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Beyond surge: Coping with mass burn casualty in the closest hospital to the Formosa Fun Coast Dust Explosion

Sheuwen Chuang [a,b], *Kuo-Song Chang* [c], *David D. Woods* [e], *Hsiao-Chun Chen* [b], *Morgan E. Reynolds* [e], *Ding-Kuo Chien* [c,d,*]

[a] *Graduate Institute of Data Science, Taipei Medical University, Taipei, Taiwan*
[b] *Health Policy and Care Research Center, Taipei Medical University, Taipei, Taiwan*
[c] *Department of Emergency Medicine, MacKay Memorial Hospital, Taipei, Taiwan*
[d] *School of Medicine, Mackay Medical College, Taipei, Taiwan*
[e] *Department of Integrated Systems Engineering, The Ohio State University, OH, USA*

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ABSTRACT

Purpose: To provide an insight into the challenges faced by the closest hospital to the Formosa Fun Coast Dust Explosion (FFCDE) disaster scene, and to examine how the hospital staff adapted to cope with the mass burn casualty (MBC) in their overcrowded emergency department (ED) after the disaster.
Material and methods: The critical incident technique was used for the investigation. Data was gathered through in-depth individual interviews with 15 key participants in this event. The interview data was combined with the medical records of the FFCDE patients and admission logs to build a detailed timeline of ED workload. Process tracing analysis was used to evaluate how the ED and other units adapted to deal with actual and potential bottlenecks created by the patient surge.
Results: Fifty-eight burn patients were treated and registered in approximately six hours while the ED managed 43 non-FFCDE patients. Forty-four patients with average total body surface area burn 51.3% were admitted. Twenty burn patients were intubated. The overwhelming demand created shortages primarily of clinicians, ED space, stretchers, ICU beds, and critical medical materials for burn care. Adaptive activities for the initial resuscitation are identified and synthesized into three typical adaptation patterns. These adaptations were never previously adopted in ED normal practices for daily surge nor in periodical exercises. The analysis revealed adaptation stemmed from the dynamic re-planning and coordination across roles and units and the anticipation of bottlenecks ahead.
Conclusion: In the hospital closest to the FFCDE disaster scene, it caused an overwhelming demand in an already crowded, beyond-nominal-capacity ED. This study describes how the hospital mobilized and reconfigured response capacity to cope with overload, uncertainty, and time pressure. These findings support improving disaster planning and preparedness for all healthcare entities through organizational support for adaptation and routine practice coping with unexpected scenarios.

* *Corresponding author at*: 92, Section 2, Chungshan North Road, Taipei 10449, Taiwan.
E-mail address: mmhter2017@gmail.com (D.-K. Chien).

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1. Introduction

Mass burn casualty incidents are considered one of the most difficult events for hospitals to manage. Burn patients require specialized treatment, large quantities of resources, rapid response, and vigilant monitoring because burns threaten to deteriorate quickly [1,2]. Additionally, if a hospital happens to be located in proximity to a disaster scene, lack of trauma designation or burn care experience will not shield it from a sudden influx of patients in ambulances or private cars [3]. Although there are guidelines, standards, procedures, and general reports to prepare for mass burn casualty events, these are distillations that do not capture the real difficulties in early stages of disaster management. Description and analysis of hospitals' prompt and effective responses to incidents that exceed practiced capacity can better prepare staff to offer patients the appropriate, timely care after disasters [4,5].

The Formosa Fun Coast Dust Explosion (FFCDE) in New Taipei City (NTC), Taiwan injured 499 people at approximately 20:30 on Saturday, June 27, 2015. It was the largest man-made mass casualty incident in Taiwan's history. Victims, average age of 23, wore flammable swimwear resulting in large total body surface area burns (TBSA, average 44%; 281 people with TBSA >40%, 41 people >80%) and inhalation injuries. Nearly 300 emergency vehicles were dispatched. Within six hours, 499 victims were delivered to 34 hospitals [6].

The FFCDE disaster has led to several studies that document different aspects of the medical response. Some of these provide a general account of the system response to the mass burn casualty incident (MBCI) [7–9], while others focus on the clinical details and the appropriate treatment for those burned [10,11]. However, no other studies have combined cognitive engineering and healthcare to provide a comprehensive insight into the hospitals' prompt and effective responses. This insight is essential to improve hospital disaster planning for specialized care, including burns, when the number of patients exceeds the nominal, practiced, and predicted surge capacities of local hospitals.

During the last decade, most healthcare systems have had enough surge capacity to respond effectively to conventional multiple casualty incidents (e.g. a bus accident); however, less progress has been made in preparedness for catastrophic disasters (e.g. massive explosion, nuclear detonation). Thus, this study examines how the closest hospital to the disaster site treated victims of the FFCDE and analyzes how it adapted to challenges associated with an influx of severe specialty patients. The authors aim to help hospitals develop more realistic and comprehensive plans for mass burn casualty events in disaster planning.

2. Materials and methods

Retrospective research interviews were conducted in MacKay Memorial Hospital Tamsui Branch (MMHTB) in New Taipei City. The hospital is a medical center (level 1 trauma care hospital) and part of a five-hospital network. It is located 12.5 km from the disaster site and has 1093 total beds including 28 medical ICU beds, 14 surgical ICU beds, 11 neurological ICU beds, and 5 pediatric ICU beds; however, it lacks a specialized burn unit. The ED is divided into six major treatment rooms: acute areas (trauma room, acute medical treatment room, and observation room 1–2) and non-acute areas (pediatric room and observation 3). The ED's surge capacity is 55 beds including 28 conventional beds and 27 contingency stretchers. The trauma room can treat a maximum of four acute patients simultaneously. The ED has approximately 5000 visits per month. The average number of visits per shift is 75 daytime (08:00–16:00), 65 night (16:00–24:00), and 30 late night (0:00–08:00). The night shift is generally comprised of 4 physicians, 2 nurse practitioners, 10 nurses, and 14 other staff.

Preceding the incident, the hospital had periodically practiced mass casualty scenarios with an influx of 12–15 patients of varying severity, including heart attacks and car accidents. It also practiced receiving 2 patients from radiation incidents. The hospital had neither planned nor practiced for a mass burn casualty incident, let alone one that would exceed their practiced surge (contingency) capacity with uncertainty about the number and severity of patients that would continue to arrive.

The hospital's response was studied using the critical incident technique [12,13]. Hospital records were reviewed prior to the interviews. ED admission logs were reviewed to classify FFCDE and non-FFCDE patients arriving between arrival of the first burn patient and the discharge of the last burn patient. For all patients, the ED arrival time, ED departure time (transfer to ICU/wards, to other hospitals, or discharge), and triage level were recorded. For FFCDE patients the age, gender, and %TBSA burned were also recorded. Finally, the ED video record was checked to validate the accurate arrival time of some critical burn patients. These data were used to develop a graphic timeline, later used by interviewers to trigger event recall and capture interviewees' roles, experiences, and perspectives on the challenges and adaptations for use during the interviews. To calculate burn patient arrival times, time zero was defined as the time the ED received the first victim.

Open-ended interview questions were developed from a literature review that included treatment of burn patients in the context of the MBCI and interviews with two experts on managing mass casualty incidents. The questions were designed to probe for challenges faced during the incident, how and when challenges were recognized, actions taken to cope with challenges, and general perceptions of the ED environment during the incident. Interviews with 15 key participants, beginning with the ED director, were conducted by the lead researcher and a research assistant between May 2017 and November 2017. Five physicians, eight nurses, and two medical material management staff were interviewed. Each interview lasted two to three hours. Conflicts and ambiguities between interviewee accounts of the event were clarified through later calls, emails, or in-person discussions.

Then, interviews were transcribed into time-binned spreadsheets (Excel) along with patient data. The transcriptions were organized for process tracing analysis, performance in critical incidents [14,15]. The process trace highlighted how the patient surge played out over time, how it challenged the ED, and how the ED and other hospital units adapted to avoid deterioration of patient care. Figs. 1–3 chart the process in terms of load on the ED, actual and potential bottlenecks, and

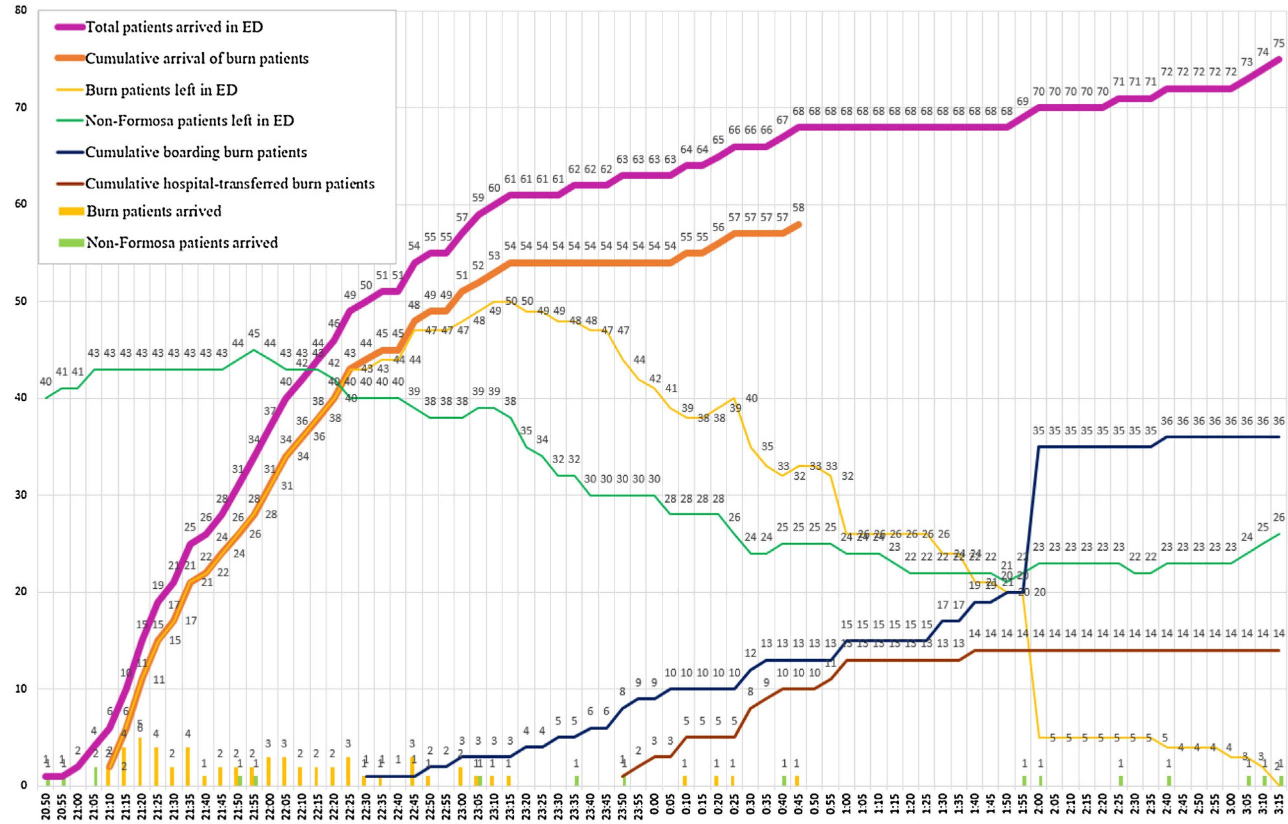

Fig. 1 – Patients inflow and outflow to the emergency department (ED) in detail timeline.

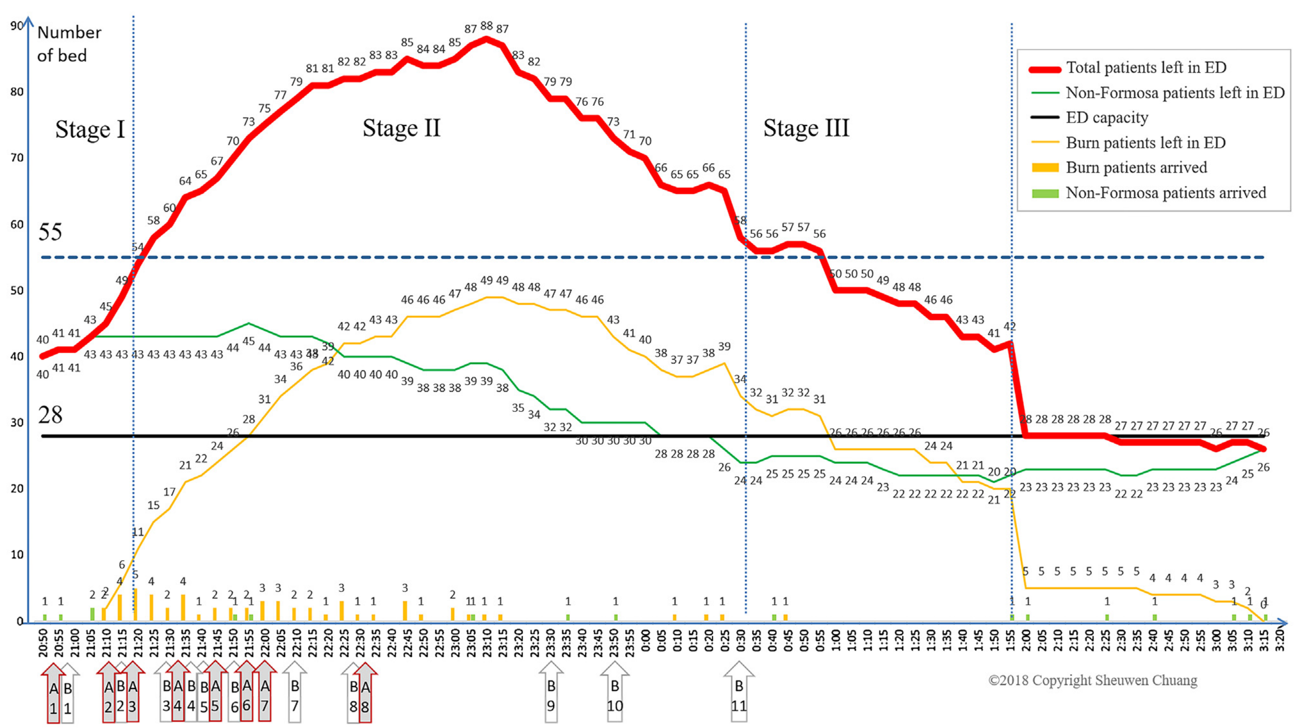

Fig. 2 – Three stages before the ED resumed to normal operation.

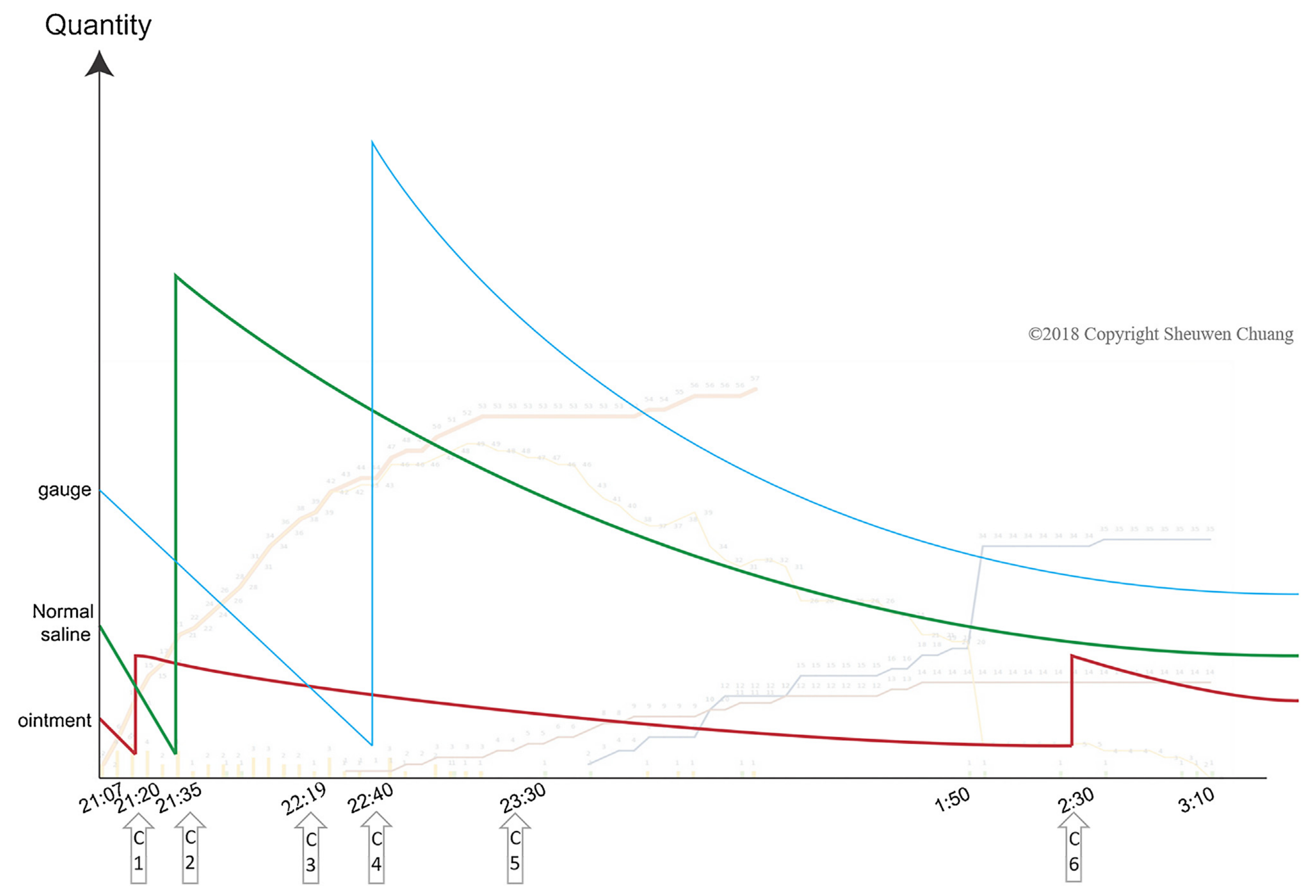

Fig. 3 – Shortage of three critical medical supplies and corresponding hospital's responses.

adaptive responses. The study was approved by the Institutional Review Board of Taipei Medical University.

3. Results

3.1. *Patient characteristics*

Overall, 60 burn patients were counted, which includes 58 that arrived in the ED the night of June 27, 2015 for treatment, and 2 patients who arrived the next morning. This excludes any patients who were treated but missing in registration. Only forty-four of the admitted burn patients are included for the analysis in Table 1 due to incomplete discharged patient data. The average age of burn patients was 22.6, and injuries ranged from TBSA 1% to 90%; the average was 51.3%. An additional 12 non-FFCDE patients arrived for treatment during the event and 43 patients were already present in the ED prior to the incident (Table 2). 43.3% of the 60 patients were sent by ambulance and 56.6% were sent by friends/family or arrived on their own accord. Twenty-five percent of the patients arrived with 30 min, and 50% arrived within 60 min of time zero.

Table 1 – Burn patients characteristics.

Characteristics	No. (%)	Mean (SD)
Age (17–36)		22.6 (3.5)
≦20	13 (29.5)	
<age ≦ 30	30 (68.2)	
>30	1 (2.3)	
Gender		
Female	28 (63.6)	
Male	16 (36.4)	
Severity (TBSA 1–90%)		51.3 (22.8)
≤5%	1 (2.3)	
5% < TBSA ≤ 20%	6 (13.6)	
20% < TBSA ≤ 40%	5 (11.4)	
40% < TBSA ≤ 60%	18 (40.9)	
>60%	14 (31.8)	
Total	44[a]	

TBSA: Total Body Surface Area.
[a] Excluding the discharged patients who had incomplete data.

3.2. *Sequence of events*

The following is a detailed timeline of events, starting with first knowledge of the FFCDE disaster and ending with the discharge or transfer of all FFCDE patients from the ED. Fig. 1 displays different types of ED patient flows for this time period. In addition to the patients described previously, 300 cumulative personnel gradually arrived to assist in treatment, but it is unknown how many were treating patients at any one time.

Table 2 – Non-FFCDE patients.

	Triage level	Count	Remark
Existing ED patients before 21:07	1	4	29 non-FFCDE patients were discharged within 5 h
	2	9	
	3	29	
	4	1	
	5	0	
Total		43	
New arrivals between 21:07 and 03:15 (last burn patient discharged)	1	0	3 pediatric patients, 1 gynecologic patient, 7 internal medicine patients, 1 alcohol addiction patient.
	2	3	
	3	9	
	4	0	
	5	0	4 discharged
Total		12	

FFCDE: Formosa Fun Coast Dust Explosion.

The ED's earliest awareness a patient surge was around 20:50 when the NTC Dispatch Center called asking how many beds they could provide for burn patients. At approximately 20:55, a call was made to the ED Director, who was not currently in the ED, and it was asked if the mass casualty alarm (333 signal) should be activated. The ED Director postponed the 333 signal, requested the ED be ready for its activation, and asked for the clearance of both trauma and acute medical treatment rooms, as the standard operating procedure stated. To accomplish this the ED nurses were divided between existing patients and incoming FFCDE patients (Table 3, A1). Existing patients were moved into observation rooms 1–3, depending on acuity to open acute beds for the initial surge of burn patients. Stretchers were prepared on standby (Table 3, B1).

The first FFCDE patient arrived at 21:07, immediately followed by six severe burn patients with TBSA 80–90% and two of them required intubation. After the first burn patient was intubated, the on-duty ED physician activated the 333 signal to recruit on-hospital staff (Table 3, A2). This led to clinicians moving to the ED from within the hospital (Table 3, A3). To cope with the influx of high acuity burn patients, the on-duty ED physicians moved all 43 existing patients from observation rooms 1–2 into room 3 (Table 3, B2).

After the 333 signal was activated, the central supplies unit of the hospital provided supplies to the ED on standby. However, the standby supplies were for surgical wounds–most commonly needed after mass casualty events–not large amounts of specific medical materials needed to treat burns. Therefore, the patient demand overwhelmed the supply quickly.

Due to the potentially limited supply of burn dressing material in the ED pharmacy and lack of ED space and time for treating a continuous stream of patients, it was decided that the burn patients would be administered the ointment (Silver sulfadiazine) after moving up to the wards. Only about ten patients were treated with the burn ointment (Table 3, C1).

Registration protocol also changed after the 333 signal was activated. Standard protocol was to complete patient identification prior to treatment unless the patient was too acute to answer questions during triage; acute patients would be identified after treatment. In mass casualty incidents, patient identification was simplified to using the mass casualty numbers which were assigned according to arrival; for example, the first patient to arrive was assigned number 333-001. This made registration more efficient in getting all patients treated; however, it was more difficult to report to anxious families on the status and location of their loved one. Because patients who had been intubated were unable to identify themselves verbally and the registration protocol changed after several patients had been registered with a standard registration number instead of a mass casualty registration number, some registrations were missed and others duplicated.

After 17 burn patients arrived the ED had surpassed practiced surge capacity (55 patients) and the shortage of ED clinicians became apparent a call for off-hospital physicians was initiated (Table 3, A4). In anticipation of critical need, the Tamsui ED Director called the both ICU directors of the Taipei and Tamsui Branches to prepare beds and centrally control the supply and demand of ICU beds (Table 3, B3).

The ED pharmacy exhausted the saline, but quickly the pharmacy warehouse door was opened under the supervision of on-duty head nurse and an inventory staff (Table 3, C2). The ED also exhausted the intubation tubes after only seven patients were intubated and additional tubes had to be borrowed from ICU (Table 3, C3). Finally, the ED exhausted the wound dressing gauze and the central supplies unit helped to restock (Table 3, C4).

Shortly after, a call for off-hospital nurses was initiated by on-duty head nurse and a nursing supervisor (Table 3, A4). Simultaneously, the hospital called the Emergency Operation Center (EOC) to request that the emergency services stop sending FFCDE patients because the ED was reaching saturation of space and clinicians, but burn patients continued to arrive (Table 3, B4). At 21:50, a mass of ED clinical personnel arrived to assist (Table 3, A5).

There was insufficient space in the ED for simple treatments due to overcrowding of clinicians, administration staff, patients, families, and reporters. Spontaneously, it was decided simple treatments for low acuity patients (e.g. flushing patient's wound area and covering with wet gauze) would be conducted at the triage area before moving the patients inside the main ED. In addition, the meeting room, storage room, staff lounge, and shower room would be opened up to allow low-acuity patients to flush their own burns to reduce wound temperature and pain (Table 3, B5).

Facing the gridlock of ED space, at 21:50 the ED Director of Taipei MacKay arrived and proceeded to reorganize the space. First, entry into the main ED was regulated, reporters and spectators were removed from the ED and not allowed to reenter, chairs in the waiting area were removed, and a few patients who were not victims of FFCDE but were waiting for clinical services were asked to leave. Second, the main ED was divided into two zones–patient zone and non-patient zone–separated by a guarded door. Third, the scattered beds were reconfigured into lines, each patient was only permitted one bedside family member, and nurses were assigned to specific patients. Fourth, to make patients easier to find for clinicians

Table 3 – Summary of adaptations.

	Code	Time	Key adaptation
Workload saturation & clinician shortage	A1	20:55	The ED nurses were divided between existing patients and incoming FFCDE patients to assist in clearing the trauma and acute medical rooms.
	A2	21:10	After the first burn patient was intubated, the on-duty ED physician activated the 333 signal to recruit on-hospital staff. Also, patient identification was simplified to using the mass casualty numbers which were assigned according to arrival, making registration more efficient in getting all patients treatment.
	A3	21:15	Clinicians began moving to the ED from within the hospital.
	A4	21:30	After 17 burn patients had arrived the ED had surpassed practiced surge capacity (55 patients) and the shortage of ED clinicians became apparent; a call for off-hospital physicians was initiated.
	A5	21:40	A call for off-hospital nurses was initiated by on-duty head nurse and a nursing supervisor.
	A6	21:50	A mass of ED clinical personnel arrived to assist in treatment.
	A7	22:00	Contingency stretchers in the ED and ambulances for transfer were exhausted so ED nurses put patients with injured limbs in wheelchairs, the ED Head Nurse borrowed stretchers from 119 ambulances and other units of the hospital, and the Manager of General Affairs gathered ten ambulances through formal and informal channels.
	A8	22:30	ED senior attending doctor escorted the transferred patients to other hospitals, usually this was done by residents and nurses
ED space approaching gridlock and shortage of ICU beds	B1	20:55	Existing patients were moved into observation rooms 1–3, depending on acuity to open beds for the initial surge of burn patients. Stretchers were prepared on standby.
	B2	21:15	To cope with the influx of high acuity burn patients, the on-duty ED physician moved all 43 existing patients from observation rooms 1–2 into room 3.
	B3	21:30	In anticipation of critical need, the Tamsui ED Director called the both ICU directors of the Taipei and Tamsui Branches to prepare beds and centrally control the supply and demand of ICU beds.
	B4	21:35	The hospital called the Emergency Operation Center (EOC) to request that the emergency services stop sending FFCDE patients because the ED was reaching saturation of space and clinicians, but burn patients continued to arrive.
	B5	21:50	Simple treatments for low acuity patients (e.g. flushing patient's wound area and covering with wet gauze) would be conducted at the triage area before moving the patients inside the main ED. In addition, the meeting room, storage room, staff lounge, and shower room would be opened up to allow low acuity patients to flush their own burns to reduce wound temperature and pain.
	B6	21:50	The actions of the ED Director and Head Nurse (e.g. regulating door, reorganizing beds, removing bystanders, etc.) significantly reduced crowding and confusion in the treatment area.
	B7	22:10	The Vice-Superintendent activated emergency transfer protocol in the ICU and general wards to start transferring existing patients out of these wards to accommodate FFCDE patients. Subsequently, ten ICU beds in-hospital and an additional 10 ICU beds in the Taipei branch were subsequently opened to the burn patients.
	B8	22:30	The first of ten intubated patients was transferred to the ICU of Taipei branch containing a burn unit.
	B9	23:50	The first of ten additional intubated patients was transferred to an in-hospital ICU.
	B10	23:30	The first of twenty-three other FFCDE patients was transferred to general wards.
	B11	00:30	The first of four FFCDE patients was transferred to another hospitals.
Exhaustion of critical medical supplies, stretchers, and ambulances	C1	21:20	Due to the limited supply of burn dressing material in the ED pharmacy and lack of ED space and time for treating the continuous stream of patients entering the ED, it was decided that the burn ointment will be administered to patients after transfer to the wards. Only ten patients were treated with the burn ointment.
	C2	21:35	The ED pharmacy exhausted the saline, but quickly the pharmacy warehouse door was opened under the supervision of on-duty Head Nurse and an inventory keeper.
	C3	22:19	The ED also exhausted the intubation tubes after only seven patients were intubated, and additional tubes had to be borrowed from ICU.
	C4	22:30	The ED exhausted the wound dressing gauze and the central supplies unit helped to restock.
	C5	23:30	A young attending physician, anticipating the exhaustion of burn ointment in the wards after the transfer of patients, took the initiative to call a supplier and requested an urgent delivery of burn treatment ointment.
	C6	02:30	The supplier delivered burn ointment for the ICU and general wards.

and families and to mitigate registration numbering issues, the ED Head Nurse reassigned medical record numbers for all burn patients and attached a piece of A4 white paper with patient name and number to the drip stand of each bed. These actions significantly reduced crowding and confusion in the treatment area (Table 3, B6).

Next, the Vice-Superintendent activated emergency transfer protocol in the ICU and general wards to start transferring existing patients out of these wards to accommodate FFCDE patients. Ten ICU beds in-hospital and an additional 10 ICU beds in the Taipei branch were subsequently opened to the burn patients (Table 3, B7).

Contingency stretchers in the ED were exhausted by 22:00 so ED nurses put patients with injured limbs in wheelchairs until a stretcher was available. Because burn treatment was more convenient in stretchers than wheelchairs, the ED Head Nurse borrowed stretchers from 119 ambulances and other units of the hospital until transfer of patients out of ED created available stretchers. In the meantime, the ED faced shortage of ambulances so the ED Head Nurse contacted a General Affairs staff who gathered ten ambulances through formal and informal channels.

The ED started the transfer of burn patients to ICU around 22:30. Generally, intubated patients were sent to ICU and others were sent to general wards. Therefore, knowledge and expertise needed to be transferred to treat burn patients in inexperienced general wards. The first of ten intubated patients was transferred to the ICUs within the hospital (Table 3, B8).

An hour later, a young attending physician, anticipating the exhaustion of burn ointment in the wards after the transfer of patients, took the initiative to call a supplier and requested an urgent delivery of burn treatment ointment and other medical materials (Table 3, C5).

Then, the first of twenty-three other FFCDE patients was transferred to the general wards (Table 3, B9), the first of ten intubated patients was transferred to the ICUs of Taipei MacKay, containing a burn unit (Table 3, B10), and the first of four FFCDE patients was transferred to another hospitals (Table 3, B11). The ED resumed to the conventional care around 02:00 June 28th. At 02:30, the supplier delivered burn ointment for the ICU and general wards (Table 3, C6). The last of 14 minor burn patients were discharged at 03:10.

After the burn patients were admitted in ICUs and general wards, plastic surgeon teams re-evaluated and treated the patients with necessary sterile dressings. The director of burn care center of the Taipei Branch arrived June 28th at approximately 08:00. He initiated two evaluation teams led by the director and a senior plastic surgeon to check patients' infusion volume, urine output, and gas data for intubated patients. Provision of adequate fluid resuscitation, escharotomy, early wound debridement, or temporary wound coverage were followed until the applications of multiple advanced therapeutic modalities. To prevent infection for the burn patients, the neurologic ICU with 11 beds was reconfigured as a burn ICU within two days and a general ward was reconfigured as a burn care ward within three days of the FFCDE. Eleven patients were transferred to other hospitals within nine days, seven patients were referred to the burn care ward of the Taipei Branch in September, and seventeen patients were eventually discharged including the last patient on November 13, 2015.

3.3. *Challenges over time*

Based on the ED daily surge capacity (55 beds), three stages have been identified before the ED resumed normal operation: (1) initial surge, (2) super overload, and (3) patient transfer out of the ED. These stages are shown in Fig. 2 and represent a different set of challenges and adaptations. The challenges the hospital personnel faced in each stage are described below.

I. Initial surge (20:50–21:25)

1. ED had already exceeded nominal capacity (28 patients) before the patient influx
2. ED nearly exceeded practiced daily surge capacity (55 patients) of stretchers/beds, space, medical materials, and clinicians
3. Four of first twelve burn patients required intubation
4. Exhaustion of physical space in designated critical care rooms and overcrowding of other ED spaces
5. High uncertainty about how many patients would continue to arrive
6. Risk of exhaustion of necessary materials
7. Patients needed ICU level care but no ICU beds were immediately available and ICU transfer ability was uncertain

II. Super overload (21:25–00:35)

1. Acute shortage of clinician staff to support intubation and patient care
2. Exhaustion of available treatment spaces, including contingency spaces to hold stretchers and aisles to move through ED
3. Shortage of supplies (i.e. endotracheal tube, Ambu, normal saline, and large-size gauze)
4. Exhaustion of stretchers
5. Continued uncertainty about how many more patients would arrive
6. Patient identification for anxious family members is hindered by multiple factors including number and pace of arriving patients, intubation interference with communication, and scattered layout of patients
7. ED overcrowded with patients, healthcare staff, volunteers, media reporters, and spectators
8. Exhaustion of conventional ICU beds
9. Shortage of available ambulances for transfer of patients to other hospitals
10. Anticipated risks to quality of care with the overwhelming demand for burn dressings

III. Patient transfer out of the ED (00:35–02:00)

1. Deciding which patients to transfer and where they should go
2. Continued shortage of ambulances to transfer patients out of the hospital
3. Shortage of clinicians to accompany patients in need of transfer

4. Sparse and delayed patient identification in order to provide adequate, legally requested information for transferring patients to receiving hospitals
5. How to follow up patients transferred within-hospital and between-hospital

3.4. Key adaptations

The overload manifested into three axial challenges: (a) workload saturation and shortage of clinicians, (b) ED space approaching gridlock and shortage of ICU beds, and (c) shortage of critical medical materials, stretchers, and ambulances for burn care. A variety of adaptations emerged to cope with challenges, including regularly-trained protocols and novel initiatives to extend capacity for care. Adaptations associated with each of the three axial challenges are summarized in Table 3. Each adaptation has an associated code (e.g. A1). A and B codes can be referenced in Fig. 2 timeline which shows multiple types of patients flows over time. C codes can be referenced in Fig. 3 which shows the shortage of three critical medical supplies and hospital's response.

4. Discussion

The study provides insight into how the adaptive responses played out through a detailed timeline. These responses led to expanded scales of operation, dramatic new capabilities, extensive and hidden interdependencies, and new vulnerabilities in each identified patient surge stage. The ED is crowded daily and already runs beyond nominal capacity (28 patients). According to the Back et.al. study, EDs that are overcrowded normally reconfigure (mobilize and deploy) resources to maintain the ability to deliver patient care, without compromising safety, by modifying "normal" processes to extend operation capabilities every day. Most of the time, internal escalation actions are performed with the ED's existing resources and occasionally external resources that are not currently available within the department and have to be garnered elsewhere [11].

The definition of surge capacity made by the American College of Emergency Physicians had been revised in 2017 from the concept of daily surge to a broad definition which describes conventional (daily), contingency, and crisis surge capacities as, "Surge capacity is a measurable representation of ability to manage a sudden influx of patients. It is dependent on a well-functioning incident management system and the variables of space, supplies, staff and any special considerations (contaminated or contagious patients, for example)" [16]. However, health care administrations have been in the realm of daily surge. Internal operations in health care facilities manage daily surge on a routine basis. Periodic drills or exercises to train health care staff are designed with the concept of daily or contingency surge and with very little preparation for disaster surge [17,18].

Mass burn casualty disasters that create an influx of severely injured patients are likely to overrun ED capacity. This can happen if the number of patients exceeds what surge planning anticipates (i.e. 59 beds in an ED's daily surge capacity). If the ED is already working at daily surge capacity there may be no other resources readily available to cope with the mass casualty. Moreover, if the hospital is located near the disaster scene, mass burn patients may arrive promptly, giving the hospital less time to acquire additional resources necessary for treatment. The resources needed to mobilize were not only from the ED but from the entire hospital and external agencies. The intensified pressures and the scale of demand were far greater than they would have reasonably thought of and planned for regularly [3,19]. Therefore, it required a massive ad hoc effort to generate adequate resources.

To respond to this MBCI, the hospital staff initiated standard protocols based on the daily or contingency surge which included use of a mass casualty numbering system, development of a nurse queue to receive assignment in the triage area, early relocation of ED acute area for victims, cooperation with logistic support units to fulfill demand, and implementation of incident command center. However, these responses were only some of the notable adaptations to cope with the influx of burn patients under an overwhelmed disaster surge capacity.

The FFCDE disaster was a sudden-onset, no-notice disaster. The study revealed several irregular adaptations initiated by individuals or groups. Five additional adaptation patterns were identified:

1) Utilize patients' youthful stability to provide additional buffering capacity, (e.g. placing patients in wheelchairs or chairs, patients flush themselves to reduce wound heat)
2) Compromise lower priority goals to achieve higher priority ones (e.g. limiting non-FFCDE patients care, discharging non-FFCDE patients, and postponing patient registration to prepare patients referral documents)
3) Relax regulation barriers, giving personnel additional authority to attain timely supplies and extend treatment area (e.g. opening the warehouse door to move required materials promptly with inventory accounting check afterwards and opening additional spaces in ED for low-acuity patients to flush their own wounds)
4) Downplay clinicians' position level to extend the best use of manpower (e.g. ED senior attending doctors escorted the transferred patients to other hospitals when usually this was done by residents and nurses)
5) Initiate anticipatory deployment and mobilization of external resources (e.g. mobilization of ICU/GW beds across hospitals and initiation of medical material suppliers by a young physician)

The immediate care given to stabilize mass burn patients in ED was a highly distributed and specialized effort. Development of surge capacity requires augmenting existing capacity as well as generating capacity to resolve resource limitations in real time. This is fully dependent on effective coordination and integration between individuals as well as across units and roles during critical stages of the MCI [20]. The study revealed evidence of effective coordination including the staff's willingness to take-on additional workload and risk for others and the clearly communicated actions taken to mobilize and deploy resources. Coordination requires implementation of various mechanisms that allow team members to manage interdependencies between their roles and tasks and to manage conflicts between their goals [21]. Burstein showed that effective coordination is built on people frequently practicing coordination through regular and simple drills; thus they know how to communicate correctly in disasters [22].

Beyond the challenges of coordination and mass treatment of burn patients, the hospital examined had to cope with high tempo and uncertainty due to unsuccessful communication with the EOC during the disaster response [20]. It was the closest medical facility to the disaster scene and normally operates beyond nominal surge capacity. Aside from the high acuity burn patients sent by the EOC, 56% of victims self-evacuated and arrived at the hospital for treatment. Further, the hospital had no knowledge of how many acute patients would arrive due to unsuccessful communication with the EOC or the difficulties for the EOC to collect detailed patient information on ambulance-transported and self-evacuated burn patients. All challenges combined created a highly uncertain and immediately chaotic environment [23,24]. The staff demonstrated anticipatory abilities to overcome the uncertainty. Multi-level individuals including the VP (high-level manager), the ED directors of two hospital branches (middle -level managers), and a young physician showed their anticipatory abilities to make effective decisions throughout the event. Effective response in this beyond-surge capacity incident, especially under the context of uncertainty, depended on anticipation of potential bottlenecks and on dynamically reconfiguring coordination across roles and units.

In addition, timely anticipatory action requires that an organization looks ahead to read the signs that its adaptive capacity as it currently is configured and performs is becoming inadequate to meet the demands it will or could encounter in the future [25]. Failing to anticipate forces a working group to generate the means to respond in the middle of a challenging event — greatly increasing the risk of failure to keep pace and tempo with dynamic events. This implies that anticipatory ability is an imperative core ability for disaster response. It not only comes from senior staff who have greater familiarity with the hospital's resources and conditions but also relies on routine practice coping with unexpected scenarios and reconfiguring adaptive capacity to fit the environment of changing pressures and opportunities [22,25].

The study shows successful responses to a MBCI rely on the abilities of organizations, units and individuals to adapt in a timely manner, to empower initiative and support pre-planned and emergent coordination, as well as to anticipate resources needed to meet the changing and uncertain demands ahead. To support MCI readiness, disaster experts emphasize that hospitals need to continuously exercise to build up adaptive capabilities. The study reveals that standard protocols are insufficient to support and guide many aspects of an effective response to the unique challenges of actual MBCIs. Hospitals should expand their disaster preparation investments to include simulations of MBCIs by developing varied levels of multiple complex scenarios with surprises and time pressure for their emergency response teams to experience. In each regular and irregular exercise, the hospital emergency response teams need to work through the challenges, and experienced personnel help teams reflect on how to best adapt to the surprises and bottlenecks built into each simulation. Due to the context-dependent capabilities of each ED, hospitals will need to tailor general simulation capabilities and scenarios to fit the pressures and constraints for their context.

5. Conclusions

Most healthcare systems have been required to prepare surge capacity to respond to conventional multiple casualty incidents, but have paucity of experiences in a sudden onset no-notice disaster. The FFCDE disaster caused multiple MBCIs in a variety of hospitals with unique capabilities and limitations; in the hospital closest to the disaster scene it caused an overwhelming demand in an already crowded, beyond-nominal capacity ED. This study shows what happened in the hospital and what it took to mobilize and reconfigure response capacity despite overload, uncertainty, and time pressure. The hospital's ability to adapt was based on anticipation in the face of uncertainty and on coordination across roles and units to keep pace with the dynamic demands. All healthcare entities should have plans to provide crisis care with the goal of the greatest good for the greatest number of people. These findings support learning and improving disaster planning and preparedness for all healthcare entities through organizational support for adaptation and routine practice coping with unexpected scenarios, especially for burn disasters.

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Authors' contributions

SC conceived and designed the study and obtained research funding. KSC and DKC conducted quantitative data collection and assisted the clarification of qualitative data. HCC conducted the first round data analysis and drafted all tables and figures, SC conducted the second round data analysis, SC, DDW, and MER drafted and edited the manuscript, all authors contributed substantially to its final revision. DKC takes responsibility for the paper as a whole.

Conflict of interest statement

None of the authors have any conflicts of interest to disclose.

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