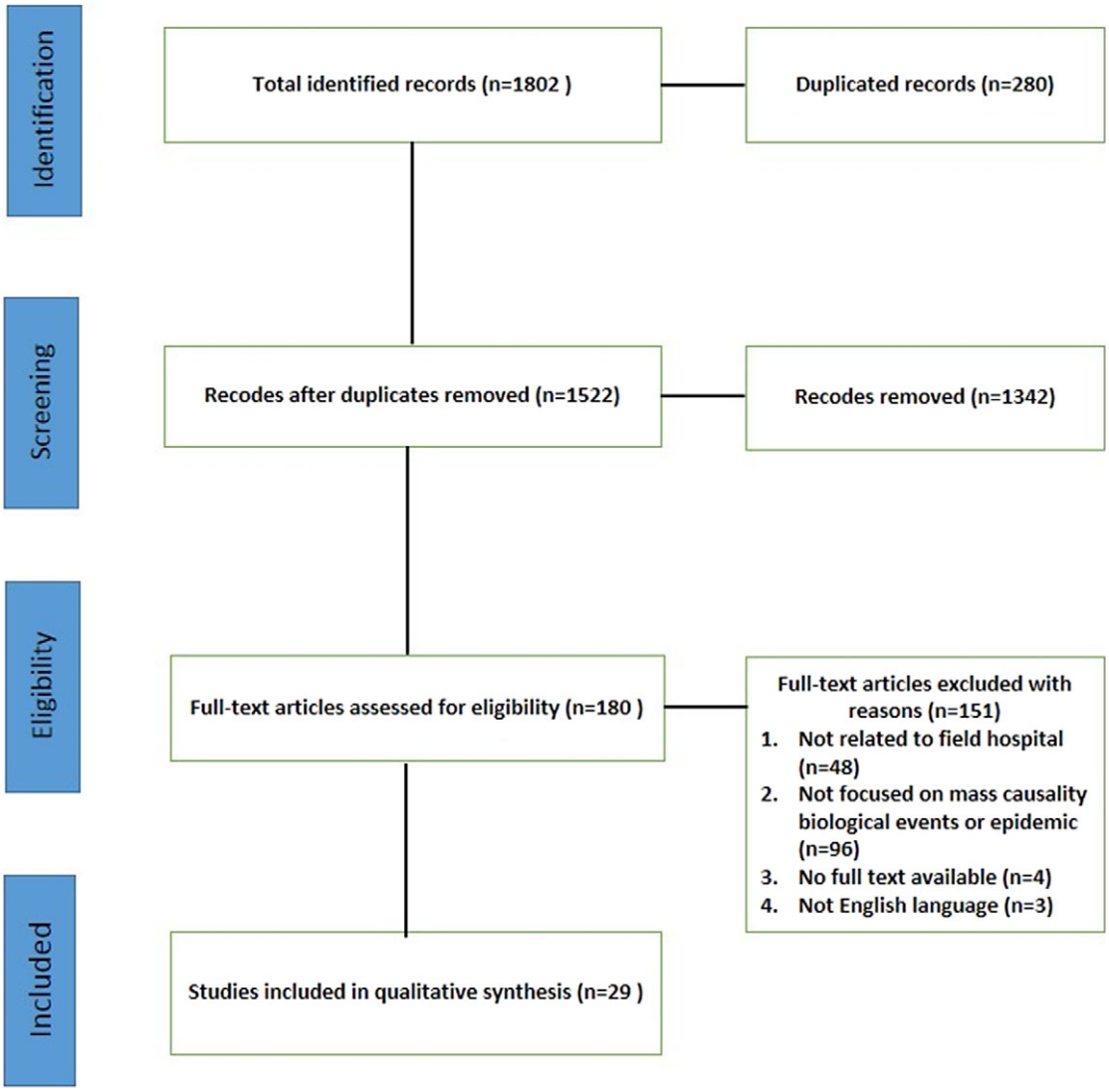

Figure 1. PRISMA flowchart for included articles.

public venues such as theaters, stadiums, and large buildings into shelter hospitals in response to intentional and unintentional mass causality biological accidents such as pandemics and biological warfare. The design criteria were extracted in the form of themes, sub-themes, and criteria presented in Table 3.

Placement and Site Selection

Site selection for a temporary hospital or choosing a venue that can be converted into a shelter hospital is very important. One of the main criteria and primary requirements is the presence of stable resources of water and electricity in the large building. The preliminary resources should be adaptable for converting to a hospital and then returning to the primary condition. Additionally, escape routes are other important criteria for a temporary hospital. A shelter hospital without evacuation routes is not acceptable in the risk assessment.[31,32,40,45] Also, the location of the shelter hospital should be accessible by the main roads for easy movement of patients and hospital personnel.[41] Shelter hospitals are usually constructed for isolated patients with mild to middle stages of the disease. Normally, shelter hospitals do not have intensive care unit (ICU) wards and advanced laboratories. Therefore, the shelter hospitals should be placed in the vicinity of the referral hospital where the severe patients are transferred and there are advanced treatment facilities and laboratories. Accordingly, easy and quick access to a referral hospital is an important factor for the site of the shelter hospital.[9,16,34] In addition, based on earlier studies, it is recommended that hospitals be located in the city center, however, they should be far away from at-risk buildings and places where susceptible populations gather, such as schools.[9,45,46,48] In a study conducted by Moradian et al. (2018) focused on the site selection of temporary hospitals; criteria such as access to the airport, vicinity to permanent and referral hospitals, proximity to universities of medical sciences, distance from high-risk areas such as dense location, and the placement of the hospital in the central cities were suggested.[51]

Structure and Layout

Various layouts have been suggested for the establishment of a hospital. However, in earlier studies, a 3-area and 2-pathway layout is highly recommended as the main layout of shelter hospitals in

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Table 2. Characteristics of studied shelter hospitals

Author(s)	Year	Country (Continent)	Type of study	Name of field hospital	Primary space	Provided capacity	Admitted number
Jie et al.[15]	2020	China (Asia)	Research article	Jiangxia Hospital	Sports center of Jiangxia	–	–
Delgado et al.[27]	2021	Spain (Europe)	Research report	Hospital H144	Central pavilion of Gijon Chamber of Commerce	144	334
Shu et al.[28]	2020	China (Asia)	Letter to the editor	Several hospitals			
Chen et al.[14]	2021	China (Asia)	Correspondence	Huangpi stadium cabin hospital	Huangpi stadium		223
Tadavarthy et al.[29]	2021	USA (North America)	Global perspective article	Alternate care site (ACS)	Liacouras Center gymnasium	250	
Smolova and Smolova[30]	2021	China (Asia)	Research article	Leishenshan hospital		1600	
Marinelli[31]	2020	Global	–				
Zhu et al.[32]	2020	China (Asia)	Special section	Wuchang Ark hospital	800		
Wang et al.[33]	2021	China (Asia)	Research article	Fangcang shelter	Wuhan Sports Center Stadium		
Chen et al.[10]	2020	China (Asia)	Health policy	Fangcang shelter			
Shang et al.[34]	2020	China (Asia)	Commentary	Dongxihu Fangcang shelter	Exhibition center	1000	1012
Naganathan et al.[16]	2020	USA (North America)	Commentary	Alternate hospital site	Rhode Island Convention Center	600	
Fang et al.[9]	2020	China (Asia)	Practice	Fangcang shelter			
Zhang et al.[35]	2021	China (Asia)	Health policy	Wuhan mobile cabin hospitals	Hongshan Sports Center	13000	12000
Sun et al.[36]	2020	China (Asia)	The editorial	Wuhan Mobile Cabin Hospitals	Sports stadium and convention centers		
Zhou et al.[37]	2020	China (Asia)	Report	Several field hospitals	Large indoor exhibition centers, stadiums, or schools	13467	12000
Candel et al.[38]	2021	Spain (Europe)	Review	temporary 1,300–bed hospital	IFEMA Exhibition Center	1300	3817
Yuan et al.[39]	2021	China (Asia)	Research article	Temporary Ark Hospital	Sports stadium	800	1124
Luo et al.[40]	2020	China (Asia)	Research article	The Leishenshan Hospitals	Wuhan Military Games Athletes' Village	2300	2011
Shen et al.[41]	2020	China (Asia)	Research article	Fangcang shelter	A large comprehensive gymnasium	800	
Levy et al.[42]	2020	USA (North America)	Research article	Boston Hope hospital	Boston Convention and Exhibition Center	500	
Jones et al.[43]	2021	USA (North America)	Research article	Field hospital	Baltimore Convention Center (BCCFH)	250	1478
Gordon et al.[44]	2021	USA (North America)	Evaluation	Alternative care sites			
Tekin et al.[45]	2017	Turkey (Europe)	Review	–	–	–	–
You and Mao[46]	2014	Liberia (Africa)	Perspective piece	Chinese Ebola treatment center	Samuel Kanyon Doe Sports Stadium	100	
He et al.[47]	2021	China (Asia)	System–level quality improvement	Fangcang shelter	Large–scale public venue		

(*Continued*)

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Table 2. (*Continued*)

Author(s)	Year	Country (Continent)	Type of study	Name of field hospital	Primary space	Provided capacity	Admitted number
Liu et al.[48]	2017	Liberia (Africa)	Report from the field	Chinese Ebola treatment center	Samuel Kanyon Doe Sports Stadium	100	
Chen and Zhao[49]	2020	China (Asia)	Letter to editor	Makeshift hospitals	Large–scale public venues		
Bhagat and Linden[50]	2020	UK (Europe)	Perspective	Makeshift hospitals	Large–scale public venues		

Table 3. Themes and related criteria for conversion of large public venues to shelter hospitals

Themes	Subthemes	Criteria
Location	Proximity to main road	Access to the main roads is 1 of the important design criteria of the shelter hospital.[38]
	Possibility to provide important primary requirements	The selected building for a shelter hospital must already have a reliable water and electricity supply. It should be possible to provide basic requirements such as oxygen and other items in the place.[32,40,45]
	Proximity to referral hospital	Shelter hospitals should be located near or in a place with easy and quick access to referral hospitals (where there are ICU wards, advanced laboratories, imaging, and radiology facilities).[9,16,34]
	Proximity to susceptible population and dense location and availability	Shelter hospitals should be located in the city center, however, they should be away from crowded and susceptible areas such as schools.[9,45] The shelter should be easily accessible for health–care staff.[16]
	Capacity	The normal suggested capacity of a shelter is 600–1000 beds.[16,28]
Layout and structure	Separation of wards and ward's design	Use a 3–zone and 2–pathway approach for the transformation of the public venue into a shelter hospital.[9,14–16,27–29,32,35–37,39,40,46,48] Avoid making corners in the design and use washable materials, considering the type of biological agent (bacteria or virus) in the building transformation.[30] Use a double–sided cabinet in the wall of each room for food and drug delivery.[34,40] Create a small area for commuting ambulances to the hot zone.[16] Provide a section in the warm zone for patients who need more specialized care or need to be transferred to a referral hospital.[32] Depending on the type of biological agent, an additional laboratory testing facility may be required.[9]
	Triage and admission sections	Set triage and admission sections at the entrance of the hospital.[27]
	Labeling each part	Label and provide signs in all wards and sections.[28]
	Places for end stage patients visit with relatives	Assign a waiting room for relatives of patients.[27]
	Disinfection cannel	Construct a disinfection channel for spraying disinfectant on personnel, and recovered patients.[16,28]
	Pathways and escape or evacuation ways	Assemble evacuation pathways in the wards.[30,32,40,46] Provide 2 exits for every 42 beds.[9] A meter width of the exit path for every 100 people.[16] The distance between each bed and the exit point should not be more than 30 meters.[32] The width of the passage between the zones (contaminated or semi–contaminated or clean) should not be less than 4 meters.[50]
	Donning and doffing areas	Use donning and doffing rooms or channels as the buffer zone. Provide showers between donning/doffing rooms and clean areas.[9,14–16,44] Set a donning station for the rapid response team immediately before the entrance door of the hospital hall.[42]
	Number of toilets and showers	Assemble primary living facilities in each zone (a toilet seat for every 10 women and a seat for every 20 men).[9]
	Parking area	Allocate some parts of the outdoor space of the hospital to parking for health–care staff and relatives of patients.[38]
	Height and surface of patient rooms	Separate the rooms using 3 of 4 panels or prefabricated walls with a height of 1.8–2.7 meters. Provide a 2 × 2 to 3 × 3 meters space for each room.[9,27,28] The suggested distance between beds is 1.2 meters.[39]

(*Continued*)

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Table 3. (*Continued*)

Themes	Subthemes	Criteria
Waste and wastewater management	Waste separation method	Label infected waste for all the waste collected in the contaminated area.[27] The waste collected from other wards will be classified based on their nature.[27]
	Transferring channel for hazardous waste	Transfer contaminated waste from the hot zone.[35,46]
	Location of incinerator	Locate an incinerator in the logistic area located in the outside space of the hospital.[39,40]
	Wastewater treatment	Construct small–size pretreatment and disinfection pounds, in the logistic area, for the treatment of hospital wastewater before discharging wastewater into municipal wastewater sewage.[9,40]
Ventilation	Gradient of pressure	Minimize air transfer from patients' wards to clean areas.[9,31] A negative pressure gradient from contaminated to clean area is required.[9] Mostly, the ventilation system of public venues should be redesigned.[43]
	Type of ventilation in the sections	Replace central ventilation with negative pressure one.[30]
	Innovations for ventilation	Filter exhausted air from contaminated and semi–contaminated zones.[9] Provide air purifiers for unventilated areas.[49] Use displacement ventilation.[50] Apply a 2–channel ventilation method for all rooms.[44]
	Ventilation rate	Air exchange should be carried out 2–3 times per day.[33] Construct a negative pressure room for patients with severe symptoms.[42]
IT and communication	Remote working and keeping connection with referral hospital	Provide a communication system between the shelter hospital and the referral hospital.[47] Screen the patients in community isolation sites and designated hospitals.[20] Refer patients with mild to middle symptoms to the shelter hospitals through an online system managed out of the shelter.[33]
	Communication with patients	Provide a receive–accept system for orders of patients.[35]
Drug and food delivery	Pharmacy design	Assemble a central pharmacy in the logistic area.[28]
	Food and drug order	Food and drug orders are sent to the kitchen and pharmacy located in the logistic area through a communication system.[9,16,41,46,47]
	Drug delivery	Use robots for drug delivery.[47]
Humanitarian and social supports	Places for playing and library	Provide a recreation place and facilities for the patients.[10,15,16,47]
Post curing acts	Provide clean clothes	Set a room for giving clean clothes to the discharged patients and spraying disinfectant on the patients.[10]
	Isolation for reduce the risk of infection transmission or readmission	
Management measures	Risk assessment	Perform health risk assessment for the selected sites.[29]
	Education	Provide educational courses for health–care staff and volunteers.[10,47]
	Logistic supplementation and Protection of personal	Provide enough PPE.[41]
	Hospital monitoring	Monitor all parts of the hospital, especially donning and doffing rooms and washing rooms, by a camera–controlled system.[46,48]

response to unintentional biological accidents. The physically separated areas are: (1) contaminated or red or hot area, (2) semi-contaminated or yellow or warm area, and (3) clean or green or cold area. The contaminated area is an area where patients are treated. The semi-contaminated area surrounds the contaminated area. The semi-contaminated area acts as a buffer zone between the contaminated and clean areas to reduce the possibility of infection transmission between patients and health staff. The clean area is very carefully controlled; it includes some free-contamination wards and sections such as the storage area for keeping raw materials, kitchen and pharmacy, resting rooms for hospital staff, and administrative parts. In addition, in shelter hospitals, there are 2 main routes, 1 is contaminated and the other is clean. The structure and shape of the hospital are designed in such a way that patients cannot enter the clean path.[9,10,14–16,27–30,32–34,37–41]

The space between contaminated and clean zones is filled with donning and doffing rooms. The donning and doffing rooms are places where the treatment staff must wear all the personal protective equipment (PPE) to enter the contaminated area and remove PPE completely when leaving the contaminated area.[9,10,16,44,46] Also, there are strict camera-supervised controls for these rooms to ensure that all required steps of changing clothes and washing hands and faces are performed correctly.[46,48] In some studies, innovation has been designed by creating 2 channels, the first channel is directed to the contaminated zone, that is, the place where PPE is worn. Another channel is linked to the clean area where

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health staff should remove PPE and wash their hands. These channels are also moniored by cameras and are equipped with sound broadcasting and warning systems through which the inspectors can remind personnel of the correct wearing, removing, and washing acts. The difference between channels and rooms is the long length of the channels; for this reason, the longer the channels, the more time and the more accuracy for donning and doffing PPE.[10,14]

The triage and reception of shelter hospitals are located at the entrance.[27] However, in some plans, actual triage operations are performed in larger health-care centers (referral hospitals or temporary health-care sites) with an advanced IT system. In the plan, an IT-based connection is established between a referral hospital and the shelter hospital. Before the admission of the patient to the shelter hospital, his/her information has been sent to the shelter hospital using a well-coordinated IT system. In this model, IT staff are outside the shelter hospital and most of the administrative processes are performed out of the shelter hospital.[47]

Concerning the placement of a disinfection channel to spray disinfectants, it is recommended that the disinfection channel be equipped with a lane of showers placed inside the hospital. The channel also can be located in the open space of the hospital.[10,52,53] Of course, it should be considered that the frequent application of disinfectants during the COVID-19 epidemic posed health-care staff and patients with health risks.[54]

An essential item in the structure of a shelter hospital is evacuation routes and corridors. Corridors should have enough space for delivering food and drug, commuting employees, as well as the exit and escape of patients and personnel. The width of the evacuation way should be 1 meter per 100 patients. Also, the width of the pathway between each zone should not be less than 4 meters.[9,30,32,40,45,46] To facilitate the movement of health-care staff and patients, fixing signs and labeling are very important. All wards and pathways should be marked with different colors. Also, the pathways for patients and staff should be recognizable.[28] Infected hazardous waste, collected in the contaminated area, should be transferred to the incineration area through a specific pathway at the end of the contaminated.[35,46] To reduce the contact between the hospital staff and the patients, walls with 2-sided cabinets can be used. Health-care staff can put food and drug on 1 side of the cabinet and then patients bring the material from the other side of the cabinet without any face-to-face connection.[16] Also, in each section, a sufficient number of basic life facilities such as showers and toilet seats should be installed. For example, 1 toilet seat should be placed for every 10 women and a seat for every 20 men.[9] Due to religious issues in Islamic countries, the separation of women's wards from those of men is suggested.[52]

In the previous studies, the space of room allocated for each patient was differently suggested. For example, the dimensions of 2 × 2 meters[28] or 3 × 3 meters[27] and a 1.2 meters distance between beds[39] were recommended for each room. Regarding the methods of separating the beds, it was generally recommended that the rooms be partitioned with 3 or 4 walls. In the 3-wall model, a curtain is used at the entrance. But in all these isolation methods, the main point was sufficient ventilation for the patients.[9,44]

Outdoor Space

The outdoor space of a public venue has several applications. First, the placement of parking is very essential, although most public places already have enough space for parking. In some studies, it has been recommended to install a room or space for the relatives of patients.[27] Another outdoor part is a recreational area where patients can take a walk or do sports such as yoga. One of the main differences between Fangcang hospitals compared with previous models of shelter hospitals was the recreational facilities. Because the patients had to stay in the hospital for a long time, facilities for entertainment activities were provided by a big digital library including a collection of books, video clips, and other electronic media. The electronic resources had mostly motivational and psychological content.[10,15,35] The outdoor space of the public venue was also assigned to the waste incinerator, which was connected to the contaminated zone through the waste transfer pathway.[39,40] In addition, because infected wastewater should not be directly discharged into municipal wastewater sewage, the hospital should be equipped with a small-scale wastewater treatment plant for the pretreatment and disinfection of wastewater before discharging wastewater into municipal sewage.[9,40]

Ventilation

One of the main problems with the transformation of public places into shelter hospitals is the adaptation of the ventilation system. In most cases, the ventilation system should be redesigned.[9,31,34] Two general principles recommended for changing ventilation systems in shelter hospitals are the provision of negative pressure in the contaminated zone and the negative pressure gradient from the contaminated zone to the clean zone in a way that the contaminated zone has the most negative pressure.[9,16,30,44] At the beginning of the project, if negative ventilation is not available in the contaminated zone, providing a positive pressure in the donning and doffing rooms, the negative pressure will be created in the contaminated area as a temporary solution.[9] An innovation used in a shelter hospital in the United States was the application of 2 air transmission channels for the entire hospital. For each room, there were 2 air vents; a blower vent above the entrance of the room, which brought clean air (from a clean air channel) into the room, and a suction vent connected to the second channel, which was installed above the patient's bed and removed air from the room.[44] The ventilation system is connected to high-efficiency filters that minimize the risk of airborne contamination. The filters are disinfected by ultraviolet (UV) disinfection, which reduces the risk of contamination for the workers who change the filters.[44] Furthermore, in another study, displacement ventilation was suggested as an alternative to improve the ventilation system of shelter hospitals. All the rooms had 2 types of inlets: (1) low-level air intake located near the surface, (2) high-level extract placed in the ceiling. It provides negative pressure. The model works as either mechanical or natural ventilation (50). Based on the standards for ventilation in hospitals, replacement of fresh air should be performed 2 to 3 times per day.[33] If a shelter hospital has an ICU, ICU rooms should be occupied by an independent negative pressure ventilation system.[42]

Along with ventilation, another elemental factor is temperature. In cold climates or during cold seasons, excessive ventilation may increase the need for heating inside the hospital. In this case, it is better to use electric blankets for patients, which increases energy consumption. Also, due to the large space of shelter hospitals, air ventilation may not be well-performed in some areas. For this problem, it is recommended to use air purifiers in unventilated areas to reduce virus-laden aerosols. The filters applied in the air purifiers should be disposed of as hazardous medical waste.[49]

IT and Communication

The role of the IT unit is very important in the case of shelter hospitals. For example, during the COVID-19 pandemic, many tasks were IT-centered performed. In some projects, the IT unit was

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in the referral hospital close to the shelter hospital; and the reception, monitoring preparing documents for the transfer of patients, and providing laboratory tests were implemented by the IT unit. The better the IT unit is operated, the less contact between patients and the treatment staff will be. However, it should be considered that complete reliance on the technology-based system may have some problems. For example, following a biological incident, a cyber-attack may also happen, if there is no ability to quickly shift from an electronic system to a manual one, many problems may arise.[46–48]

Food and Drug Delivery

The valuable experience that Chinese scientists reached out in the fight against Ebola helped them to control the COVID-19 pandemic. For example, there were many similarities between the shelter hospital established in Samuel Kanyon Doe Sports Stadium by Chinese scientists in response to the Ebola epidemic in Liberia and the Fangcang shelter hospital which was designed for hospitalization and isolation of COVID-19 patients in China. In both models of the shelter hospital, the IT and communication unit had a substantial role in drug and food delivery. Every day, the amount and types of required food and drug were ordered to the hospital catering and central pharmacy, respectively, using an IT system.[46–48]

When it comes to the design of the pharmacy, it has 2 rooms: dressing and drug storage rooms. The dressing room is the place to wear PPE for the pharmacy staff who must distribute the medicines in the hot zone. The staff wears PPE based on the place where they must deliver the medicine.[41]

Management Measures

Because the use of a large public place as a hospital is a sensitive matter, before starting the project, a detailed risk assessment must be performed for the proposed places. The results of the risk assessment must be considered by the health providers, architects, and other involved specialists. After choosing a place, effective communication with the neighborhood council or influential persons in the area could be useful in speeding up the project.[29] During an epidemic, especially considering the experience gained from the COVID-19 pandemic, it is very important to provide PPE for the medical staff. In shelter hospitals, the importance of using PPE is much higher due to the risk of cross-contamination in these hospitals.[41] Another important management measure is training health-care staff using updated guidelines. During epidemics or mass casualties in biological accidents, many volunteers cooperate with the medical staff in different medical centers. The training of these people can lead to the improvement of services.[10,46]

Important Consideration for Design of Shelter Hospitals

In addition to supplementation of basic needs such as water and electricity, it is essential to provide alternative sources for emergencies. An essential factor for choosing a building is the space, the amount of minimum space varies in different regions; generally, the shelter hospital should provide space of 600 to 1000 beds, although in some cases, depending on the type of building, undertaking incident or epidemic, and population of the city, the number of beds may vary.[9,14,16,31,43] Also, it should be considered by policymakers, as well as architects of public places, to have an active plan for all the large public buildings. The action plan is a map showing how a large building can be converted into a shelter hospital or health-care facility. The plan should be provided at the end of the building construction.[9] Another important issue is related to the post isolation care of recovered patients in some places like hotels. Based on the nature of biological accidents or pandemics, it may be necessary to quarantine the patients after healing, because some biological agents may be active for a long time.[10]

Conclusions

In mass causality biological accidents or epidemics, creating additional capacity to hospitalize and isolate patients is very important, because it can reduce the spread of disease in the community. A successfully applied way to create surge capacity is the transformation of large public buildings or venues into shelter hospitals. They can be constructed easily and quickly. However, a lot of criteria and considerations should be taken into account for the establishment of shelter hospitals to isolate patients and prevent cross-contamination among health-care staff. Previous studies have indicated many criteria and innovations to transform public places into temporary hospitals, which have been systematically collected in this study. Having a suitable space, redesigning the ventilation system, and providing basic resources such as water, electricity, and oxygen are among the main measures for the conversion of public places into shelter hospitals. Although design criteria may vary in different regions due to cultural, social, and economic differences, the results of the present study can be used as a reference through which health policy-makers could correctly respond to biological accidents and pandemics.

Competing interest. None declared.

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