What A Disaster! The Hydrofluoric Acid Leak in Gumi City in 2012: Lessons What We Have Earned From Review of the Past Hospital's Disaster Response

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Abstract

Objective: This study aimed to analyze the characteristics of hydrogen fluoride–exposed patients (HFEPs) treated at an emergency department (ED) at a local university hospital, and to review the hospital's disaster response according to staff, stuff, space, and system (4Ss).

Method: This is retrospective observational chart review and descriptive study included 199 HFEPs among 2628 of total ED patient who visited a local university emergency medical center for treatment between September 27 and October 20, 2012, following an HF leak at the Hub Globe factory in Gumi City, Republic of Korea. Descriptive results concerning 4Ss were obtained from interview with ED specialist staff physician on duty during the study period. According to the criteria of the American Burn Association, patients requiring burn center referral were assigned to the major burn group (MBG) as severe condition.

Result: During the first 24 h after the accident, 161 (80.9%) HFEPs were treated in the ED. Among the 55 (27.6%) patients in the MBG, 8 (4% of the HFEPs) came to the ED during the acute phase (within the first 8 h after the leak began). During the acute phase, the ED was staffed with three doctors and three nurses. Among the total 2628 patients in the ED during the study period, 262 (9.97%) patients, including 167 (83.92%) of the 199 HFEPs, were there during the subacute phase, defined as the 24 h after the acute phase. During the subacute phase, the ED staff consisted of six doctors and 10 nurses. No concepts according to 4Ss that allowed for the expansion of ED space with securing disaster reserve beds or an increase in manpower with duty time adjustments or duty relocation for ED working personnel were in place as well as reinforcement of logistics such as antidote or PPE or disaster related measures of administration department or decontamination zone setup or decontamination or disaster related diagnostic testing measures or unification and management of the entrances and exits of hospital or implementation of previously designated disaster triage.

Conclusion: Hospital disaster response was insufficient for all aspects of 4Ss. Detailed guidance for hospital disaster management plan establishment is required.

Introduction

The cycle of disaster risk management is known as four stages: mitigation, preparedness, response, and resilience [1-4]. In terms of disaster response, in the conventional traumatic mass casualty incident (MCI) situation, based on the evaluation of the extent of damage by the physical injury mainly by the medical resource provider, the patient severity classification and prioritization of treatment are promoted for efficient resource distribution [5]. However, in the special situation that corresponds to chemical, biological, radiological, nuclear, and explosive (CBRNE) disaster, including previous considerations covered by the conventional traumatic MCI, another consideration of special situations such as zone setup, personal protective equipment (PPE), most suitable special triage in CBRNE situation, decontamination, and antidote management if applicable is required [6-8]. Gumi, Gyeongsangbuk-do, Republic of Korea is a state-governed industrial city with factories located in an industrial park [9, 10]. Chemical leaks have occasionally occurred in the community over the past several years [9-12]. These events include the Hube Globe factory leak of hydrogen fluoride (HF) in 2012, which drew not only domestic, but also international, attention due to the human and economic losses, as well as the severe environmental damage, including to crops, caused by the disaster [9, 12, 13]. The accident led to the creation of comprehensive chemical safety measures by the Ministry of the Environment and the establishment of the National Institute of Chemical Safety [14]. The HF leak impacted the local community, with patients sent to nearby local hospitals. However, those hospitals were unprepared for the disaster and had limited experience with zone setup, PPE and decontamination agent supplies, and the expansion of capacity to handle the sudden surge in patients [9, 13, 15-17].

In this study, the authors analyzed the basic demographic characteristics and clinical outcomes of hydrogen fluoride-exposed patients (HFEPs) treated at an emergency department (ED) of a 400-bed university hospital and examined the response of hospital to a sudden surge of patients injured during an HF leak at a local factory with reviewing literatures.

Methods

1. Study population

Gumi, Gyeongsangbuk-do, is Korea's leading industrial city, with a population of 162,743 in September 2012 [18]. The population of interest in this study comprised 199 HFEPs who visited the ED at Soonchunhyang University Gumi Hospital due to the HF leak disaster at the Hube Globe factory in Gumi in 2012. Soonchunhyang University Gumi Hospital is a level II secondary hospital with approximately 39,000 annual patient visits to its ED. It is one of two main university hospitals in Gumi and has a total of 400 beds, including 20 ED beds. During the study period, 2628 patients visited the hospital's ED.

1.1. Inclusion criteria for HFEPs

All patients aged > 18 years who visited the ED of Soonchunhyang Gumi University Hospital due to HF exposure caused by the Hube Globe factory leak on September 27, 2012, were enrolled in the study.

1.2. Inclusion criteria for all patients in the ED

All patients who visited the ED of Soonchunhyang University Gumi Hospital between September 27 and October 20, 2012, were also included in the study.

1.3. Study period

The study period was September 27–October 20, 2012.

2. Study design

This retrospective observational cross-sectional chart review and descriptive study was performed to examine the demographic and clinical characteristics of the patients and the disaster response of the hospital when confronted with a surge of patients following the HF leak. In addition, this study reflected study result from interview with ED specialist staff physician on duty at Soonchunhyang University Gumi Hospital during the study period.

3. Study population

3.1. Basic demographic characteristics and clinical outcomes of the 199 HFEPs according to timeline

The epidemiological and clinical outcome data of independent variables including age, sex, number of patients according to ED visit time, injury mechanism of patient, occupation, distance between patient location and incident spot, injury severity, diagnosis, extent of damage, damaged site, and ED disposition were recorded and analyzed according to timeline.

3.2. Frequencies of HFEPs and total patients in the ED according to date

The numbers and percentages of HFEPs and total patients in ED (TPs), and the percentages of TPs who were HFEPs, were recorded by date.

3.3. Distribution of the 199 HFEPs by major burn criteria and ED manpower over time

3.3.1. Timeline of patient management (acute, subacute, and chronic phases)

- Acute phase: 16:00 on September 27 to 00:00 on September 28, 2012 (the first 8 h after the HF leak)

- Subacute phase: 00:00 on September 28 to 00:00 on September 29, 2012 (the 24-h period after the acute phase)

- Chronic phase: 00:00 on September 29 to 00:00 on October 21, 2012

3.3.2. Major burn criteria

Patients requiring burn center referral, according to the criteria of the American Burn Association [19, 20], were assigned to the major burn group (MBG). MBG inclusion criteria as follows: (i) Partial thickness > 25% BSA, age 10–50 years or (ii) Partial thickness > 20% BSA, age < 10 years or > 50 years or (iii) Full thickness > 10% BSA in any individual or (iv) Burns involving hands, face, feet, or perineum or (v) Burns crossing major joints or (vi) Circumferential burns of an extremity or (vii) Burns complicated by inhalation injury or (viii) Electrical burns or (ix) Burns complicated by fracture or other trauma or (x) Burns in high-risk patients who will require special social/emotional and/or long-term rehabilitative support, including cases involving suspected child abuse and substance abuse. The authors set the MBG as severe patient. All other patients were assigned to the non–major burn group (NMBG). One patient who was declared dead on arrival (DOA) and one patient who died during treatment in the ED were included in the MBG.

3.3.3. Subgroup analyses

The numbers of patients in the MBG and NMBG and the numbers of doctors and nurses on duty in the ED were investigated according to the timeline presented in Section 3.3.1.

3.4. Treatment orders for HFEPs in the ED

Treatment orders issued in the ED were categorized according to their targets (respiratory tract, skin burn, and systemic toxicity).

3.5. Checklist results of hospital disaster response according to staff, space, stuff, and system

The authors developed checklist (Appendix) composed of multiple questions for hospital's disaster response mainly categorized as staff, space, stuff, and system (4Ss) after review of literatures [1-3, 5-17]. And the authors checked and confirmed the answers by medical chart review and by interview with ED specialist staff physician on duty during the study period.

4. Statistical methods

Data are reported as means ± standard deviations (SDs) for continuous variables and as frequencies (percentages) for categorical variables. P-values were calculated by one-way ANOVA test for continuous variables and the chi-square test with Yates' continuity correction or Fisher's exact test with two-sided for categorical variables. Statistical analyses were performed by Rex (Version 4.0.2, RexSoft Inc., Seoul, Korea).

5. Institutional Review Board approval

This study was supported by Soonchunhyang University and was approved by the Institutional Review Board of Soonchunhyang University Gumi Hospital (IRB_SCHUH 2019-18).

Results

1. Basic demographic characteristics and clinical outcomes of the 199 HFEPs according to timeline

The 132 (66.3%) male and 67 (33.7%) female HFEPs had a mean (SD) age of 41.6 (14.4) years (Table 1). There was no difference on age and sex according to timeline respectively ($p=0.3625$), ($p=0.1983$). In terms of mechanism of patient, proportion of inhalation injury were higher than complex (more than two) injury in all subgroups of timeline ($p<0.0001$), (Table 1). In terms of occupation, worker group as 5 (62.5%) in acute phase, unknown group both as 93 (55.69%) in subacute phase and as 16 (66.67%) in chronic phase were the most ($p=0.0021$), (Table 1). In terms of distance between patient location and incident spot, both 8 (100%) in acute phase and 86 (51.50%) in subacute phase were reported being within 100 m from the incident location and were more than away from 100 m group but vice versa on 15 (62.5%) in chronic phase ($p=0.0062$), (Table 1). According to injury severity, frequencies of the NMBG were the most in subacute phase and chronic phase both as 122 (73.05%) and 22 (91.67%) but vice versa in acute phase as 8 (100%) of the MBG ($p=0.0001$), (Table 1). Frequencies of chemical intoxication group among diagnosis were the most in all phases as 5 (62.5%) in acute phase, 163 (97.6%) in subacute phase, and 22 (91.67%) in chronic phase ($p=0.0012$), (Table 1). The single site group in extent of damage were the most in all phases as 5 (62.5%) in acute phase, 167 (100%) in subacute phase, and 20 (83.33%) in chronic phase ($p<0.0001$), (Table 1). The respiratory tract group in damaged site were the most in all phases as 5 (62.5%) in acute phase, 163 (97.6%) in subacute phase, and 22 (91.67%) in chronic phase ($p=0.0001$), (Table 1). In terms of ED disposition, the DAMA group in acute phase as 5 (62.5%), the discharge group both in subacute and chronic phase as 167 (100%) and 23 (95.83%) were the most ($p<0.0001$), (Table 1). One patient in chronic phase was admitted to the hospital after visiting ED with chief complaint of vomiting on 6, October, 2012 after hydrogen fluoride exposure and diagnosed as gastric ulcer. However, there was no definite data in terms of criteria for admission on the chart review (Table 1). Five patients of DAMA were comprised of three factory workers on the scene and two news reporters on the scene. They got medical treatment of calcium gluconate nebulizer for their dyspnea symptom and were recommended to admit the hospital but they refused. Only one worker among them visited ophthalmological outpatient department later (Table 1). Two patients died [one was dead on arrival at the ED and the other was alive on ED arrival but had severe hypocalcemia (blood calcium level, 3 mg/dL; normal adult range, 8.6–10.2 mg/dL) and recurrent refractory ventricular dysrhythmia. The patient died despite >1 h advanced cardiovascular life support, including calcium gluconate administration] (Table 1).

Table 1. Basic demographic characteristics and clinical outcomes of the 199 HFEPs according to timeline

Variable	Total (N=199)	Acute phase (N=8)	Subacute phase (N=167)	Chronic phase (N=24)	p-value
Age (years)	41.6 ± 14.4	36.63 ± 11.06	41.52 ± 14.22	44.08 ± 16.54	*0.3625
Sex					†0.1983
Male	132 (66.3%)	7 (87.50%)	112 (67.07%)	13 (54.17%)	
Female	67 (33.7%)	1 (12.50%)	55 (32.93%)	11 (45.83%)	
Injury mechanism of patient					‡<0.0001
Inhalation	195 (97.99%)	5 (62.50%)	167 (100%)	23 (95.83%)	
Complex (more than two)	4 (2.01%)	3 (37.50%)	0 (0%)	1 (4.17%)	
Occupation					‡0.0021
Worker	48 (24.12%)	5 (62.50%)	39 (23.35%)	4 (16.67%)	
Resident	14 (7.04%)	0 (0%)	10 (5.99%)	4 (16.67%)	
Fire fighter	17 (8.54%)	0 (0%)	17 (10.08%)	0 (0%)	
EMS person	3 (1.51%)	0 (0%)	3 (1.80%)	0 (0%)	
Police	5 (2.51%)	0 (0%)	5 (2.99%)	0 (0%)	
Reporter	2 (1.01%)	2 (25.00%)	0 (0%)	0 (0%)	
Unknown	110 (55.28%)	1 (12.50%)	93 (55.69%)	16 (66.67%)	
Distance between patient location and incident spot					‡0.0062
>100 m	96 (48.24%)	0 (0%)	81 (48.50%)	15 (62.50%)	
≤100 m	103 (51.76%)	8 (100%)	86 (51.50%)	9 (37.50%)	
Injury severity					‡0.0001

MBG	55 (27.6%)	8 (100%)	45 (26.95%)	2 (8.33%)	
NMBG	144 (72.4%)	0 (0%)	122 (73.05%)	22 (91.67%)	
Diagnosis					‡0.0012
Chemical intoxication	190 (95.48%)	5 (62.50%)	163 (97.60%)	22 (91.67%)	
Complex (more than two)	9 (4.52%)	3 (37.50%)	4 (2.40%)	2 (8.33%)	
Extent of damage					‡<0.0001
Single site	192 (97.0%)	5 (62.50%)	167 (100%)	20 (83.33%)	
Multiple sites	7 (3.0%)	3 (37.50%)	0 (0%)	4 (16.67%)	
Damaged site					‡0.0001
Respiratory tract	188 (94.47%)	5 (62.50%)	163 (97.60%)	20 (83.33%)	
Complex (more than two)	11 (5.53%)	3 (37.50%)	4 (2.40%)	4 (16.67%)	
ED disposition					‡<0.0001
Discharge	191 (96.0%)	1 (12.50%)	167 (100%)	23 (95.83%)	
DAMA	5 (2.5%)	5 (62.50%)	0 (0%)	0 (0%)	
Death	2 (1.01%)	2 (25%)	0 (0%)	0 (0%)	
ADM	1 (0.5%)	0 (0%)	0 (0%)	§1 (4.17%)	

ADM, admission; Chronic phase, time period from 00:00 am on September 29 to 00:00 am on October 21, 2012; DAMA, discharge against medical advice; ED, emergency department; EMS, emergency medical service; HFEPs, hydrogen fluoride-exposed patients; MBG, major burn group; NMBG, non−major burn group; Subacute phase, time period from 00:00 am on September 28 to 00:00 am on September 29, 2012 (the 24-h period after the acute phase); *, One-way ANOVA test was performed; †, chi-square test with Yates' continuity correction was performed; ‡, Fisher's Exact Test with two-sided was performed; §, one patient was admitted to the hospital after visiting ED with chief complaint of vomiting on 6, October, 2012 after hydrogen fluoride exposure and diagnosed as gastric ulcer. However there was no definite data in terms of criteria for admission on the chart review; Subgroups of timeline were composed of acute phase, subacute phase, and chronic phase.; Acute phase, time period from 16:00 pm on September 27 to 00:00 am on September 28, 2012 (the first 8 h after the HF leak); Five patients of DAMA on acute phase were comprised of three factory workers on the scene and two news reporters on the scene. They got medical treatment of calcium gluconate nebulizer for their dyspnea symptom and were recommended to admit the hospital but they refused. Only one worker among them visited ophthalmological outpatient department later.; Two patients confirmed as death on acute phase classified as categorized diagnosis of complex (more than two) combined of chemical intoxication and burn [one was dead on arrival at the ED and the other was alive on ED arrival but had severe hypocalcemia (blood calcium level, 3 mg/dL; normal adult range, 8.6–10.2 mg/dL) and recurrent refractory ventricular dysrhythmia. The patient died despite >1 h advanced cardiovascular life support, including calcium gluconate administration].

Data are reported as the mean ± standard deviation for continuous variables and number (%) for categorical variables. P-values were calculated by one-way ANOVA test for continuous variables and the chi-square test with Yates' continuity correction or Fisher's exact test with two-sided for categorical variables.

2. HFEPs and TPs in the ED by date

Among the 2628 TPs, including the 199 HFEPs, who visited the ED during the study period, 8 (4.02%) HFEPs and 83 (3.16%) TPs were seen during the acute phase. Thus, HFEPs accounted for 9.64% of the acute-phase TPs (Table 2, Figure 1). During the subacute phase, 167 (83.92%) HFEPs and 262 (9.97%) TPs visited the ED, with HFEPs accounting for 63.74% of the TPs (Table 2, Figure 1). During the chronic phase, 24 (12.06%) HFEPs and 2283 (86.87%) TPs were seen in the ED, with HFEPs making up 20.35% of the TPs (Table 2, Figure 1).

Table 2. Frequencies of hydrogen fluoride–exposed patients (HFEPs) and total patients (TPs) in the emergency department by date

Date	HFEP *n* (%)	TP *n* (%)	(HFEPs / TPs) * 100 (%)
2012-Sept. 27 (acute phase)	8 (4.020100503)	83 (3.158295282)	9.638554217
2012-Sept. 28 (subacute phase)	167 (83.91959799)	262 (9.9695586)	63.74045802
2012-Sept. 29 (chronic phase)	10 (5.025125628)	214 (8.143074581)	4.672897196
2012-Sept. 30 (chronic phase)	1 (0.502512563)	189 (7.191780822)	0.529100529
2012-Oct. 01 (chronic phase)	1 (0.502512563)	194 (7.382039574)	0.515463918
2012-Oct. 02 (chronic phase)	0 (0)	95 (3.614916286)	0
2012-Oct. 03 (chronic phase)	1 (0.502512563)	128 (4.870624049)	0.78125
2012-Oct. 04 (chronic phase)	2 (1.005025126)	80 (3.04414003)	2.5
2012-Oct. 05 (chronic phase)	2 (1.005025126)	68 (2.587519026)	2.941176471
2012-Oct. 06 (chronic phase)	2 (1.005025126)	111 (4.223744292)	1.801801802
2012-Oct. 07 (chronic phase)	0 (0)	146 (5.555555556)	0
2012-Oct. 08 (chronic phase)	1 (0.502512563)	78 (2.96803653)	1.282051282
2012-Oct. 09 (chronic phase)	1 (0.502512563)	87 (3.310502283)	1.149425287
2012-Oct. 10 (chronic phase)	1 (0.502512563)	62 (2.359208524)	1.612903226
2012-Oct. 11 (chronic phase)	0 (0)	64 (2.435312024)	0
2012-Oct. 12 (chronic phase)	1 (0.502512563)	61 (2.321156773)	1.639344262
2012-Oct. 13 (chronic phase)	0 (0)	114 (4.337899543)	0
2012-Oct. 14 (chronic phase)	0 (0)	125 (4.756468798)	0
2012-Oct. 15 (chronic phase)	0 (0)	72 (2.739726027)	0
2012-Oct. 16 (chronic phase)	0 (0)	76 (2.891933029)	0
2012-Oct. 17 (chronic phase)	0 (0)	61 (2.321156773)	0
2012-Oct. 18 (chronic phase)	0 (0)	74 (2.815829528)	0
2012-Oct. 19 (chronic phase)	0 (0)	76 (2.891933029)	0
2012-Oct. 20 (chronic phase)	1 (0.502512563)	108 (4.109589041)	0.925925926
2012-Sept. 29–Oct. 20 (TP during the chronic phase)	24 (12.06030151)	2283 (86.87214612)	1.051248357
Total	199 (100)	2628 (100)	(100)

(HFEPs / TPs) * 100 (%), percentage of hydrogen fluoride–exposed patients (HFEPs) among the total patients (TPs) in the emergency department; acute phase, first 8 h after the onset of the HF leak; subacute phase, the 24 h after the acute phase; chronic phase, the month after the acute and subacute phases.

3. Distribution of HFEPs by major burn criteria and ED manpower according to the timeline

During the acute phase, eight patients in the MBG and no patient in the NMBG were seen in the ED, which was staffed at that time by three doctors and three nurses (Table 3). During the subacute phase, 45 patients in the MBG and 122 patients in the NMBG were seen in the ED, which was staffed at that time by 6 doctors and 10 nurses (Table 3). During the chronic phase, 2 patients in the MBG and 22 patients in the NMBG were seen in the ED. No data were available regarding the number of doctors and nurses on duty in the ED during that time (Table 3). It was confirmed by interview with ED specialist staff physician on duty at Soonchunhyang University Gumi Hospital during the study period that there was no special ED triage for HFEPs was done on every phase (Table 3).

Table 3. Distribution of the 199 HFEPs by major burn criteria and ED manpower during the disaster timeline

Timeline	MBG + NMBG (*n*)	MBG (*n*)	NMBG (*n*)	Doctors (*n*)	Nurses (*n*)
Acute phase (16:00 Sept. 27–00:00 Sept. 28)	8	8	0	3	3
Subacute phase (00:00 Sept. 28–00:00 Sept. 29)	167	45	122	6 (3 on day shift, 3 on night shift)	10 (3 on day shift, 4 on evening shift, 3 on night shift)
Chronic phase (00:00 Sept. 29–00:00 Oct. 21)	24	2	22	NA	NA

ED, emergency department; HF, hydrogen fluoride; HFEPs, hydrogen fluoride–exposed patients; MBG, major burn group; NMBG, non–major burn group; NA, not available or not accountable; acute phase, first 8 h after the onset of the HF leak; subacute phase, the 24 h after the acute phase; chronic phase, the month after the acute and subacute phases. It was confirmed that there was no special ED triage for HFEPs was done on every phase by interview with ED specialist staff physician on duty at Soonchunhyang University Gumi Hospital during the study period.

4. ED treatment orders implemented for HFEPs

Treatment of the HFEPs, as determined from the ED treatment orders, was classified according to the targets (respiratory tract, skin burns, and systemic intoxication; Table 4).

Table 4. Emergency department treatment orders implemented for HFEPs in the 2012 Gumi City HF leak disaster

Target site	Emergency department treatment order for HFEPs
Respiratory tract	Applying nebulizer with 2 ml mixed calcium gluconate solution comprising 1 ampoule calcium gluconate (2.084 g/20 ml) dissolved in 100 ml normal saline (0.9 g sodium chloride)
Skin burn	Applying gauze soaked with 1 ampoule calcium gluconate (2.084 g/20 ml) dissolved in 100 ml normal saline
Systemic intoxication	Administering calcium gluconate (2.084 g/20 ml) intravenously

HFEPs, hydrogen fluoride–exposed patients; HF, hydrogen fluoride. According to target sites of HFEPs, treatments based on calcium gluconate were done in ED. These results were confirmed by medical chart reviews and by interview with ED specialist staff physician on duty during the study period.

5. Checklist results of hospital disaster response according to staff, space, stuff, and system

In the staff category, there was no reinforcement of hospital disaster response personnel or duty time adjustments or duty relocation for ED working personnel (Table 5). In the space category, there was no expansion of ED space to inside or outside of ED or securing disaster reserve beds (Table 5). In the stuff category, there were no reinforcement of medicines including antidote such as calcium gluconate or supplying of PPE as well as other logistics required for hospital's disaster response (Table 5). In the system category, there were no operations of hospital's disaster command system or disaster related measures of administration department or disaster triage such as START or SALT or decontamination zone setup or decontamination or disaster related diagnostic testing measures or unification and management of the entrances and exits of hospitals (Table 5).

Table 5. Checklist results of hospital disaster response according to staff, space, stuff, and system

Category	Question	Yes or No
Staff	Were there any reinforcement of hospital disaster response persons such as doctors or nurses or administration persons or security persons?	*No
	Were there any duty time adjustments or duty relocation of ED working personnel?	*No
Space	Was there any expansion of ED space to accommodate surging patients inside ED?	*No
	Was there any expansion of ED space to accommodate surging patients outside ED?	*No
	Were there any disaster reserve beds secured in the hospital?	*No
Stuff	Were there any reinforcement of medicines including antidote such as calcium gluconate?	*No
	Was there any personal protective equipment provided for hospital disaster response personnel to respond to the CBRNE disaster?	*No
	Were there any reinforcement of logistics other than those mentioned above for the hospital's disaster response?	*No
System	Were there any hospital's disaster command systems in operation?	*No
	Did the administration department implement disaster related measures to accept a large number of patients different from usual?	*No
	Has disaster triage such as START or SALT in preparation for multiple casualty accidents or disasters been implemented apart from usual ED patient triage?	*No
	Was there any decontamination zone setup in the hospital?	*No
	Did the hospital perform decontamination of the patients?	*No
	Were there any different diagnostic testing measures implemented to address the rapidly surging ED patient testing needs different from usual?	*No
	Were there any unification and management of the entrances and exits of hospitals that should be operated in case of disaster?	*No

CBRNE, chemical, biological, radiological, nuclear, and explosives; ED, emergency department. *, the authors checked and confirmed these results by medical chart review and by interview with ED specialist staff physician on duty during the study period. The authors developed these checklist questions by review of literatures concerning hospital’s disaster response [1-3, 5-17].

Discussion

No concepts according to 4Ss that allowed for the expansion of ED space with securing disaster reserve beds or an increase in manpower with duty time adjustments or duty relocation for ED working personnel were in place as well as reinforcement of logistics such as antidote or PPE or disaster related measures of administration department or decontamination zone setup or decontamination or disaster related diagnostic testing measures or unification and management of the entrances and exits of hospital or implementation of previously designated disaster triage.

It is essential to plan how hospitals will utilize their own resources to adequately address the rapidly growing patient demand when a large number of casualty flock to the ED due to a CBRNE disaster or multiple casualty incident (MCI). The focus of this study was the ED of a secondary university hospital with 400 beds, including 20 ED beds. The basic demographic characteristics and clinical outcomes of the 199 HFEPs according to timeline, the proportions of HFEPs and TPs present during the study period, and the distribution of the 199 HFEPs according to major burn criteria were investigated, together with the ED manpower during the three phases of the study period, the treatments implemented, and checklist results of hospital’s disaster response according to 4Ss. The results are discussed here, including in relation to those obtained in a review of the disaster management literature.

Among the 199 HFEPs, there were twice as many males as females. Most of the HFEPs came to the ED during the subacute phase and over 80% of the 199 HFEPs visited the ED within 24 h after the outbreak of the incident. These results are similar to those of a previous study [17]. Almost half of the patients visited the ED due to inhalation complaints, had been 100 m away from the incident location, and were diagnosed with chemical intoxication. The injuries reflected the delayed evacuation of Gumi’s residents in the absence of governmental guidance, as described in two reports [12, 13]. The eight HFEPs assigned to the MBG based on injury severity presented to the ED during the acute phase, consistent with the results of a CDC simulation study in which almost all acute casualties arrived at the nearest EDs within approximately 7 h [21]. During the subacute phase of our study, HFEPs accounted for >60% of the TPs, and thus for the ED surge in the first 24 h of the factory leak. One patient was admitted to the hospital after visiting ED with chief complaint of vomiting on 6, October, 2012 after hydrogen fluoride exposure and diagnosed as gastric ulcer. The authors interpreted that there was the association between HF exposure as a cause and gastric ulcer occurrence as a result according to pathophysiology of HF which was introduced in literature mentioned as “other strong acids, produces a high concentration of hydrogen ions, causing coagulative protein necrosis, and direct destruction of exposed tissues. HF at low concentration behaves as a weak acid, usually causing no apparent tissue destruction, although there may be erythema” [22].

During the 8 h comprising the acute phase, three doctors and three nurses were assigned to 75 TPs, including 8 patients in the MBG, as per usual work schedule. The two patients who died were in the MBG; one patient was DOA at the ED and the other was alive on ED arrival, but had severe hypocalcemia (total blood calcium level, 3 mg/dL; normal adult range, 8.6–10.2 mg/dL), which resulted in recurrent refractory ventricular dysrhythmia. The patient died despite >1 h advanced cardiovascular life support and calcium gluconate treatment. Concerning this fatality of highly concentrated HFEPs, severe cases of myocardial irritability, arrhythmia and even death have been reported in some literature [22]. During the subacute phase, 6 doctors (3 each on the day and night shifts) and 10 nurses (3 on the day shift, 4 on the evening shift, and 3 on the night shift) were on duty and managed 262 TPs, including 167 HFEPs (45 in the MBG and 122 in the NMBG).

For burn patients in MCI or CBRNE disaster, a nurse: patient ratio of 1:2–1:4 and a doctor: patient ratio of 1:50–3:50 are recommended [23]. In order to maintain the continuity of the standard of care in MCI or CBRNE disaster, hospitals must distinguish 3 levels of care situations: “Conventional care” as usual care, “Contingency care” as functionally equivalent care in contingency situation, and “Crisis care” as crisis standard of care for space, staff, and supplies such as securing disaster reserve beds by using non-patient care areas like conference room for patient care [5, 24]. It is important to separate patient with guardian, staff entry areas, triage areas, and parking lots and to manage unified entrances and exits of hospitals in MCI or CBRNE disaster [1, 2, 5, 7]. ED staff require administrative support to manage patients efficiently by avoiding bottleneck phenomena of ED registration. Prepared offline registration methods such as numbered disaster patient tag of necklace or bracelet would be alternative. Since fatal situations are rare, it is important that ED staff have the opportunity to make screening decisions and opportunities by using simulation setting (on-line or off-line), tabletop exercises, courses dealing with modules such as triage and discussion including debriefing in MCI or additive actions to be taken in CBRNE disaster, or functional disaster exercises [5-8]. In the event of an MCI or CBRNE disaster, the ED doctors should minimize diagnostic tests and target lifesaving procedures [5, 15-17, 24]. At the same time, laboratory workers and radiologists must prioritize testing [5, 15-17, 24]. It is required to make system to detect and reinforce shortage or absence of medicines or stuffs such as PPE for hospital’s disaster response [3, 5, 15-16]. Moreover, when faced with resource shortages caused by a surge in disaster demand, suppliers can use six key strategies of prepare, conserve, substitute, adapt, reuse, and reallocate [5]. Proactive measures to be applied to each level of care must be promised in advance and applied when a situation occurs [5, 24]. ED care providers should be aware of the risks to the community through a hazard vulnerability assessment, understand the possible medical consequences, and provide education on CBRNE topics to the ED staff [16]. For example, in an industrial city such as Gumi City, considering that various chemical substances are handled in factories, ED-based response training is needed in preparation for a scenario in which a chemical disaster occurs due to a large amount of chemical leakage. Such training should include zone setup, decontamination, level of PPE determination, and the use of antidotes, if applicable [7, 8]. To find the most suitable disaster triage model as ever known, Craig, J.B. et al [25] compared and evaluated various ED triage methods such as START, ESI, CBRN, and SALT using data extracted from medical records of the patients from the Graniteville chlorine disaster owing to train derailment in 2005. Distinguishing whether the patient was actually exposed to HF or not and evaluating the severity by early ED triage mainly using initial vital signs, present illness, symptoms, and signs was very challenging with limited human resources as well as no ED space expansion within a limited time for multiple HFEPs rushing to ED where HF inhalation constitutes the majority of the patient incident mechanism. One effort to address this challenge was Cully et al. [26] who analyzed retrospectively on patient data from a chlorine leak disaster caused by train derailment in Graniteville, South Carolina, USA in 2005 and made an announcement that it was considered that irritant gas syndrome agent exposure could be validated, and ED care should be given priority, if the patient met 2 or more clusters among 3 clusters of symptoms and signs which constituted respiratory, chest discomfort, and eye, nose and / or throat. Emergency department set order for 199 HFEPs was produced and applied according to target site which were comprised of respiratory tract, skin burn and systematic intoxication on our hospital's own way. It is important to know the treatment of inhalation exposure in HF accidents, as it was found that the NMBG was the most common with at least over 70% in all periods except just for the initial 8 hours and most of the damaged areas were exposed through the respiratory tract in this study. The evidence based recommended treatment for respiratory HFEP was 2.5–3.0% calcium gluconate using a nebulizer with inhalation and management of systemic toxicity [22]. However, to date, various studies have suggested various treatment protocols, but it has been reported that there is no widely accepted protocol for treating HF burns [22,27-29]. Before implementing these disaster triages, the premise of judgment must be preceded by seven core ethical decision-making systems of fairness to all individual and process itself, duty to care, duty to steward resources, transparency of the process and criteria, consistency to all patients, proportionality in degree of resource restriction according to demand, and accountability of triage officers and others to capable of defending their decision and answering questions from others [5, 30].

Limitation

This study has the potential of selection bias as patient information collected retrospectively from a single institution. However, it should be considered that disasters are mainly studied in retrospective anecdotal case reviews in an environment that is not ethically feasible for a randomized controlled trial.

Conclusion

Hospital disaster response was insufficient for all aspects in view of 4Ss. Detailed guidance for hospital disaster management plan establishment is required.

List Of Abbreviations

CBRNE: chemical, biological, radiological, nuclear, and explosive

ED: emergency department

HFEPs: hydrogen fluoride-exposed patients

MCI: multiple casualty incident

PPE: personal protective equipment

TPs: total patients in the ED

Declarations

All methods were carried out in accordance with relevant guidelines and regulations.

Informed consent was obtained from all subjects or, if subjects are under 18, from a parent and/or legal guardian.

Ethics approval and consent to participate

This study was supported by Soonchunhyang University and was approved by the Institutional Review Board of Soonchunhyang University Gumi Hospital (IRB_SCHUH 2019-18). All of the authors consent to participate this study.

Consent for publication

Not applicable.

Availability of data and materials

The data that support the findings of this study are available from electronic medical record database in Soonchunhyang University Gumi Hospital located at the Southeastern Region of South Korea, Gyeongsangbuk-do, Gumi city but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission from the given registry. Data access and analysis was approved by the Institutional Review Board of Soonchunhyang University Gumi Hospital (IRB_SCHUH 2019-18).

Competing interests

The authors declare no competing interests.

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Author Contributions

HJS participated in conception and design of the research. HJS, SKO, HYL, HJC, SYY, SYC,

and JHK acquired and analyzed the data. HJS, SKO, and JHK interpreted the results. HJS wrote

the manuscript. All authors read the manuscript and approved its submission to BMC Emergency Medicine.

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References

1. Halpern P, Goldberg SA, Keng JG, Koenig KL. Principles of Emergency Department facility design for optimal management of mass-casualty incidents. *Prehosp Disaster Med* 2012;27:204-212.
2. Hansoti B, Kellogg DS, Aberle SJ, et al. Preparing Emergency Physicians for Acute Disaster Response: A Review of Current Training Opportunities in the US. *Prehosp Disaster Med* 2016;31:643-7.
3. Sheikhbardsiri H, Raeisi AR, Nekoei-Moghadam M, Rezaei F. Surge Capacity of Hospitals in Emergencies and Disasters With a Preparedness Approach: A Systematic Review. *Disaster Med Public Health Prep* 2017;11:612-620.
4. Zhong S, Clark M, Hou XY, Zang YL, Fitzgerald G. Development of hospital disaster resilience: conceptual framework and potential measurement. *Emerg Med J* 2014;31:930-938.
5. Hick JL, Hanfling D, Cantrill SV. Allocating scarce resources in disasters: emergency department principles*. Ann Emerg Med* 2012;59:177-187.
6. Anan H, Otomo Y, Kondo H, et al. Development of Mass-casualty Life Support-CBRNE (MCLS-CBRNE) in Japan. *Prehosp Disaster Med* 2016;31:547-550.
7. Coleman CN, Bader JL, Koerner JF, et al. Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) Science and the CBRNE Science Medical Operations Science Support Expert (CMOSSE). *Disaster Med Public Health Prep* 2019;13:995-1010.
8. Alessandro Barelli IB, Maurizio Soave, Chiara Tafani and Francesca Bononi. The comprehensive medical preparedness in chemical emergencies: 'the chain of chemical survival'. *European Journal of Emergency Medicine*. 2008;15:110-8.
9. SB P. Alert over South Korea toxic leaks. YONHAP NEWS/YNA/NEWSCOM. Vol 494. *Nature: Macmillan Publishers*; 2013.
10. Lim HS, Lee K. Health care plan for hydrogen fluoride spill, Gumi, *Korea. J Korean Med Sci* 2012;27:1283-4.
11. Joo-An Kim S-YY S-YC, Jin-Hyun Yu, Hwa-Sung Kim, Gune-Il Lim and Jin-Seok Kim. Acute health effects of accidental chlorine gas exposure. *Annals of Occupational and Environmental Medicine.* 2014;26.
12. Joo-Yong Na K-HW S-YY, Seong-Yong Cho, In-Ung Song, Joo-An Kim and Jin-Seok Kim Acute Symptoms after a Community Hydrogen Fluoride Spill*. Annals of Occupational and Environmental Medicine.* 2013;25.
13. Yoo SH, Yoon SY, Woo KH, et al. Psychological effects of a disastrous hydrogen fluoride spillage on the local community. *Ann Occup Environ Med.* 2017;29:40.

14. National Institute of Chemical Safety, Ministry of Environment. Foundation Purpose of National Institute of Chemical Safety. available at http://nics.me.go.kr/eng/sub.do?menuId=8. Vol 2019.
15. Kaji A, Koenig KL, Bey T. Surge capacity for healthcare systems: a conceptual framework. *Acad Emerg Med* 2006;13:1157-9.
16. McManus J, Huebner K, Scheulen J. The science of surge: detection and situational awareness. *Acad Emerg Med* 2006;13:1179-1182.
17. Stratton SJ, Tyler RD. Characteristics of medical surge capacity demand for sudden-impact disasters. *Acad Emerg Med* 2006;13:1193-7.
18. Population of Gumi city at Gyeongsangbuk-do providence on September in 2012. http://kosis.kr/statisticsList/statisticsListIndex.do?menuId=M_01_01&vwcd=MT_ZTITLEparmTabId=M_01_01#SelectStatsBoxDiv. [Assessed at 12. November. 2020].
19. Sheridan, R. L. (2002). *Burns.* Critical Care Medicine, 30(Supplement), S500–S514. doi:10.1097/00003246-200211001-00015
20. Judith E. Tintinalli M, MS, J. Stephan Stapczynski, MD, O. John Ma, MD, Donald M. Yealy, MD, Garth D. Meckler, MD, MSHS, David M. Cline, MD. *Tintinallis Emergency Medicine A Comprehensive Study Guide_8th chapter 216> Thermal burns> Table 216-3 .pdf* 2016.
21. CDC (2006), U.S. Department of Homeland Security, Homeland Security Digital Library (2019). Mass Casualties Predictor. retrived from Centers for Disease Control and Prevention: http://www.cdc.gov (2006). https://www.hsdl.org/?abstract&did=24463. [Assessed at 12. November. 2020].
22. Wang X, Zhang Y, Ni L, et al. A review of treatment strategies for hydrofluoric acid burns: current status and future prospects. *Burns* 2014;40:1447-1457.
23. Abir M, Davis MM, Sankar P, Wong AC, Wang SC. Design of a model to predict surge capacity bottlenecks for burn mass casualties at a large academic medical center. *Prehosp Disaster* Med 2013;28:23-32.
24. Institute of Medicine. Guidance for Establishing Crisis Standards of Care for Use in Disaster Situations: A Letter Report. Washington, DC: Institute of Medicine, *National Academies of Science*; 2009.
25. Craig JB, Culley JM, Tavakoli AS, Svendsen ER. Gleaning data from disaster: a hospital-based data mining method to study all-hazard triage after a chemical disaster. *Am J Disaster Med* 2013;8:97-111.
26. Culley JM, Richter J, Donevant S, Tavakoli A, Craig J, DiNardi S. Validating Signs and Symptoms From An Actual Mass Casualty Incident to Characterize An Irritant Gas Syndrome Agent (IGSA) Exposure: A First Step in The Development of a Novel IGSA Triage Algorithm. *J Emerg Nurs* 2017;43:333-8.
27. Bajraktarova-Valjakova E, Korunoska-Stevkovska V, Georgieva S, et al. Hydrofluoric Acid: Burns and Systemic Toxicity, Protective Measures, Immediate and Hospital Medical Treatment. *Open Access Maced J Med Sci* 2018;6:2257-2269.

28. Ball CG, Kirkpatrick AW, Mulloy RH, Gmora S, Findlay C, Hameed SM. The impact of multiple casualty incidents on clinical outcomes. *J Trauma* 2006;61:1036-9.
29. Zhang YH, Han CM, Chen GX, et al. Factors associated with chemical burns in Zhejiang province, China: an epidemiological study. *BMC Public Health* 2011;11:746.
30. O'Laughlin DT, Hick JL. Ethical issues in resource triage. *Respir Care*. 2008;53:190-197; discussion 197-200.

Appendix

Appendix. Checklist of hospital disaster response according to staff, space, stuff, and system

Category	Question	Yes or No
Staff	Were there any reinforcement of hospital disaster response persons such as doctors or nurses or administration persons or security persons?	Yes or No
	Were there any duty time adjustments or duty relocation of ED working personnel?	Yes or No
Space	Was there any expansion of ED space to accommodate surging patients inside ED?	Yes or No
	Was there any expansion of ED space to accommodate surging patients outside ED?	Yes or No
	Were there any disaster reserve beds secured in the hospital?	Yes or No
Stuff	Were there any reinforcement of medicines including antidote such as calcium gluconate?	Yes or No
	Was there any personal protective equipment provided for hospital disaster response personnel to respond to the CBRNE disaster?	Yes or No
	Were there any reinforcement of logistics other than those mentioned above for the hospital's disaster response?	Yes or No
System	Were there any hospital's disaster command systems in operation?	Yes or No
	Did the administration department implement disaster related measures to accept a large number of patients different from usual?	Yes or No
	Has disaster triage such as START or SALT in preparation for multiple casualty accidents or disasters been implemented apart from usual ED patient triage?	Yes or No
	Was there any decontamination zone setup in the hospital?	Yes or No
	Did the hospital perform decontamination of the patients?	Yes or No
	Were there any different diagnostic testing measures implemented to address the rapidly surging ED patient testing needs different from usual?	Yes or No

	Were there any unification and management of the entrances and exits of hospitals that should be operated in case of disaster?	Yes or No

CBRNE, chemical, biological, radiological, nuclear, and explosives; ED, emergency department. The authors developed these checklist questions by review of literatures concerning hospital's disaster response [1-3, 5-17].

Figures

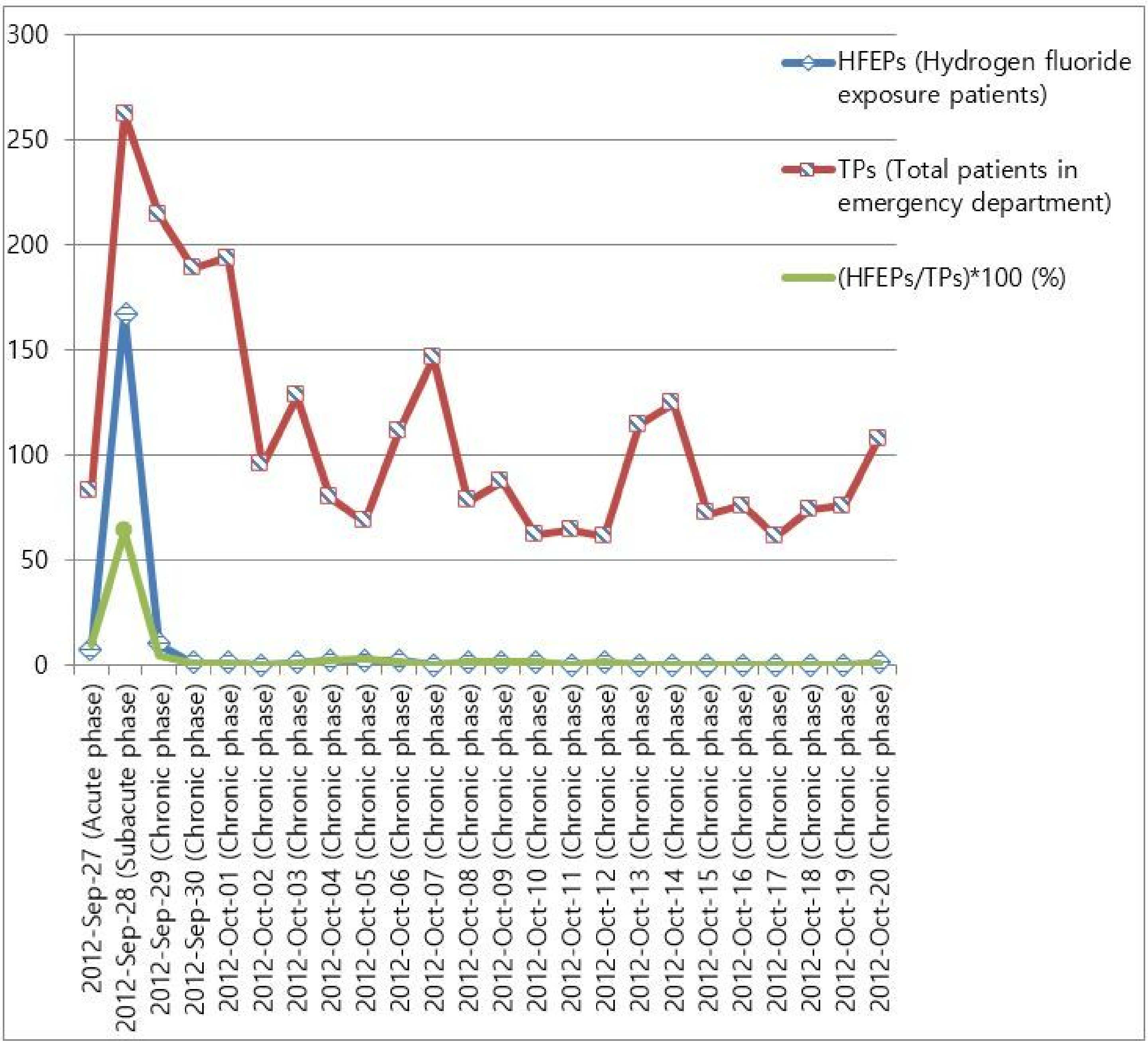

Figure 1

Frequencies of hydrogen fluoride–exposed patients (HFEPs) and total patients (TPs) in the emergency department by date. HFEPs, hydrogen fluoride exposure patients; TPs, total patients in emergency department; (HFEPs/ TPs) *100 (%), proportion of hydrogen fluoride exposure patients among total patients in emergency department; Vertical axis represent number of HFEPs and TPs as well as proportion of (HFEPs/ TPs) *100 (%). Acute phase, first 8 h after the onset of the HF leak; subacute phase, the 24 h after the acute phase; chronic phase, the month after the acute and subacute phases. The numbers and percentages of HFEPs and TPs are provided in Table 2.