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Injury Pattern and Spectrum of Tornado Injury and Its Geographical Information System Distribution in Yancheng, China

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Abstract

Objectives The studies on tornado injury have rarely considered differences in damage and Enhanced-Fujita (EF) scale areas. This research aimed to study the injury pattern, spectrum, and geographical distribution of the Yancheng tornado, and provide guidelines for effective emergency medical strategies.

Setting The study was conducted in 3 hospitals which treated the injured following tornado in Yancheng, China.

Participants 451 records of patients injured in the tornado were obtained. 401valid trauma medical records were included in this study, while 50 records were excluded for not having enough information. Informed consent was obtained from all patients by telephone.

Main outcome measures We analyzed injury sites and injury types of the patients in tornado, and used the Abbreviated Injury Scale (AIS) to standardize injury severity. GIS and nonparametric tests were used to analyze the influence of geographical factors on casualties.

Results Women accounted for 51.62% of the injured, and 77.30% of injured were middle-aged or elderly being aged >45, while 12.47% were aged <18 years. Head (46.63%), body-surface (39.90%), and lower-limb (29.43%) injuries were common. Soft-tissue injuries, fractures, and organ damage occurred in 90.77%, 38.90%, and 19.70% of patients. Minor injuries (AIS=1) were common (60.85%), while critical and fatal injuries were very rare (AIS ≥5; 2.50%). There were differences in the density of injured in different damage and EF areas, but it was insignificant in terms of injury severity (AIS scores) (P>0.05).

Conclusion The age distribution of patients injured in the tornado had "dumbbell shape", with most injured being aged <18 years or >45 years. Medical staff should prioritize the treatment of high-risk head and multiple-organ injuries, and medical rescuers should follow the "same quality and different quantity" principle—paying

equal attention to the injured in all affected areas, but dispatching a different number of medical personnel in differently affected areas.

Strengths and limitations of this study

- We studied the pattern and spectrum of tornado injuries in China and the distribution of the 401 injuries in different damage and EF-scale areas by Geographical Information System.
- Maybe there were selection bias, as we only selected three hospitals which treated most of the injured following Yancheng tornado.
- Further study should include larger samples and more detailed meteorology information.

INTRODUCTION

Tornados are deadly storms, usually resulting in significant casualties [1]. At 14:30 on June 23, 2016, a devastating tornado occurred in Yancheng, eastern China, killing 99 people and injuring 846 [2]. This was the deadliest tornado disaster in China in nearly half a century [3], and the China Meteorological Administration rated it as Enhanced Fujita 4 (EF4), with a maximum wind power exceeding 17 and wind speed surpassing 266 km/h [3]. Although the incidence of tornados in China cannot be compared with that in the United States, a total of 2,210 recorded tornados occurred in China during the 30 years from 1984 to 2013, killing 2,000 people and injuring 30,000 [4]. Moreover, tornados in China have occurred primarily in developed coastal provinces with higher population densities and degrees of economic development. Therefore, there is substantial risk for serious damage and life loss caused by tornados in China [5].

Research on tornados has primarily been performed in the United States. Moreover, the impact of tornados on public health, such as injury, has drawn increasing attention [6]. Some studies have analyzed the characteristics of tornado injuries [7, 8] and found that soft-tissue, head, and limb injuries were the most common types. However, these studies did not follow any standardized methodology for injury severity scoring [6] despite the fact that the methods of analysis of traumatic injuries (i.e., recording injury sites, types, and severity), as well as the Abbreviated Injury Scale (AIS), have been updated and standardized [9]. Understanding the injury pattern and spectrum of tornados can help improve the efficiency of rescue efforts; therefore, standardization of reporting of tornado-related injuries should be carried out urgently.

More importantly, the Geographical Information System (GIS) has been widely used to aid disaster rescue [10, 11]. Peek-Asa et al. analyzed the injuries in the 1994 Northridge Earthquake with regard to the distance from the earthquake epicenter, the Modified Mercalli Intensity Index, peak ground acceleration, and damaged buildings proportion [12]. Curtis et al. used GIS technology to assess the distribution of medical needs in the Los Angeles area after an earthquake [13]. In general, the tornado's ability to kill people has obvious geographical characteristics related to the area and wind level of the damage area [14, 15], and was related to emergency medical rescue. Specifically, the risk of injury increases with the wind speed and decreases with the distance to the tornado. Simmons and Sutter analyzed tornado data collected by the National Weather Service from 1950 to 2007 and concluded that 62% of tornado-related deaths in the United States resulted from Fujita (F)4 or F5 tornados [16].

Currently, the severity of a tornado is evaluated on the Enhanced Fujita scale (EF), which is based on the 1971 Fujita scale (F) and revised in 2007 [14, 17]. The EF scale ranges from 0 to 5, with 5 indicating the highest severity. Some studies have comprehensively assessed the proportion of damaged buildings and other factors to rate different damage areas [3, 14]. However, rating by using either the EF-scale or the damage areas within tornado-stricken areas is difficult, because it requires meteorological radar information, ground-based instrument observation, as well as property loss and other field-investigation information. Therefore, studies on tornado-related injuries rarely employ GIS data. While several studies have presented information on injuries in different areas, they did not explore the interaction between them. Paul and Stimers studied the distribution of 162 deaths caused by the Joplin tornado in different damage areas [14]. Curtis and Fagan analyzed the distribution of 135 tornado-related deaths by capturing damage assessments with a spatial video [18]. Presently, no scholar has provided data on the injuries recorded in different damage areas for the entire tornado path. Moreover, no studies have reported the spatial distribution of tornado-related injuries in China. However, injury characteristics, especially injury severity, have an important impact on injury outcomes. Injuries of different severity in different areas have different requirements for timely treatment. Thus, understanding the geographical distribution of tornado-related injuries is helpful in developing timely and effective emergency medical rescue strategies. It is necessary to evaluate the distribution of tornado-related injuries in different tornado damage and severity (EF-scale) areas.

The present study had three aims. First, we aimed to study the characteristics of tornado-related injuries, including injury site, type, and severity, and to compare these with the injury characteristics recorded for other disasters and tornados in the United States. Second, we aimed to study the spatial distribution of tornado-related injuries in Yancheng. Third, we aimed to analyze the differences in AIS scores among different damage and EF-scale areas. This research will help understand the characteristics of tornado-related injuries and provide a reference for predicting potential medical needs in different geographical regions and improving medical rescue strategies.

MATERIALS AND METHODS

Medical records data

We collected medical records from the three hospitals in Yancheng that treated the most tornado patients following the June 23rd tornado: the Funing County People's Hospital, the Jianhu County People's Hospital, and the Yancheng Third People's Hospital. These three hospitals received 53.31% of all patients injured in the tornado (451/846), while the remaining injured was scattered among the other 16 hospitals, which were farther away. Among the studied hospitals, the Funing County People's Hospital was the nearest to the disaster area, and thus most of the injured were treated or referred by this hospital. The Jianhu County People's Hospital was the second closest to the disaster area. The Yancheng Third People's Hospital was located in the urban center of Yancheng and belonged to a tertiary hospital (the highest level of Chinese hospital), admitted a large number of severely injured tornado patients who were referred by lower-level hospitals. Patients included in the study were those who were directly injured as a result of the tornado and whose location during the tornado could be identified. Patients with recurrent chronic disease or stress-related conditions due to the tornado, but no trauma, were excluded.

Unified medical record collection forms were developed. Data extraction was independently performed by two investigators and proofread for inconsistent entries. Three types of information were extracted: (1) demographic information including age, sex, marriage status, and occupation; (2) trauma information, including the cause of injury, prehospital time, length of hospitalization, and injury site, type, and severity; and (3) location during the tornado. Injury site was categorized based on the body region affected [19,20] and included the head, neck, face, chest, spine, abdomen/internal organs, upper extremities, lower extremities/pelvis, and body surface/other. Injury severity was judged by clinical experts, based on the 2005 version of the AIS. In patients with multiple injuries, only their most severe injury site was considered in the final AIS score [19-21]. The AIS score ranges from 1 (minor injury) to 6 (fatal injury). The investigators were Master's degree students in Social Medicine and Public Health Service Management. Prior to data collection, the investigators received training to familiarize themselves with the medical record structure and research guide. Four investigators went to the three hospitals between

July 12, 2016 and July 30, 2016 (one month after the tornado). A total of 451 records of patients injured in the tornado were obtained. Of these, 50 records were excluded for not mentioning the location of the injured during the tornado. Finally, 401 (88.91%) valid trauma medical records were included in the analysis.

GIS data analysis

The China National Disaster Reduction Center and Chinese Academy of Sciences carried out a detailed study of the June 23rd Yancheng tornado. They classified the disaster area into four categories (disaster affected area, general area, severe area, and very severe area) based on six factors including the number of deaths, injuries, emergency relocations, disaster relief staffs employed, and direct economic losses [3]. A team led by Professor Zhiyong Meng from Peking University conducted an accurate survey on the June 23rd Yancheng tornado and classified areas as EF0 – EF4, based upon in-the-field investigation, aerial image data, ground weather station information, and radar data.

Based on the above research, the Arcview 10.3 software (Redlands, California, USA) was used for geographic image data vectorization including four kinds of damage areas and EF0- EF4 areas. The result was added on the China Online Street Warm map in ArcGIS Online. Tested by the data comparison, the precision meets the demanding of analysis. Based on the geographic location of in medical records, the injured was located on the map one by one, which was matched to the damage and EF-scale area. In the aspect of making maps, when the locations of the wounded were extremely close, for the sake of clarity, they were aggregated into one point and marked the number of the wounded involved around the point. However, this did not alter the location of the wounded in different damage areas and related statistical analysis.

Statistical analysis

The age, prehospital time, and length of hospitalization were converted into categorical variables. Descriptive analysis was conducted for the demographic information and the trauma characteristics. Based on the GIS, the number of injured, the area size, and the density of injured in different damage and EF-scale areas were analyzed. Non-parametric tests were performed to determine the influence of geographical characteristics on the AIS scores. The statistical software used was SPSS version 21.0 (SPSS Inc., Chicago, IL, USA). All tests were two-way, and a P-value <0.05 was considered to be statistically significant.

Ethical statement

Access to medical records was approved by the three participating hospitals and by all patients. Informed consent was obtained from the participants by telephone. For injured patients aged <18 years, consent was given by the legal guardians. Ethical approval was awarded by the Medical Ethics Committee of the Second Military Medical University.

RUSULTS

Demographic characteristics

51.62% of the injured were women. 77.30% were middle-aged or elderly people aged more than 45 years. 91.77% were married. And 81.55% were classified as farmers by occupation (Table 1).

Table 1. Demographic characteristics of the injured.

Items	Groups	Number	Percentage(%)
Sex	Male	194	48.38
	Female	207	51.62
Age(years)	<18	50	12.47
	18-29	18	4.49
	30-44	23	5.74
	45-64	124	30.92
	>=65	186	46.38

Marriage	Married	368	91.77
	Unmarried[a]	33	8.23
Occupation	Farmer	327	81.55
	Student	40	9.98
	Worker	11	2.74
	Others	23	5.74

Injury characteristics and standardized scores

60.10% were injured due to the collapse of a building; 63.09% received hospital treatment within 12 hours, and 58.61% had lengths of hospitalization of 2 weeks or less (Table 2).

Of the nine injury sites, the top three were head (46.63%), body surface (39.90%), and upper extremities (29.43%). Chest injury also accounted for a large proportion (22.69%). From the number of injuries, most of the injured had multiple injuries (58.60%), and seven patients had five injury sites (1.75%) (Table 2).

The top three injury types were skin and soft tissue injuries (90.77%), fractures (38.90%), and organ injuries (19.70%). The number of fractures was counted for each of the nine injury sites defined, meaning that multiple fractures at the same injury site were recorded as a single fracture. Single fracture was noted in 71.79% of patients, while two patients had four fractures. Bacterial infection occurred in 5.24% of patients, and disturbance of consciousness occurred in 3.74% (Table 2).

Regarding the severity of injury, 60.85% of patients sustained injuries with AIS score 1, while 2.50% sustained injuries with AIS score ≥5 (Table 2). With respect to the distribution of AIS scores at different injury sites, of the 10 patients with very severe injuries (AIS score ≥5), all sustained injuries at high-risk sites: head injury in 7 patients, thorax injury in two patients, and spine injury in one patient. Three patients with fatal injury (AIS score 6) sustained severe crush injury to the head or chest, and one died of head injury as a result of medical failure (Table 3).

Table 2. Injury characteristics of the injured[a].

Items	Groups	Number	Percentage(%)
Cause of injury	Injuried by collapse of the house	241	60.10
	Stricken by heavy object	142	35.41
	Blow down by tornado	18	4.49
Prehospital time(hour)	<=1	15	3.49
	2-3	77	19.20
	4-12	162	40.40
	13-24	99	24.69
	>24	49	12.22
Length of Hospitalization(day)	0	14	3.49
	<=7	118	29.43
	8-14	117	29.18
	15-21	62	15.46
	>21	37	9.23
	unknow	53	13.22
Injury site[b]	Head	187	46.63
	Body surface / others	160	39.90
	Lower extremities/pelvis	118	29.43
	Chest	91	22.69
	Face	64	15.96
	Upper extremities	63	15.71
	Spine	39	9.73
	Abdomen / internal organs	29	7.23

	Neck	2	0.50
Injury number	1	166	41.40
	2	148	36.91
	3	64	15.96
	4	16	3.99
	5	7	1.75
Injury type[b]	Skin and soft tissue injuries	364	90.77
	Fracture	156	38.90
	Traumatic organ injuries	79	19.70
	Pulmonary contusion	30	7.48
	Central nervous system injuries	17	4.24
	Traumatic haemopneumothorax	16	3.99
	Concussion brain	4	1.00
	Destruction	3	0.75
Fracture number	0	245	61.10
	1	112	27.93
	2	31	7.73
	3	11	2.74
	4	2	0.50
Bacterial infection	Yes	21	5.24
	No	380	94.76
Disturbance of consciousness	Yes	15	3.74
	No	386	96.26
AIS score	1（minor）	244	60.85
	2	62	15.46
	3	58	14.46
	4	27	6.73

5	7	1.75
6（fatal）	3	0.75

[a] This table contains all injury information, including all injury sites and types.

[b] The relative percentage of injury site and type indicate incidence rate.

Table 3. The distribution of AIS scores in different injury sites[a].

AIS score	Head	Face	Neck	Chest	Abdomen / internal organs	Spine	Upper extremities	Lower extremities/ pelvis	Body surface / others
1	70(28.69)	32(13.11)	1(0.41)	13(5.33)	11(4.51)	3(1.23)	21(8.61)	52(21.31)	41(16.80)
2	10(16.13)	1(1.62)	0	13(20.97)	3(4.84)	13(20.97)	10(16.13)	12(19.35)	0
3	21(36.21)	0	1(1.72)	22(37.93)	3(5.17)	7(12.07)	0	4(6.90)	0
4	0	0	0(0.00)	23(85.19)	3(11.11)	0	0	1(3.70)	0
5	6(85.71)	0	0	0	0	1(14.29)	0	0	0
6	1(33.33)	0	0	2(66.67)	0	0	0	0	0
Sum up	108(26.93)	33(8.23)	2(0.50)	73(18.20)	20(4.99)	24(5.99)	31(7.73)	69(17.21)	41(10.22)

[a] This table presents the most severe injury sites related to the final AIS scores.

Distribution of injured in different areas

Regarding different damage areas, since there was only one casualty in the general area, this study analyzed the general area and the severe area together, calling it collectively the 'severe area'. The number of injured was lower in the disaster-affected area (37 persons) than that of the severe damage area (64 persons) or the very severe area (300 persons). The density of injured per square kilometer increased with the severity of damage in the area, with the highest density (2.26 injured/km^2) in the very severe area (Table 4, Figure 1).

Table 4. The distribution of the injured in different damage and EF-scale areas.

	Areas（km^2）	Number	Percentage(%)	Density（number/km^2）
Damaged areas				
Disaster affected area	2457.18	37	9.23	0.02
Severe area	118.13	64	15.96	0.54
Very severe area	133.02	300	74.81	2.26
Sum up	2708	401	100.00	0.15
EF scale				
EF0	129.74	20	8.10	0.15
EF1	84.19	139	56.28	1.65
EF2	27.61	40	16.19	1.45
EF3	13.66	33	13.36	2.42
EF4	5.66	15	6.07	2.65
Sum up	260.86	247	100.00	0.95

Although the geographical scope of the EF0-EF4 areas is smaller (260.86 km^2) than that of the entire disaster-stricken area, the wind level classification is more accurate. The density of injured increased with the wind levels in the area, with the highest density (2.65 injured/km^2) noted for the EF4 area. Because the entire disaster-stricken area was very large, Professor Meng was only able to conduct an in-the-field investigation of the centerline-related area of the tornado, for this reason, 154 patients included in the study, who had reported locations outside of the EF-scale areas, were not included in the analysis of EF-scale areas (Table 4, Figure 2).

Injury severity in different areas

In order to further study injury severity in different damage and EF-scale areas, non-parametric tests were conducted. The results showed that the geographical characteristics had no significant influence on the AIS scores (P>0.05; Table 5).

Table 5. Non-parametric tests for AIS scores among different damage and EF-scale areas.

	AIS=1 (n,%)	AIS=2 (n,%)	AIS=3 (n,%)	AIS=4 (n,%)	AIS=5 (n,%)	AIS=6 (n,%)	P
Damaged areas							0.131
Disaster affected area	23(62.16)	8(21.62)	3(8.11)	2(5.41)	0(0.00)	1(2.70)	
Severe area	33(51.56)	8(12.50)	14(21.88)	8(12.50)	1(1.56)	0(0.00)	
Very severe area	188(62.67)	46(15.33)	41(13.67)	17(5.67)	6(2.00)	2(0.67)	
EF scale							0.322
EF0	9(45.00)	6(30.00)	4(20.00)	1(5.00)	0(0.00)	0(0.00)	
EF1	92(66.19)	18(12.95)	17(12.23)	8(5.76)	3(2.16)	1(0.72)	
EF2	26(65.00)	7(17.50)	5(12.50)	1(2.50)	1(2.50)	0(0.00)	
EF3	17(51.52)	6(18.18)	5(15.15)	4(12.12)	1(3.03)	0(0.00)	
EF4	10(66.67)	3(20.00)	2(13.33)	0(0.00)	0(0.00)	0(0.00)	

DISCUSSION

Demographic characteristics

The age distribution of injured patients had "dumbbell shape", as 77.30% of injured victims were middle-aged or elderly, 12.47% were aged <18 years, while only 10.23% were young adults. In 1999, 38.69% of injury victims of the Oklahoma tornado were aged >45 years, while 16.78% were younger than 15 years [22]. Studies on the 2001 Alabama tornado reported that 49% of injury victims were older than 45 years [7]. For other natural disasters such as earthquakes, age distribution of the victims tends to follow local demographics. For example, following the 2013 Lushan earthquake in China, 44.4% of injured were middle-aged (31–50 years) [23]. First, this may be related to disaster characteristics. Earthquakes are unpredictable and occur in a few minutes or seconds; therefore, young adults, as well as elderly people, cannot escape to safe places. In contrast, tornados last much longer and there are warnings. Teenagers and elderly individuals are more vulnerable to injury due to reduced opportunities for receiving the warning and relocating to a safe place in time. Second, geographical characteristics may also play a role. Earthquakes are prone to happen in cities and counties. Some severe earthquakes even occurred in big cities, causing a huge damage and life loss among all age groups. However, tornados tend to occur in rural areas. In Chinese village, the population mainly consists of elderly people and adolescents, as young adults move to the city to find better job opportunities. These aspects may be responsible for the "dumbbell shape" of the age distribution of tornado victims.

Injury site

In our study population, the three most common injury sites were the head (46.63%), limbs (45.14%), and chest (22.69%). By comparison, in the 2010 Yushu earthquake in China, the most common injury sites were the limbs (48.1%), chest (13.3%), and spine (12.1%), while head injuries made up only 10.1% of injuries [24]. Among earthquake victims, crush by a heavy object is the main reason for limb injury, while tornado victims typically sustain head and limb injuries caused by flying objects and collapsing buildings. In the 2011 Alabama tornado, limb and pelvis injuries were the most common, followed by head injuries. Moreover, head injuries accounted for 46.5% of hospitalizations, 56.3% of intense care unit admissions, and 71.4% of deaths [7]. Head injury is the greatest cause of death in tornados occurring in the United States [6]. In our study, victims with AIS scores ≥5 primarily had head injuries, and the only death in hospital was due to a head injury. Therefore, it is recommended that people protect their heads during tornados [25, 26], and medical rescue teams should prioritize head injury victims.

Injury type

In our study, the three most common injury types were skin and soft-tissue injuries (90.77%), fractures (38.90%), and organ damage (19.70%). During a tornado, skin and soft-tissue injury caused by weighty flying objects are common [26-28]. Collapse of houses, collision with heavy objects, and many other events lead to fractures. Both the present investigation and other studies revealed that organ damage following tornados is common [29]. During tornados with strong winds, people fall or are even lifted up and then dropped down, which can cause serious organ damage and internal bleeding, greatly threatening the victims' life. However, organ damage is harder to diagnose than skin injury. Therefore, medical rescuers should attend more closely to victims who are quiet, but in pain. Bacterial infections occurred in 5.24% of injury victims, likely caused by the chaotic environment [26-28, 30, 31]. To prevent gangrene and sepsis, it has been suggested that medical rescuers perform extensive surgical debridement early, instead of suturing wounds too early [6].

Injury severity

According to AIS scores [19, 20], 60.85% of victims sustained minor injury, 15.46% moderate injury, 14.46% severe injury without life threatening, 6.73% severe injury with life threatening, 1.75% critical injury, and 0.75% fatal injury. A report on the 2011 Alabama tornado found that 89% of injuries were minor and 6% were moderate, while only 5% were severe [7]. There were more severely injured victims in our study. This may be related to the lack of tornado protection awareness and ability in China.

Different damage and EF-scale areas reported no difference in victims' AIS scores. Severe destruction areas had a similar percentage of severely injured victims as that noted in areas with minor-destruction and low-wind. The "Trauma Golden Hour Policy" [32] and the "Brass 10 Minutes" [33] play a vitally important role in saving severely injured patients. Therefore, it is highly recommended that similar attention be given to severely injured victims in different damage and EF-scale areas. All tornado-affected areas deserve to receive the "same quality" of medical care at the same time.

Injury density in different areas

Despite the similar distribution of injury severity in different damage and EF-scale areas, the density and number of injured were different. The density of injured increased with the severity of tornado-related damage in the area, which was mainly related to wind speed and destruction of buildings. From the edge of a tornado to its center, the wind speed ranges from EF1 to EF4 [14]. It is highly recommend that a "different quantity" of emergency medical personnel be deployed to different disaster areas. More medical personnel should be deployed to the severely affected areas where there are more victims and higher density of injured. We recommend that the "same quality and different quantity" policy should be implemented in tornado-related emergency medical rescues.

Limitations

There were two limitations in this study. First, we only collected 451 medical records of the injured. However, our study included both the frontline hospital (Funing County People's Hospital) and two rear-line hospitals (Jianhu County People's Hospital and Yancheng Third People's Hospital), which treated 53.31% of all 846 injured; thus, our dataset is considered representative of the target population. Second, this study did not evaluate the geographical distribution of deaths because of limited information about them.

CONCLUSION

To sum up, the present study is the first to describe the injury pattern and spectrum of tornado-related injuries in China, as well as to analyze injury location characteristics in different damage and EF-scale areas by GIS. We found a "dumbbell-shaped" age-distribution of tornado victims in China, and recommend that the "same quality and different quantity" strategy should be applied to handle tornado-related emergency medical rescues. Our findings are expected to be very helpful in planning emergency-medical rescue efforts and appraising potential medical demands following tornados.

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Contributions

Q.D., Y.L., C.X., P.K., J.D. and L.Z. discussed and developed the question for this study. Q.D. and Y.L. abstracted data from medical records. Q.D. and C.X. carried out all analysis. All authors were involved in the interpretation and discussion of results. Q.D. and Y.L. wrote the first draft of this paper, which was reviewed L.Z. All authors agreed on the final draft of this study. L.Z. is the guarantor.

Competing interests

The authors declare that they have no competing interests.

Patient consent

Obtained.

Ethics approval

Medical Ethics Committee of the Second Military Medical University.

Data sharing statement

No additional data are available

Authors' information

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References

1. Ashley, W.S., *Spatial and temporal analysis of tornado fatalities in the United States: 1880-2005.* Weather and Forecasting, 2007. **22**(6): p. 1214-1228.
2. Lyu, H.M., G.F. Wang, W.C. Cheng, et al., *Tornado hazards on June 23 in Jiangsu Province, China: preliminary investigation and analysis.* Natural Hazards, 2016. **85**(1): p. 597-604.
3. Jia, H.C. and D.H. Pan, *Tornado disaster impacts and management: learning from the 2016 tornado catastrophe in Jiangsu Province, China.* Natural Hazards, 2017. **89**(1): p. 457-471.
4. Wang, K.W., S. Zhong, X.Y. Wang, et al., *Assessment of the Public Health Risks and Impact of a Tornado in Funing, China, 23 June 2016: A Retrospective Analysis.* International Journal of Environmental Research and Public Health, 2017. **14**(10).
5. Dapeng, H., Z. Shanshan, G. Ge, et al., *Disaster characteristics of tornados over China during the past 30 years.* Torrential Rain and Disaster, 2016. **35**(2): p. 97-101.
6. Bohonos, J.J. and D.E. Hogan, *The medical impact of tornados in North America.* J Emerg Med, 1999. **17**(1): p. 67-73.
7. Niederkrotenthaler, T., E.M. Parker, F. Ovalle, et al., *Injuries and post-traumatic stress*

following historic tornados: Alabama, April 2011. PLoS One, 2013. **8**(12): p. e83038.

8. Kanter, R.K., *The 2011 Tuscaloosa tornado: integration of pediatric disaster services into regional systems of care.* J Pediatr, 2012. **161**(3): p. 526-530 e1.

9. Salottolo, K., A. Settell, P. Uribe, et al., *The impact of the AIS 2005 revision on injury severity scores and clinical outcome measures.* Injury, 2009. **40**(9): p. 999-1003.

10. Bell, N. and N. Schuurman, *GIS and injury prevention and control: history, challenges, and opportunities.* Int J Environ Res Public Health, 2010. **7**(3): p. 1002-17.

11. Waring, S., A. Zakos-Feliberti, R. Wood, et al., *The utility of geographic information systems (GIS) in rapid epidemiological assessments following weather-related disasters: methodological issues based on the Tropical Storm Allison Experience.* Int J Hyg Environ Health, 2005. **208**(1-2): p. 109-16.

12. Peek-Asa, C., M.R. Ramirez, K. Shoaf, et al., *GIS mapping of earthquake-related deaths and hospital admissions from the 1994 Northridge, California, Earthquake.* Ann Epidemiol, 2000. **10**(1): p. 5-13.

13. Curtis, J.W., A. Curtis, and J.S. Upperman, *Using a geographic information system (GIS) to assess pediatric surge potential after an earthquake.* Disaster Med Public Health Prep, 2012. **6**(2): p. 163-9.

14. Paul, B.K. and M. Stimers, *Spatial Analyses of the 2011 Joplin Tornado Mortality: Deaths by Interpolated Damage Zones and Location of Victims.* Weather Climate and Society, 2014. **6**(2): p. 161-174.

15. Centers for Disease, C. and Prevention, *Tornado-related fatalities--five states, Southeastern United States, April 25-28, 2011.* MMWR Morb Mortal Wkly Rep, 2012. **61**(28): p. 529-33.

16. Simmons, K.M. and D. Sutter, *Economic and Societal Impacts of Tornados.* University of Chicago Press Economics Books, 2011. **56**(10): p. 412-415.

17. Center, W.S.a.E. *A recommendation for an Enhanced Fujita Scale (EF-Scale).* . 2013 [cited 2013 2013 May 1].

18. Curtis, A. and W.F. Fagan, *Capturing Damage Assessment with a Spatial Video: An Example of a Building and Street-Scale Analysis of Tornado-Related Mortality in Joplin, Missouri, 2011.* Annals of the Association of American Geographers, 2013. **103**(6): p. 1522-1538.

19. *Rating the severity of tissue damage. I. The abbreviated scale.* JAMA, 1971. **215**(2): p. 277-80.

20. Gennarelli, T.A. and E. Wodzin, *AIS 2005: a contemporary injury scale.* Injury, 2006. **37**(12): p. 1083-91.

21. Palmer, C.S., L.E. Niggemeyer, and D. Charman, *Double coding and mapping using Abbreviated Injury Scale 1998 and 2005: identifying issues for trauma data.* Injury, 2010. **41**(9): p. 948-54.

22. Daley, W.R., S. Brown, P. Archer, et al., *Risk of tornado-related death and injury in Oklahoma, May 3, 1999.* Am J Epidemiol, 2005. **161**(12): p. 1144-50.

23. Kang, P., B. Tang, Y. Liu, et al., *Medical Efforts and Injury Patterns of Military Hospital Patients Following the 2013 Lushan Earthquake in China: A Retrospective Study.* Int J Environ Res Public Health, 2015. **12**(9): p. 10723-38.

24. Kang, P., L. Zhang, W. Liang, et al., *Medical evacuation management and clinical characteristics of 3,255 inpatients after the 2010 Yushu earthquake in China.* J Trauma Acute Care Surg, 2012. **72**(6): p. 1626-33.

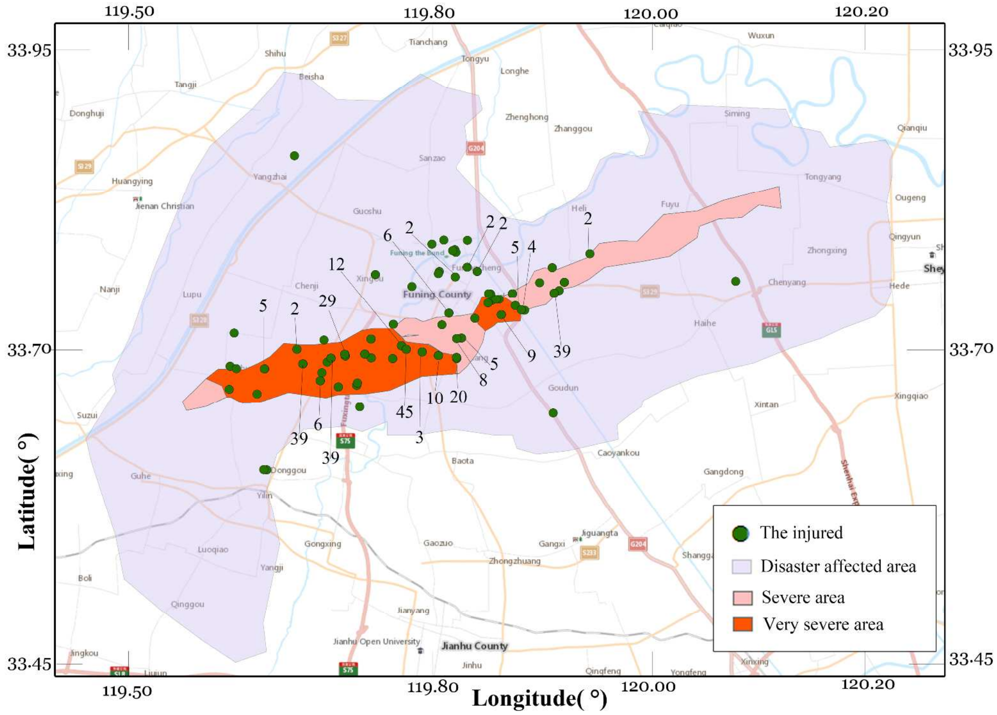
25. Brenner, S.A. and E.K. Noji, *Tornado injuries related to housing in the Plainfield tornado.* Int J

Epidemiol, 1995. **24**(1): p. 144-9.
26. Rosenfield, A.L., D.A. McQueen, and G.L. Lucas, *Orthopedic injuries from the Andover, Kansas, tornado.* J Trauma, 1994. **36**(5): p. 676-9.
27. Marr, J., *Kalamazoo medics say 'fantastic'! to health personnel response after tornados.* Mich Med, 1980. **79**(20): p. 374-6.
28. Leibovich, M., *The December 2, 1982 tornado of Saline and Pulaski counties: implications for injury prevention.* J Ark Med Soc, 1983. **80**(2): p. 98-102.
29. Ivy, J.H., *Infections encountered in tornado and automobile accident victims.* J Indiana State Med Assoc, 1968. **61**(12): p. 1657-61.
30. Mandelbaum, I., D. Nahrwold, and D.W. Boyer, *Management of tornado casualties.* J Trauma, 1966. **6**(3): p. 353-61.
31. Morris, B.A. and T.M. Armstrong, *Medical response to a natural disaster: the Barrie tornado.* CMAJ, 1986. **134**(7): p. 767-9.
32. Howard, J.T., R.S. Kotwal, A.R. Santos, et al., *Re-examination of a Battlefield Trauma Golden Hour Policy.* J Trauma Acute Care Surg, 2017.
33. Shomaker, D., *Survival, respect and equality.* Br J Nurs, 1994. **3**(15): p. 792-793.

Figure legends

Figure 1. Distribution of the injured in different damage areas. When the locations of the wounded were extremely close, for the sake of clarity, they were aggregated into one point and labeled with patients' number involved. However, this did not alter the location of the wounded in different damage areas and related statistical analyses.

Figure 2. Distribution of the injured in different Enhanced Fujita scale (EF) areas. When the locations of the wounded were extremely close, for the sake of clarity, they were aggregated into one point and labeled with patients' number involved. However, this did not alter the location of the wounded in different damage areas and related statistical analyses.



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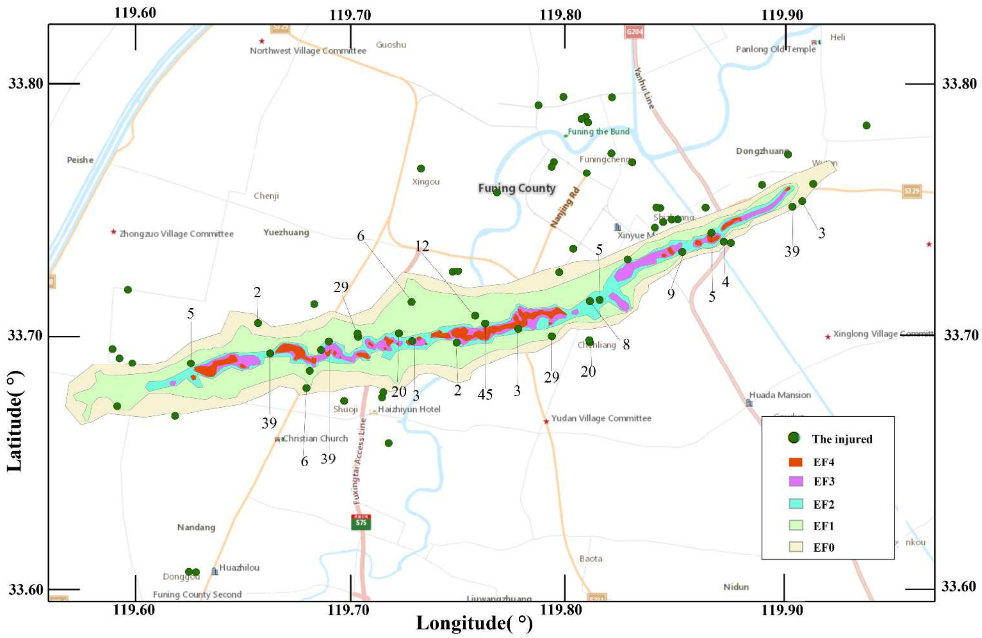

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Pattern and Spectrum of Tornado Injury and Its Geographical Information System Distribution in Yancheng, China: A Cross-sectional Study

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Pattern and Spectrum of Tornado Injury and Its Geographical Information System Distribution in Yancheng, China: A Cross-sectional Study

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Abstract

Objectives Few studies of tornado injuries have considered differences related to damage levels and Enhanced-Fujita (EF) scale ratings. This study aimed to evaluate the pattern, spectrum, and geographical distribution of injuries related to the Yancheng tornado and provide guidelines for effective emergency medical strategies.

Setting The study was conducted at three hospitals which treated patients with injuries related to the tornado in Yancheng, China.

Participants We obtained the records of 451 patients with tornado-related injuries. Of these, 401 valid trauma medical records were included; 50 other records were excluded for insufficient information. Informed consent was obtained from all patients by telephone.

Main outcome measures We analysed patients' injury sites and types and used the abbreviated injury scale (AIS) to standardise injury severity. GIS and non-parametric tests were used to analyse the effects of geographical factors on casualties.

Results Women, middle-aged/elderly individuals (age >45 years), and children/adolescents (<18 years) accounted for 51.62%, 77.30%, and 12.47% of injured patients, respectively. This caused a dumbbell-shaped age distribution. Head (46.63%), body surface (39.90%), and lower-limb (29.43%) injuries were common, as were soft-tissue injuries (90.77%), fractures (38.90%), and organ damage (19.70%). Minor injuries (AIS = 1) were common (60.85%), whereas critical/fatal injuries (AIS ≥5) were very rare (2.50%). Although the densities of injury varied among damage levels and EF ratings for different areas, area-wise differences in injury severity (AIS scores) were not significant (P >0.05).

Conclusion We recommend the use of helmets to prevent head injuries caused by tornadoes, and suggest prioritising the treatment of high-risk head and multiple-organ

injuries. Additionally, medical rescuers should follow the "same quality and different quantity" principle: the injured in all affected areas should receive equal attention, but numbers of medical personnel should be allocated based on the level of effects from the tornado.

Strengths and limitations of this study

- This is the first Geographical Information System-based study to evaluate tornado injury characteristics among areas with different damage and EF-scale ratings in China.
- Medical records of tornado patients were collected integrally from three hospitals.
- The pattern and spectrum of tornado injuries were studied according to injury site, injury type, and injury severity (AIS).
- Further studies should include larger samples of tornado patients.
- More detailed meteorology and building data will yield better results.

INTRODUCTION

Tornadoes are deadly storms that often result in significant casualties [1, 2]. At 14:30 on 23 June 2016, a devastating tornado killed 99 people and injured 846 more in Yancheng, eastern China [3] in the deadliest tornado disaster in China in nearly half a century. The China Meteorological Administration rated the storm as a 4 on the Enhanced Fujita (EF) scale, with a maximum wind speed surpassing 266 km/h [4]. Although the incidence of tornadoes in China cannot be compared with that in the United States, the former recorded a total of 2,210 tornadoes responsible for killing 2,000 people and injuring 30,000 during a 30-year period from 1984 to 2013 [5]. In China, tornadoes occur primarily in developed coastal provinces with higher population densities and degrees of economic development, which leads to a substantial risk for serious damage and losses of life [6].

To date, tornado research has primarily been conducted in the United States, and the impacts of tornadoes on public health (e.g., injury) has drawn increasing attention [7]. Some studies of the characteristics of tornado injuries [8, 9] have identified soft-tissue, head, and limb injuries as the most common types. However, these studies did not apply a standardised injury severity scoring method, despite the availability of updated and standardised versions of traumatic injury analysis methods (i.e., recording injury sites, types, and severity) [7] and the abbreviated injury scale (AIS) [10]. As an understanding of the pattern and spectrum of tornado-related injuries can improve the efficiency of rescue efforts, standardisation of the methods used to report these injuries is an urgent matter.

Importantly, the Geographical Information System (GIS) has been widely used to aid disaster rescue efforts [11, 12]. Peek-Asa et al. used such technology to analyse injuries resulting from the 1994 Northridge Earthquake with regard to the distance from the earthquake epicentre, Modified Mercalli Intensity Index, peak ground acceleration, and proportion of damaged buildings [13]. Furthermore, Curtis et al. used GIS technology to assess the distribution of medical needs in the Los Angeles area after an earthquake [14]. In general, the lethality of a tornado is clearly related to geographical characteristics such as the size of and wind level within the area of damage [15, 16], as well as emergency medical rescue efforts. Specifically, the risk of injury or death increases with increasing wind speed or intensity and decreases with increasing distance from the tornado. For example, Simmons and Sutter analysed tornado data collected by the United States National Weather Service from 1950 to 2007 and concluded that 62% of tornado-related deaths in that country resulted from tornadoes with rankings of 4 or 5 on the Fujita (F) scale [17]. Additionally, Fricker et al. demonstrated that the rate of tornado casualties increased by 33% per doubling of tornado energy [18].

Currently, tornado severity is evaluated using the Enhanced Fujita scale (EF), which was based on the 1971 F scale and revised in 2007 [15, 19]. The EF-scale ranges from 0 to 5, with 5 indicating the highest severity. Some studies have comprehensively assessed the proportion of damaged buildings and other factors to rate different damage areas [4, 15]. However, it is difficult to rate storms using either the EF-scale or damage areas within the affected region because both methods require meteorological radar data, ground-based instrumental observations, and information about property losses and other field investigations. Therefore, studies of tornado-related injuries rarely employ GIS data.

Although several studies have presented data regarding injuries in different areas, they did not explore the interactions between them. Paul and Stimers studied the distributions of 162 deaths in different damage areas caused by the Joplin, MO tornado [15], while Curtis and Fagan used a spatial video of damage assessments to analyse the distribution of 135 tornado-related deaths [20]. Ashley provided spatial and temporal analyses of tornado fatalities in the United States from 1880 to 2005 [1], while Shen and Hwang provided a spatial risk analysis of tornado injuries and fatalities in the same country [21]. Fricker et al. reported a method for the spatial apportioning of tornado casualties [2] and, more recently, evaluated the effects of tornado energy has on related casualties [18]. Both Simmons and Sutter [17] and Lim et al.[22] analysed tornado-related deaths in the United States based on F scale ranking. By contrast, no studies have reported the spatial distribution of tornado-related injuries in China. However, injury characteristics, especially severity, have an important impact on outcomes, and injuries of different severities have different requirements for timely treatment in different areas. Therefore, an understanding of the geographical distribution of tornado-related injuries is helpful for developing timely and effective emergency medical rescue strategies. It is thus necessary to evaluate the distribution of tornado-related injuries according to the tornado damage area and severity (EF-scale).

The present study had three aims. First, we aimed to study the characteristics of tornado-related injuries, including site, type, and severity, and to compare these with the injury characteristics recorded for other disasters and tornadoes in the United States. Second, we aimed to study the spatial distribution of tornado-related injuries in Yancheng. Third, we aimed to analyse the differences in AIS scores among different damage and EF-scale areas. This research will help us to understand the characteristics of tornado-related injuries and provide a reference for both predicting potential medical needs in different geographical regions and improving medical rescue strategies.

MATERIALS AND METHODS

Patient and public involvement

We collected medical records from the three hospitals in Yancheng that treated most tornado patients following the tornado on 23 June: Funing County People's Hospital, Jianhu County People's Hospital, and Yancheng Third People's Hospital. These three hospitals received 53.31% of all patients injured in the tornado (451/846); the remaining injured patients were scattered among 16 other hospitals located at greater distances. Of the studied hospitals, most of the injured were treated at or referred by Funing County People's Hospital, which was the nearest to the disaster area. Jianhu County People's Hospital was the second nearest to the disaster area. Yancheng Third People's Hospital, which is located in the urban centre of Yancheng and affiliated with a tertiary hospital (highest Chinese hospital level), admitted a large number of severely injured tornado patients who were referred by lower-level hospitals. Patients included in the study were those who had been directly injured as a result of the tornado and whose location during the tornado could be identified. Patients with recurrent chronic disease or stress-related conditions due to the tornado but no trauma were excluded.

Unified medical record collection forms were developed, and data extraction was independently performed by two investigators and proofread for inconsistent entries. Three types of information were extracted: (1) demographic information, including age, sex, marriage status, and occupation; (2) trauma information, including the cause of injury, prehospital time, length of hospitalisation, and injury site, type, and severity; and (3) location during the tornado. Injury site was categorised based on the body region affected [23, 24] and included the head, neck, face, chest, spine, abdomen/internal organs, upper extremities, lower extremities/pelvis, and body surface/other. Injury severity was judged by clinical experts using the 2005 version of the AIS scale; the AIS scores range from 1 (minor injury) to 6 (fatal injury). For patients with multiple injuries, only the most severely injured site was considered in the final AIS score [23-25].

The investigators were master's degree students in Social Medicine and Public Health Service Management. Prior to data collection, the investigators received training to familiarise themselves with the medical record structure and research guide. Four investigators visited the three hospitals during 12–30 July 2016 (1 month after the tornado). A total of 451 records of patients injured in the tornado were obtained. Of these, 50 records were excluded for not mentioning the location of the injured person during the tornado. Finally, 401 (88.91%) valid trauma medical records were included in the analysis.

GIS data analysis

The China National Disaster Reduction Centre and Chinese Academy of Sciences conducted a detailed study of the 23 June Yancheng tornado. They classified the disaster area into four categories (disaster-affected area, general area, severe area, and very severe area) based on six factors, including the number of deaths, injuries, emergency relocations, employment of disaster relief staff, and direct economic losses [4]. A team led by Professor Zhiyong Meng from Peking University conducted an accurate survey of the 23 June Yancheng tornado and classified areas as EF0 –EF4 based on an in-the-field investigation, aerial image data, ground weather station information, and radar data.

Based on the above research, Arcview 10.3 software (Redlands, CA, USA) was used to vectorise the geographic image data, which included four types of damage areas and EF0–EF4 areas. The results were added to the China Online Street Warm map in ArcGIS Online. A data comparison test revealed that the level of precision was sufficient to meet the demands of analysis. Based on the geographic locations listed in medical records, the injured patients were located individually on the map, and their locations were matched to the damage and EF-scale areas. If the locations of multiple wounded patients were extremely close on the map, they were aggregated into a single point for clarity and the number of wounded was marked near the point. However, this did not alter the recorded locations of the wounded in different damage areas or the related statistical analysis.

Statistical analysis

Patient age, prehospital time, and length of hospitalisation were converted into categorical variables. The demographic information and trauma characteristics were subjected to a descriptive analysis. The number of injured patients, area size, and densities of injured patients in different damage and EF-scale areas were analysed using the GIS. Non-parametric tests were performed to determine the effects of geographical characteristics on the AIS scores. SPSS version 21.0 (SPSS Inc., Chicago, IL, USA) was used for the statistical analyses. All tests were two-tailed, and a P-value <0.05 was considered to indicate statistically significance.

Ethical statement

Access to medical records was approved by the three participating hospitals and all patients. Informed consent was obtained from the participants by telephone. For injured patients aged <18 years, consent was given by the legal guardians. Ethical approval was awarded by the Medical Ethics Committee of the Second Military Medical University.

RESULTS

Demographic characteristics

Of the injured patients, 51.62% were women and 77.30% were middle-aged or elderly (age >45 years). Additionally, 91.77% were married and 81.55% were employed as farmers (Table 1).

Table 1. Demographic characteristics of the injured.

Items	Groups	Number	Percentage(%)
Sex	Male	194	48.38
	Female	207	51.62
Age(years)	<18	50	12.47
	18-29	18	4.49
	30-44	23	5.74
	45-64	124	30.92
	>=65	186	46.38
Marriage	Married	368	91.77
	Unmarried[a]	33	8.23
Occupation	Farmer	327	81.55
	Student	40	9.98
	Worker	11	2.74
	Others	23	5.74

Injury characteristics and standardised scores

Of the injuries, 60.10% were attributed to the collapse of a building. Furthermore, 63.09% of injured patients received hospital treatment within 12 hours, and 58.61% had a hospitalisation length of ≤2 weeks (Table 2).

Of the nine injury sites, the head, body surface, and upper extremities were most frequently affected, followed by the chest. Most patients had multiple injuries, and seven patients had five injury sites (Table 2).

Skin and soft tissue injuries, fractures, and organ injuries were most frequently reported. The number of fractures was counted for each of the nine injury sites defined; accordingly, multiple fractures at the same injury site were recorded as a single fracture. Single fracture was reported in 71.79% of affected patients, while two patients had four fractures. Bacterial infection and disturbance of consciousness occurred in 5.24% and 3.74% of the patients, respectively (Table 2).

Regarding the severity of injury, 60.85% of patients sustained injuries with AIS scores of 1, while 2.50% sustained injuries with AIS scores of ≥5 (Table 2). Regarding the distribution of AIS scores at different injury sites, all 10 patients with very severe injuries (AIS score ≥5) had sustained injuries at high-risk sites, including the head in seven patients, thorax in two patients, and spine in one patient. Three patients with fatal injuries (AIS score= 6) had sustained severe crush injuries to the head or chest, and one died of a head injury consequent to medical failure (Table 3).

Table 2. Injury characteristics of the injured[a].

Items	Groups	Number	Percentage(%)
Cause of injury	Injured by collapse of the house	241	60.10
	Stricken by heavy object	142	35.41
	Blow down by tornado	18	4.49
Prehospital time(hour)	<=1	15	3.49
	2-3	77	19.20
	4-12	162	40.40
	13-24	99	24.69
	>24	49	12.22
Length of	0	14	3.49

Hospitalisation(day)			
	<=7	118	29.43
	8-14	117	29.18
	15-21	62	15.46
	>21	37	9.23
	unknown	53	13.22
Injury site[b]	Head	187	46.63
	Body surface / others	160	39.90
	Lower extremities/pelvis	118	29.43
	Chest	91	22.69
	Face	64	15.96
	Upper extremities	63	15.71
	Spine	39	9.73
	Abdomen / internal organs	29	7.23
	Neck	2	0.50
Injury number	1	166	41.40
	2	148	36.91
	3	64	15.96
	4	16	3.99
	5	7	1.75
Injury type[b]	Skin and soft tissue injuries	364	90.77
	Fracture	156	38.90
	Traumatic organ injuries	79	19.70
	Pulmonary contusion	30	7.48
	Central nervous system injuries	17	4.24
	Traumatic haemopneumothorax	16	3.99
	Concussion brain	4	1.00

	Destruction	3	0.75
Fracture number	0	245	61.10
	1	112	27.93
	2	31	7.73
	3	11	2.74
	4	2	0.50
Bacterial infection	Yes	21	5.24
	No	380	94.76
Disturbance of consciousness	Yes	15	3.74
	No	386	96.26
AIS score	1（minor）	244	60.85
	2	62	15.46
	3	58	14.46
	4	27	6.73
	5	7	1.75
	6（fatal）	3	0.75

[a] This table contains all injury information, including all injury sites and types.

[b] The relative percentage of injury site and type indicate incidence rate.

Table 3. The distribution of AIS scores in different injury sites[a].·

AIS score	Head	Face	Neck	Chest	Abdomen / internal organs	Spine	Upper extremities	Lower extremities/ pelvis	Body surface / others
1	70(28.69)	32(13.11)	1(0.41)	13(5.33)	11(4.51)	3(1.23)	21(8.61)	52(21.31)	41(16.80)
2	10(16.13)	1(1.62)	0	13(20.97)	3(4.84)	13(20.97)	10(16.13)	12(19.35)	0
3	21(36.21)	0	1(1.72)	22(37.93)	3(5.17)	7(12.07)	0	4(6.90)	0
4	0	0	0(0.00)	23(85.19)	3(11.11)	0	0	1(3.70)	0
5	6(85.71)	0	0	0	0	1(14.29)	0	0	0

6	1(33.33)	0	0	2(66.67)	0	0	0	0	0
Sum up	108(26.93)	33(8.23)	2(0.50)	73(18.20)	20(4.99)	24(5.99)	31(7.73)	69(17.21)	41(10.22)

[a] This table presents the most severe injury sites related to the final AIS scores.

Distribution of injured patients in different areas

Regarding different damage areas, only one casualty occurred in the general area; therefore, for analytical purposes, the general and severe areas were combined into a collective 'severe area'. The number of injured patients was lower in the disaster-affected area than in the areas of severe or very severe damage. Furthermore, the density of injured patients per square kilometre increased with increasing damage severity in the area, with the highest density reported in the very severe area (Table 4, Figure 1).

Table 4. The distribution of the injured in different damage and EF-scale areas.

	Areas（km^2）	Number	Percentage(%)	Density（number/km^2）
Damaged areas				
Disaster affected area	2457.18	37	9.23	0.02
Severe area	118.13	64	15.96	0.54
Very severe area	133.02	300	74.81	2.26
Sum up	2708	401	100.00	0.15
EF scale				
EF0	129.74	20	8.10	0.15

EF1	84.19	139	56.28	1.65
EF2	27.61	40	16.19	1.45
EF3	13.66	33	13.36	2.42
EF4	5.66	15	6.07	2.65
Sum up	260.86	247	100.00	0.95

Geographically, although the scope of the EF0–4 areas was smaller than that of the entire disaster-stricken area, the wind level classification of the former was more accurate. The density of injured patients increased with increasing wind levels, and the highest density was observed in the EF4 area. Given the immensity of the entire disaster-stricken area, Professor Meng could only conduct an in-field investigation of the area related to the centreline of the tornado. Accordingly, 154 patients who had reported locations outside of the EF-scale areas were not included in the analysis of EF-scale areas (Table 4, Figure 2).

Injury severity in different areas

We also conducted non-parametric tests to further evaluate the severity of injuries among different damage and EF-scale areas. These analyses demonstrated that the geographical characteristics had no significant effects on AIS scores ($P > 0.05$; Table 5).

Table 5. Non-parametric tests for AIS scores among different damage and EF-scale areas.

	AIS=1 (n,%)	AIS=2 (n,%)	AIS=3 (n,%)	AIS=4 (n,%)	AIS=5 (n,%)	AIS=6 (n,%)	P

Damaged areas							0.131
Disaster affected area	23(62.16)	8(21.62)	3(8.11)	2(5.41)	0(0.00)	1(2.70)	
Severe area	33(51.56)	8(12.50)	14(21.88)	8(12.50)	1(1.56)	0(0.00)	
Very severe area	188(62.67)	46(15.33)	41(13.67)	17(5.67)	6(2.00)	2(0.67)	
EF scale							0.322
EF0	9(45.00)	6(30.00)	4(20.00)	1(5.00)	0(0.00)	0(0.00)	
EF1	92(66.19)	18(12.95)	17(12.23)	8(5.76)	3(2.16)	1(0.72)	
EF2	26(65.00)	7(17.50)	5(12.50)	1(2.50)	1(2.50)	0(0.00)	
EF3	17(51.52)	6(18.18)	5(15.15)	4(12.12)	1(3.03)	0(0.00)	
EF4	10(66.67)	3(20.00)	2(13.33)	0(0.00)	0(0.00)	0(0.00)	

DISCUSSION

Demographic characteristics

The age distribution of injured patients had "dumbbell shape", as 77.30% of injured victims were middle-aged or elderly (age >45 years), 12.47% were children/adolescents (<18 years), while only 10.23% were young adults. By comparison, 38.69% of victims injured during the Oklahoma tornadoes of 1999 were aged >45 years (16.78% were aged <15 years) [26]. Studies on the Alabama tornadoes of 2001 showed that 49% of injury victims were older than 45 years [8]. For other natural disasters such as earthquakes, the age distributions of the victims tend to follow local demographics. For example, 44.4% of patients injured during the 2013 Lushan earthquake in China were middle-aged (31–50 years) [27]. We note that this discrepancy may be related to disaster characteristics. Earthquakes are unpredictable and occur within a few minutes or seconds; therefore, both young adults and elderly people are unable to escape to safety. By contrast, tornadoes are of much longer duration, and warnings are generally provided. Therefore, teenagers and elderly individuals are more vulnerable to injury because they have fewer opportunities to receive these warnings and relocate to safety. Geographical characteristics may also play a role, as earthquakes are prone to occur in cities and counties (i.e., populated areas). Some severe earthquakes have even occurred in big cities, where they have caused enormous damage and losses of life among all age groups. By contrast, tornadoes tend to occur in rural areas such as Chinese villages, where the population mainly comprises elderly people and adolescents because young adults have move to cities for better job opportunities. These aspects may be responsible for the dumbbell-shaped age distribution observed among tornado victims in this study.

Injury site

In our study population, the three most common injury sites were the head (46.63%), limbs (45.14%), and chest (22.69%). By comparison, in the 2010 Yushu earthquake in China, the most common injury sites were the limbs (48.1%), chest (13.3%), and spine (12.1%); head injuries accounted for only 10.1% of all injuries [28]. Earthquake victims are most likely to be crushed by a heavy object, whereas tornado victims typically sustain head and limb injuries caused by flying objects and collapsing buildings. During the Alabama tornadoes of 2011, limb and pelvic injuries were most common, followed by head injuries, although the latter accounted for 46.5% of hospitalisations, 56.3% of intense care unit admissions, and 71.4% of deaths [8]. Another study found that head injury was the greatest cause of tornado-related deaths in the United States [7]. In our study, head injury was the most frequent cause of an AIS score ≥5 and the cause of the only hospital death. Given the significant risk of head injury, researchers have recommended the use of a helmet to protect the head during a tornado [29, 30], and medical rescue teams aiming to reduce high mortality rates should prioritise patients with head injuries, especially in cases with concomitant hypothermia, hyperglycaemia, and coagulation disorders [31, 32].

Injury type

In our study, the three most common injury types were skin and soft-tissue injuries (90.77%), fractures (38.90%), and organ damage (19.70%). The first type is commonly caused by heavy objects rendered airborne by a tornado [30, 33, 34]. Fractures have been attributed to building collapse, collisions with heavy objects, and various other events. Consistent with previous studies, we found that organ damage occurs frequently during a tornado [35]. The strong winds associated with a tornado can cause people to fall or even to be lifted and subsequently dropped, which can cause serious organ damage and potentially fatal internal bleeding. However, organ damage is more difficult to diagnose, compared to a skin injury. Therefore, medical rescuers should attend more closely to victims who remain quiet but exhibit signs of pain.

We additionally found that 5.24% of injury victims developed bacterial infections, which were likely caused by the chaotic environment [30, 33, 34, 36, 37]. Recommendations suggest that to prevent gangrene and sepsis during the early stage, medical rescuers should perform extensive surgical debridement rather than wound suturing too early [7]. Interestingly, fractures and infections were also observed frequently among the victims of explosions at the Boston Marathon in 2013 and Tianjin Port in 2015, which suggests that tornado forces share some qualities with explosions [38, 39].

Injury severity

According to the AIS scores [23, 24], 60.85% of victims in our study sustained minor injuries, while 15.46%, 14.46%, 6.73%, 1.75%, and 0.75% sustained moderate, severe but non-life-threatening, severe and life-threatening, critical injury, and fatal injuries, respectively. A previous report found that 89% of all injuries associated with the Alabama tornadoes of 2011 were minor, 6% were moderate, and only 5% were severe [8]. The increased proportion of severely injured victims in our study may be related to the lack of tornado protection awareness and ability in China.

Notably, our analysis of different damage and EF-scale areas found no related differences in the victims' AIS scores. In other words, areas of severe destruction had similar percentages of severely injured victims as those in areas of minor destruction and low wind speeds. Because the "Trauma Golden Hour Policy" [40] and "Brass 10 Minutes" [41] play a vitally important role in saving severely injured patients, we strongly recommended that similar attention be given to severely injured victims, regardless of the level of damage and EF-scale. In other words, all tornado-affected areas deserve to receive the same quality of medical care at the same time.

Injury densities in different areas

Although the distributions of injury severity were similar among areas with different damage levels and EF-scale ratings, the densities and numbers of injured patients differed. Specifically, the density of injured patients increased with the severity of tornado-related damage in the area, which was mainly related to the wind speed and building destruction. As the wind speeds range from EF1 at the edge of a tornado to EF4 at the centre [15], we recommend that different quantities of emergency medical personnel be deployed to different disaster areas. Specifically, larger numbers of medical personnel should be deployed to severely affected areas, which contain more victims and higher densities of injured patients. We therefore recommend that the "same quality and different quantity" policy should be implemented during tornado-related emergency medical rescues.

Limitations

This study had two limitations of note. First, we only collected the medical records of 451 injured patients. However, our study included both a first-line hospital (Funing County People's Hospital) and two rear-line hospitals (Jianhu County

People's Hospital and Yancheng Third People's Hospital), which collectively treated 53.31% of all 846 injured patients. Therefore, our dataset is considered representative of the target population. Second, this study could not evaluate the geographical distribution of deaths because of limited information.

CONCLUSION

To sum up, this study is the first to describe the pattern and spectrum of tornado-related injuries in China, and the first to use the GIS to analyse the characteristics of injury locations according to different damage levels and EF-scale areas. Notably, we observed a dumbbell-shaped age distribution among the victims of a particular tornado in China. Our further findings of regional differences in the density but not severity of injury have led us to recommend the application of the "same quality and different quantity" strategy to tornado-related emergency medical rescue scenarios. Additionally, the high incidence of head injuries and associated high fatality rate have led us to recommend that people, and particularly children, wear helmets as they shelter or evacuate from a tornado. We expect that our findings will be very helpful to the planning of emergency medical rescue efforts and the appraisal of potential medical demands following tornadoes.

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Contributions

Q.D., Y.L., C.X., P.K., J.D., and L.Z. discussed and developed the hypothesis for this study. Q.D. and Y.L. abstracted data from medical records. Q.D. and C.X. performed all analyses. All authors were involved in the interpretation and discussion of results. Q.D. and Y.L. wrote the first draft of this paper, which was reviewed by L.Z. All authors agreed on the final draft of this study. L.Z. is the study guarantor.

Competing interests

The authors declare that they have no competing interests.

Patient consent

Consent was obtained from all patients or their legal guardians.

Ethics approval

Ethics approval was received from the Medical Ethics Committee of the Second Military Medical University.

Data sharing statement

No additional data are available.

Authors' information

Qiangyu Deng, Yipeng Lv, and Chen Xue are co-first authors of this article.

* Lulu Zhang is the corresponding author.

References

1. Ashley, W.S., *Spatial and temporal analysis of tornado fatalities in the United States: 1880-2005.* Weather and Forecasting, 2007. **22**(6): p. 1214-1228.
2. Fricker, T., J.B. Elsner, V. Mesev, et al., *A dasymetric method to spatially apportion tornado casualty counts.* Geomatics Natural Hazards & Risk, 2017. **8**(2): p. 1768-1782.
3. Lyu, H.M., G.F. Wang, W.C. Cheng, et al., *Tornado hazards on June 23 in Jiangsu Province, China: preliminary investigation and analysis.* Natural Hazards, 2016. **85**(1): p. 597-604.
4. Jia, H.C. and D.H. Pan, *Tornado disaster impacts and management: learning from the 2016 tornado catastrophe in Jiangsu Province, China.* Natural Hazards, 2017. **89**(1): p. 457-471.
5. Wang, K., S. Zhong, X. Wang, et al., *Assessment of the Public Health Risks and Impact of a Tornado in Funing, China, 23 June 2016: A Retrospective Analysis.* Int J Environ Res Public Health, 2017. **14**(10).
6. Dapeng, H., Z. Shanshan, G. Ge, et al., *Disaster characteristics of tornadoes over China during the past 30 years.* Torrential Rain and Disaster, 2016. **35**(2): p. 97-101.
7. Bohonos, J.J. and D.E. Hogan, *The medical impact of tornadoes in North America.* J Emerg Med, 1999. **17**(1): p. 67-73.
8. Niederkrotenthaler, T., E.M. Parker, F. Ovalle, et al., *Injuries and post-traumatic stress following historic tornados: Alabama, April 2011.* PLoS One, 2013. **8**(12): p. e83038.
9. Kanter, R.K., *The 2011 Tuscaloosa tornado: integration of pediatric disaster services into regional systems of care.* J Pediatr, 2012. **161**(3): p. 526-530 e1.
10. Salottolo, K., A. Settell, P. Uribe, et al., *The impact of the AIS 2005 revision on injury severity scores and clinical outcome measures.* Injury, 2009. **40**(9): p. 999-1003.
11. Bell, N. and N. Schuurman, *GIS and injury prevention and control: history, challenges, and opportunities.* Int J Environ Res Public Health, 2010. **7**(3): p. 1002-17.
12. Waring, S., A. Zakos-Feliberti, R. Wood, et al., *The utility of geographic information systems (GIS) in rapid epidemiological assessments following weather-related disasters: methodological issues based on the Tropical Storm Allison Experience.* Int J Hyg Environ Health, 2005. **208**(1-2): p. 109-16.
13. Peek-Asa, C., M.R. Ramirez, K. Shoaf, et al., *GIS mapping of earthquake-related deaths and hospital admissions from the 1994 Northridge, California, Earthquake.* Ann Epidemiol, 2000. **10**(1): p. 5-13.
14. Curtis, J.W., A. Curtis, and J.S. Upperman, *Using a geographic information system (GIS) to assess pediatric surge potential after an earthquake.* Disaster Med Public Health Prep, 2012. **6**(2): p. 163-9.
15. Paul, B.K. and M. Stimers, *Spatial Analyses of the 2011 Joplin Tornado Mortality: Deaths by Interpolated Damage Zones and Location of Victims.* Weather Climate and Society, 2014. **6**(2):

p. 161-174.

16. Centers for Disease, C. and Prevention, *Tornado-related fatalities--five states, Southeastern United States, April 25-28, 2011.* MMWR Morb Mortal Wkly Rep, 2012. **61**(28): p. 529-33.
17. Simmons, K.M. and D. Sutter, *Economic and Societal Impacts of Tornadoes.* University of Chicago Press Economics Books, 2011. **56**(10): p. 412-415.
18. Fricker, T., J.B. Elsner, and T.H. Jagger, *Population and energy elasticity of tornado casualties.* Geophysical Research Letters, 2017. **44**(8): p. 3941-3949.
19. Center, W.S.a.E. *A recommendation for an Enhanced Fujita Scale (EF-Scale).* . 2013 [cited 2013 2013 May 1].
20. Curtis, A. and W.F. Fagan, *Capturing Damage Assessment with a Spatial Video: An Example of a Building and Street-Scale Analysis of Tornado-Related Mortality in Joplin, Missouri, 2011.* Annals of the Association of American Geographers, 2013. **103**(6): p. 1522-1538.
21. Shen, G.Q. and S.N. Hwang, *A spatial risk analysis of tornado-induced human injuries and fatalities in the USA.* Natural Hazards, 2015. **77**(2): p. 1223-1242.
22. Lim, J., S. Loveridge, R. Shupp, et al., *Double Danger in the Double Wide: Dimensions of Poverty, Housing Quality and Tornado Impacts ☆.* Regional Science & Urban Economics, 2017. **65**.
23. *Rating the severity of tissue damage. I. The abbreviated scale.* JAMA, 1971. **215**(2): p. 277-80.
24. Gennarelli, T.A. and E. Wodzin, *AIS 2005: a contemporary injury scale.* Injury, 2006. **37**(12): p. 1083-91.
25. Palmer, C.S., L.E. Niggemeyer, and D. Charman, *Double coding and mapping using Abbreviated Injury Scale 1998 and 2005: identifying issues for trauma data.* Injury, 2010. **41**(9): p. 948-54.
26. Daley, W.R., S. Brown, P. Archer, et al., *Risk of tornado-related death and injury in Oklahoma, May 3, 1999.* Am J Epidemiol, 2005. **161**(12): p. 1144-50.
27. Kang, P., B. Tang, Y. Liu, et al., *Medical Efforts and Injury Patterns of Military Hospital Patients Following the 2013 Lushan Earthquake in China: A Retrospective Study.* Int J Environ Res Public Health, 2015. **12**(9): p. 10723-38.
28. Kang, P., L. Zhang, W. Liang, et al., *Medical evacuation management and clinical characteristics of 3,255 inpatients after the 2010 Yushu earthquake in China.* J Trauma Acute Care Surg, 2012. **72**(6): p. 1626-33.
29. Brenner, S.A. and E.K. Noji, *Tornado injuries related to housing in the Plainfield tornado.* Int J Epidemiol, 1995. **24**(1): p. 144-9.
30. Rosenfield, A.L., D.A. McQueen, and G.L. Lucas, *Orthopedic injuries from the Andover, Kansas, tornado.* J Trauma, 1994. **36**(5): p. 676-9.
31. Tude Melo, J.R., R.F. Di, S. Blanot, et al., *Mortality in children with severe head trauma: predictive factors and proposal for a new predictive scale.* Neurosurgery, 2010. **67**(6): p. 1542-1547.
32. Franko, J., K.J. Kish, B.G. O'Connell, et al., *Advanced age and preinjury warfarin anticoagulation increase the risk of mortality after head trauma.* J Trauma, 2006. **61**(1): p. 107-10.
33. Marr, J., *Kalamazoo medics say 'fantastic'! to health personnel response after tornadoes.* Mich Med, 1980. **79**(20): p. 374-6.

34. Leibovich, M., *The December 2, 1982 tornado of Saline and Pulaski counties: implications for injury prevention.* J Ark Med Soc, 1983. **80**(2): p. 98-102.

35. Ivy, J.H., *Infections encountered in tornado and automobile accident victims.* J Indiana State Med Assoc, 1968. **61**(12): p. 1657-61.

36. Mandelbaum, I., D. Nahrwold, and D.W. Boyer, *Management of tornado casualties.* J Trauma, 1966. **6**(3): p. 353-61.

37. Morris, B.A. and T.M. Armstrong, *Medical response to a natural disaster: the Barrie tornado.* CMAJ, 1986. **134**(7): p. 767-9.

38. Kim, P.S., E. Malin, J.C. Kirkham, et al., *The Boston marathon bombings: the early plastic surgery experience of one Boston hospital.* Plast Reconstr Surg, 2013. **132**(5): p. 1351-63.

39. Zhang, J.J., T.B. Wang, D. Fan, et al., *Medical Response to the Tianjin Explosions: Lessons Learned.* Disaster Med Public Health Prep, 2017: p. 1-4.

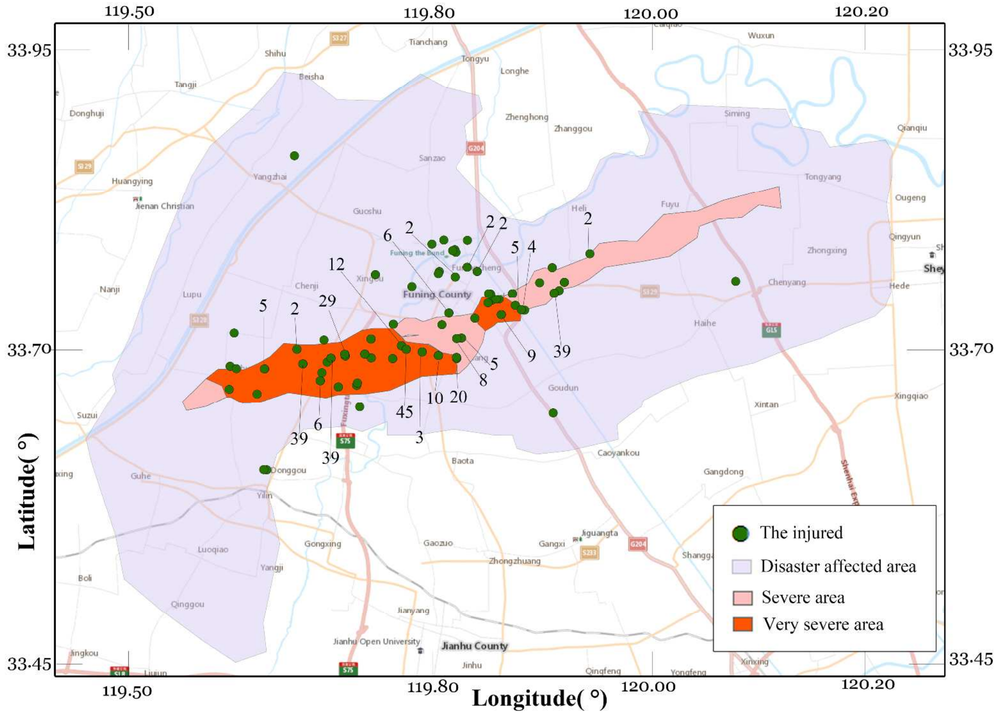
40. Howard, J.T., R.S. Kotwal, A.R. Santos, et al., *Re-examination of a Battlefield Trauma Golden Hour Policy.* J Trauma Acute Care Surg, 2017.

41. Shomaker, D., *Survival, respect and equality.* Br J Nurs, 1994. **3**(15): p. 792-793.

Figure legends

Figure 1. Distribution of the injured in different damage areas. When the locations of the wounded were extremely close, for the sake of clarity, they were aggregated into one point and labeled with patients' number involved. However, this did not alter the location of the wounded in different damage areas and related statistical analyses.

Figure 2. Distribution of the injured in different Enhanced Fujita scale (EF) areas. When the locations of the wounded were extremely close, for the sake of clarity, they were aggregated into one point and labeled with patients' number involved. However, this did not alter the location of the wounded in different damage areas and related statistical analyses.



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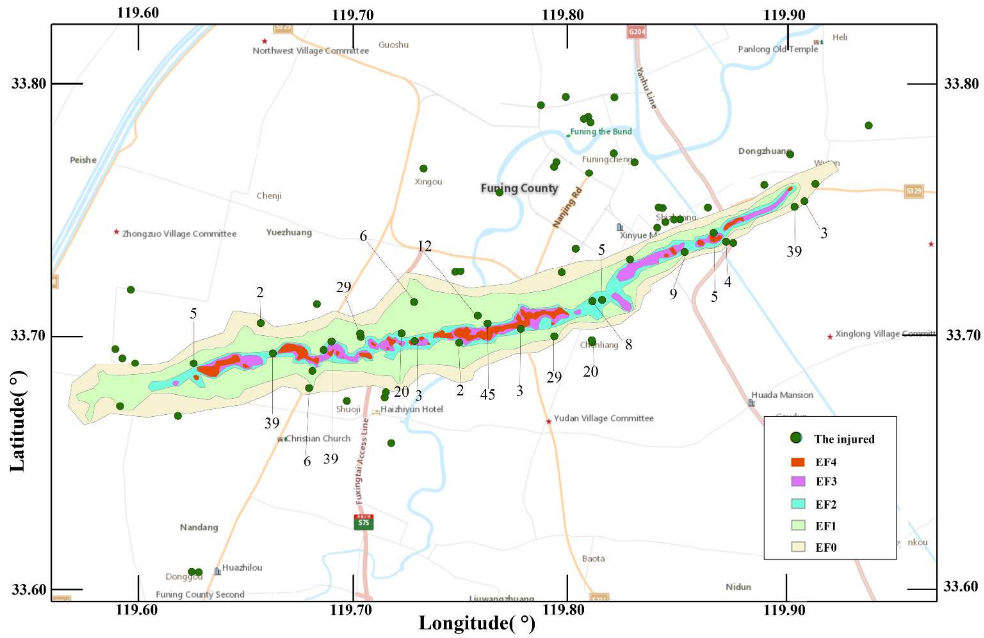

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411x275mm (300 x 300 DPI)

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Page 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page3- page6
Objectives	3	State specific objectives, including any prespecified hypotheses	Page6
Methods			
Study design	4	Present key elements of study design early in the paper	Page6- page8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page6- page8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Page6- page7
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page6- page8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page6- page8
Bias	9	Describe any efforts to address potential sources of bias	Page6- page8
Study size	10	Explain how the study size was arrived at	Page7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page6- page8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Page8
		(*b*) Describe any methods used to examine subgroups and interactions	Page8
		(*c*) Explain how missing data were addressed	Page7
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	Page6- page7
		(*e*) Describe any sensitivity analyses	Not needed
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page6- page7
		(b) Give reasons for non-participation at each stage	Page7
		(c) Consider use of a flow diagram	Not needed
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Page9
		(b) Indicate number of participants with missing data for each variable of interest	Page7, page14
Outcome data	15*	Report numbers of outcome events or summary measures	Page9- page15
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Not needed
		(*b*) Report category boundaries when continuous variables were categorized	Page8- page13
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not needed
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Not needed
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page15- page18
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page18
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page18- page19
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page18- page19
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page19

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.