ORIGINAL RESEARCH

Factors Associated with In-Patient Mortality in the Rapid Assessment of Adult Earthquake Trauma Patients

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Abstract

Objective: To date, there is limited evidence for health care providers regarding the determinants of early assessment of poor outcomes of adult in-patients due to earthquakes. This study aimed to explore factors related to early assessment of adult earthquake trauma patients (AETPs).

Methods: The data on 29,933 AETPs in the West China Earthquake Patients Database (WCEPD) were analyzed retrospectively. Then, 37 simple variables that could be obtained rapidly upon arrival at the hospital were collected. The least absolute shrinkage and selection operator (LASSO) regression analyses were performed. A nomogram was then constructed.

Results: Nine independent mortality-related factors that contributed to AETP in-patient mortality were identified. The variables included age (OR:1.035; 95%CI, 1.027-1.044), respiratory rate ([RR]; OR:1.091; 95%CI, 1.050-1.133), pulse rate ([PR]; OR:1.028; 95%CI, 1.020-1.036), diastolic blood pressure ([DBP]; OR:0.96; 95%CI, 0.950-0.970), Glasgow Coma Scale ([GCS]; OR:0.666; 95%CI, 0.643-0.691), crush injury (OR:3.707; 95%CI, 2.166-6.115), coronary heart disease ([CHD]; OR:4.025; 95%CI, 1.869-7.859), malignant tumor (OR:4.915; 95%CI, 2.850-8.098), and chronic kidney disease ([CKD]; OR:5.735; 95%CI, 3.209-10.019).

Conclusions: The nine mortality-related factors for ATEPs, including age, RR, PR, DBP, GCS, crush injury, CHD, malignant tumor, and CKD, could be quickly obtained on hospital arrival and should be the focal point of future earthquake response strategies for AETPs. Based on these factors, a nomogram was constructed to screen for AETPs with a higher risk of in-patient mortality.

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Introduction

Reducing disaster mortality was the first goal of the seven goals of the *Sendai Framework for Disaster Risk Reduction 2015-2030*,[1] which was launched at the Third United Nations World Conference in Sendai, Japan. In the past few decades, earthquakes have resulted

Keywords: earthquake; least absolute shrinkage and selection operator (LASSO); nomogram; regression; related factor; trauma

Abbreviations:
AETP: adult earthquake trauma patients
CHD: coronary heart disease
CKD: chronic kidney disease
COPD: chronic obstructive pulmonary disease
DBP: diastolic blood pressure
DVT: deep vein thrombosis
GCS: Glasgow Coma Scale
ISS: Injury Severity Score
LASSO: least absolute shrinkage and selection operator
PR: pulse rate
ROC: receiver operating characteristic
RR: respiratory rate
SBP: systolic blood pressure
WCEPD: West China Earthquake Patients Database

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in a large number of casualties. In order to reduce overall mortality, health care providers in the hospitals of earthquake-strike areas with extremely limited medical resources have to screen critically ill earthquake trauma patients with therapeutic value so that they can receive timely and effective medical care.[2] Understanding early assessment factors in the death of earthquake trauma patients will help health care providers to screen patients with higher mortality risk and pay more attention to such patients to reduce mortality among them.[3]

In previous studies, most of the factors studied have been dependent on laboratory or imaging examinations, which are difficult to apply to rapid screening in emergency departments attending to earthquake trauma victims.[4–6] Furthermore, the potential multicollinearity between some related factors, such as age and pre-existing disease, might contribute to statistical challenges.[6] Therefore, it is necessary to explore rapid and feasible factors related to mortality for the early screening of earthquake trauma patients.

In the past, traditional regression techniques were limited to the analysis and synthesis of large numbers of covariates, including multicollinear variables.[7] Most of the data on the factors related to either earthquake victims or daily trauma have utilized traditional statistical techniques. As a novel regression-based methodology that earned much attention, the least absolute shrinkage and selection operator (LASSO), a statistical technique permitting many covariates in the model, helps to automatically remove unnecessary/uninfluential covariates by penalizing the absolute value of a regression coefficient.[8,9]

In the present study, the objective was to investigate the simple and rapid predictors of in-patient mortality in adult earthquake trauma patients (AETPs) using LASSO regression. To the authors' knowledge and in reviewing the literature, this study is among the first to apply LASSO regression techniques to AETPs.

Methods

Study Design

The patient characteristics and outcomes in the West China Earthquake Patients Database (WCEPD) were extracted to analyze potential in-patient mortality-related factors in hospitalized patients. The WCEPD held the prehospital, emergency, in-patient, and discharge information of in-patients from four earthquakes (Online Appendix, Part1; available online only) which occurred over the past 12 years in West China. The WCEPD is managed by a local emergency medical rescue base, and at the time of writing this article, it included 36,604 records from 701 hospitals.

The local Institutional Review Committee approved the study and waived the requirement for informed consent due to the study design (Protocol number: 2020-477). The study complied with the international ethical guidelines for human research, such as the Declaration of Helsinki. The accessed data were anonymized.

Selection of Participants

Data were obtained from the WCEPD. The inclusion criteria for this study were adult trauma patients aged ≥18 years who were transferred from the earthquake field to the hospital, rather than patients transferred from other hospitals. From the total trauma cases due to earthquakes, 31,580 adults aged ≥18 years were selected. After excluding 1,647 cases with missing data, the remaining 29,933 records of adult patients were analyzed in this study (Figure 1). Of these, 259 patients died during hospitalization.

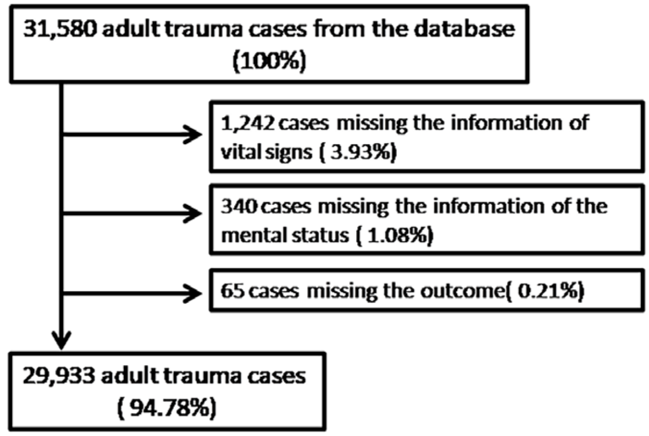

Figure 1. Flow Chart of Inclusion and Exclusion Criteria.
Note: From all 31,580 cases, 1,647 cases with missing data were excluded, including 1,242 cases missing vital signs on arrival, 340 cases missing mental status data, and 65 cases missing outcome data. Finally, 29,933 cases were analyzed.

Key Variables

From the WCEPD, data were collected on 37 available variables based on previous reports.[3–6,10–15] The variables included six categories: demographic characteristics, vital signs, states of consciousness, traumatic body region, nature of injury, and existing comorbidities. The variables of the demographic characteristics, vital signs, states of consciousness, traumatic body region, and nature of injury were original fields in the database. The variables of the existing comorbidities were extracted from the diagnosis fields of the database. None of these variables required laboratory or imaging tests, and the variables could be quickly obtained even in an earthquake disaster environment. These variables are defined as follows:

1. *Demographic Characteristics* included sex and age. Sex (variable code: X1) was either male or female and coded as zero for male and one for female, and age (X2) was measured in years.
2. *Vital Signs* were the initial values of vital signs when the patients arrived at the hospital and were composed of five variables. Axillary temperature (X3) was measured in degrees Celsius (°C). The variables X4 and X5 were respiratory rate (RR) and pulse rate (PR), measured as counts per minute. The variables X6 and X7 were systolic blood pressure (SBP) and diastolic blood pressure (DBP), respectively, measured in millimeters of mercury (mmHg).
3. *State of Consciousness* was assessed using the Glasgow Coma Scale (GCS). The GCS (X8), a widely known, reproducible, and reliable scale, is subdivided into severity categories and is ubiquitous in trauma settings and trauma treatment guidelines.[16] The scores ranged from three to fifteen, with a lower score indicating a worse state of consciousness.
4. *Traumatic Body Region* included six variables: the head/neck (X9), face (X10), chest (X11), abdomen/pelvis (X12), extremities (X13), and external injuries (X14). The classification of the body region was consistent with the six parts of the Injury Severity Score (ISS). If a patient had trauma in a particular part, regardless of whether they had other trauma in other parts, this variable would be assigned a value of one;

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otherwise, it would be zero. For example, if a patient had trauma in the head and chest, both X9 and X11 would be assigned a value of one.

5. *Nature of Injury* was described using 12 systematically classified injury characteristics of the Barell injury diagnosis matrix.[17] These included fractures (X15), dislocations (X16), sprains and strains (X17), internal injuries (X18), open wounds (X19), amputations (X20), injuries to blood vessels (X21), contusions and superficial injuries (X22), crush (X23), burn (X24), nerve injuries (X25), and others (X26).
6. *Existing Comorbidities* included chronic diseases recorded in the medical history and existing comorbidities discovered upon arrival at the hospital. Twelve variables were extracted from the initial diagnosis of hypertension (X27), coronary heart disease ([CHD]; X28), deep vein thrombosis ([DVT]; X29), stroke (X30), diabetes (X31), bedsores (X32), chronic obstructive pulmonary disease ([COPD]; X33), liver cirrhosis (X34), malignant tumor (X35), chronic kidney disease ([CKD]; X36), and wound infection (X37).

The outcome variable was in-patient death, including death in the hospital's emergency department and death during hospitalization. The in-patient deaths were included as the dependent variable, Y, and coded as zero for survivors and one for non-survivors. The mortality rate was defined as the number of deaths to the total number of patients in each of the variables mentioned above.

Statistical Analysis

Statistical analyses were performed using R4.1.1 (R Foundation for Statistical Computing; Vienna, Austria) and SPSS20.0 (IBM Corporation; Armonk, New York USA). Continuous variables were expressed as means (standard deviation [SD]) or medians (quartiles), appropriately. Categorical variables were expressed as absolute values and percentages. The means of continuous variables were compared using independent group t-tests for normally distributed data and the Mann–Whitney test for non-normally distributed data. The χ^2 or Fisher's exact test was used to compare the proportions of categorical variables.

The LASSO regression, which is suitable for analyzing high-dimensional data, was used to select the most significant predictive features.[18,19] The "glmnet" package (version 2.0-16) of R software was utilized to fit the LASSO regression. Ten-fold cross-validation was utilized to select the penalty term lambda. The binomial deviance was computed for the test data as a measure of the predictive performance of the fitted models. The built-in function in R produces two lambda values: one that minimizes the binomial deviance and the other representing the largest lambda that is still within one standard error of the minimum binomial deviance. The stricter value was chosen, allowing to reduce the number of covariates. The standard errors of the LASSO coefficients were obtained via bootstrapping within the primary sampling unit and strata.[20] Features with non-zero coefficients in the LASSO regression model were selected in the forward stepwise logistic regression model.[19] The features were presented as odds ratios (ORs) with 95% confidence intervals (95% CIs) and two-tailed P values. Statistical significance was set at P <.05.

Results

Demographic and Clinical Characteristics of Patients

A total of 29,933 AETP cases in the WCEPD were enrolled in this study. The mean age (standard deviation [SD]) was 50.43 (SD = 17.91) years for the survivors and 60.60 (SD = 19.83) years for the non-survivors. The median (25% quartile, 75% quartile) of ISS was six (4, 11) for survival and nine (4, 17) for death (P = .001). There were a total of 22 variables with significant differences (P <.05), including age; four variables of the vital signs (RR, PR, SBP, and DBP); GCS; four variables of the traumatic body region (head/neck trauma, chest trauma, extremities trauma, and external trauma); four variables of the nature of injury based on the Barell injury diagnosis matrix (fracture, crush injury, nerve injury, and other injury); and eight variables of the existing comorbidities (CHD, DVT, stroke, diabetes, bedsores, COPD, malignant tumor, and CKD). There were no significant differences between the other 15 variables (Table 1).

Selection of Independent Related Factors

Nine variables with non-zero coefficients were selected from the results of the LASSO regression. The details of the LASSO regression are shown in Online Appendix, Part 2 (available online only). The nine variables included age (OR:1.035; 95%CI, 1.027-1.044), RR (OR:1.091; 95%CI, 1.050-1.133), PR (OR:1.028; 95%CI, 1.020-1.036), DBP (OR:0.96; 95%CI, 0.950-0.970), GCS (OR:0.666; 95%CI, 0.643-0.691), crush injury (OR:3.707; 95%CI, 2.166-6.115), CHD (OR:4.025; 95%CI, 1.869-7.859), malignant tumor (OR:4.915; 95%CI, 2.850-8.098), and CKD (OR:5.735; 95%CI, 3.209-10.019); each were independent related factors contributing to the in-patient mortality of the AETPs (Table 2). The coefficients of DBP and GCS were negative, and the OR values of the two factors were both less than one, which meant that the higher the value of these two factors, the lower the risk of death. The other factor coefficients were positive, and the OR values were all greater than one, indicating that the higher the value of these factors, the higher the risk of death.

Construction of the Prognostic Nomogram

The nomogram used for assessing the in-patient death of AETPs was formulated using the variables selected by the LASSO regression. Each variable was assigned a score according to the related factors of each case, and the total score was computed by summing the individual scores. The probabilities of the in-patient death of AETPs could also be obtained from the nomogram (Figure 2). Both the calibration curve and the receiver operating characteristic (ROC) curve of the nomogram showed good discrimination and calibration (Online Appendix, Part 3; available online only). The area under the ROC curve was 0.885 (95% CI, 0.859~0.911). This showed that the nomogram had an acceptable assessment capacity for in-patient mortality. To use the nomogram, a health care provider could add the points for each factor based on personalized information and correlate the total points with the event probability that was to be predicted. For example, an 80-year-old earthquake trauma male patient with RR 28 breaths per minute, PR 120 per minute, DBP 40mmHg, and GCS of 13 points, without any existing comorbidities. First, the health care provider needed to find the value for this patient for each variable on the nomogram. The health care provider consulted the nomogram to calculate the scores for each variable as 30, 30, 42, 80, 10, 0, 0, 0, and 0, respectively. Then, the health care provider summed

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Items	Variables	Survivor N = 29674	Non-Survivor N = 259	P Value
Demographic Characteristics				
Sex	X1			
Male		14517 (48.92%)	112 (43.24%)	.069
Female		15157 (51.08%)	147 (56.76%)	
Age	X2	50.427 (17.91)	60.598 (19.828)	<.001[a]
Vital signs				
Temperature	X3	36.744 (0.458)	36.691 (0.899)	.340
RR	X4	19.962 (1.722)	21.799 (5.942)	<.001[a]
PR	X5	80.689 (11.637)	94.32 (25.136)	<.001[a]
SBP	X6	122.580 (17.193)	113.51 (27.347)	<.001[a]
DBP	X7	75.079 (10.847)	67.923 (18.132)	<.001[a]
States of Consciousness				
GCS	X8	15 [15,15]	14 [7,15]	<.001[a]
Traumatic Body Region				
Head/Neck	X9	5449 (18.36%)	85 (32.82%)	<.001[a]
Face	X10	1137 (3.83%)	6 (2.32%)	.205
Chest	X11	6068 (20.45%)	81 (31.27%)	<.001[a]
Abdomen/Pelvis	X12	4655 (15.69%)	40 (15.44%)	.915
Extremities	X13	19197 (64.69%)	118 (45.56%)	<.001[a]
External	X14	5361 (18.07%)	34 (13.13%)	.040[a]
Nature of Injury				
Fracture	X15	21336 (71.9%)	154 (59.46%)	<.001[a]
Dislocation	X16	1194 (4.02%)	9 (3.47%)	.654
Sprains and Strains	X17	117 (0.39%)	0 (0.0%)	.630
Internal Injuries	X18	6455 (21.75%)	64 (24.71%)	.251
Open Wound	X19	1460 (4.92%)	18 (6.95%)	.133
Amputation	X20	512 (1.73%)	5 (1.93%)	.808
Blood Vessel Injuries	X21	4 (0.01%)	0 (0.0%)	.999
Contusion/Superficial	X22	9400 (31.68%)	74 (28.57%)	.285
Crush Injuries	X23	604 (2.04%)	34 (13.13%)	<.001[a]
Burn	X24	47 (0.16%)	1 (0.39%)	.341
Nerves Injuries	X25	703 (2.37%)	1 (0.39%)	.036[a]
Other Injuries	X26	3613 (12.18%)	42 (16.22%)	.048[a]
Existing Comorbidities				
Hypertension	X27	1051 (3.54%)	14 (5.41%)	.107
CHD	X28	184 (0.62%)	12 (4.63%)	<.001[a]
DVT	X29	44 (0.15%)	3 (1.16%)	.008[a]
Stroke	X30	185 (0.62%)	6 (2.32%)	.007[a]
Diabetes	X31	572 (1.93%)	15 (5.79%)	<.001[a]
Bedsores	X32	253 (0.85%)	8 (3.09%)	<.001[a]
COPD	X33	411 (1.39%)	15 (5.79%)	<.001[a]
Liver Cirrhosis	X34	44 (0.15%)	2 (0.77%)	.060
Malignant Tumor	X35	281 (0.95%)	23 (8.88%)	<.001[a]
CKD	X36	169 (0.57%)	32 (12.36%)	<.001[a]
Wound Infection	X37	218 (0.73%)	0 (0.0%)	.309

Table 1. Demographic and Clinical Characteristics of Cases Enrolled in Study
Abbreviations: RR, respiratory rate; PR, pulse rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; GCS, Glasgow Coma Scale; CHD, coronary heart disease; DVT, deep vein thrombosis; COPD, chronic obstructive pulmonary disease; CKD, chronic kidney disease.
[a] $P < .05$.

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Items	Variables	Coefficient	P Value[a]	OR	95% CI
Age	X2	0.035	<.001	1.035	1.027~1.044
RR	X4	0.087	<.001	1.091	1.050~1.133
PR	X5	0.028	<.001	1.028	1.020~1.036
DBP	X7	–0.041	<.001	0.960	0.950~0.970
GCS	X8	–0.406	<.001	0.666	0.643~0.691
Crush Injuries	X23	1.310	<.001	3.707	2.166~6.115
CHD	X28	1.393	<.001	4.025	1.869~7.859
Malignant Tumor	X35	1.592	<.001	4.915	2.850~8.098
CKD	X36	1.747	<.001	5.735	3.209~10.019
/	Constant	–2.556	<.001	0.078	0.021~0.294

Table 2. Results of Regression Analysis for Predicting In-Hospital Mortality of Adult Trauma Patients in an Earthquake
Abbreviations: RR, respiratory rate; PR, pulse rate; DBP, diastolic blood pressure; GCS, Glasgow Coma Scale; CHD, coronary heart disease; CKD, chronic kidney disease.
[a] All P values <.05.

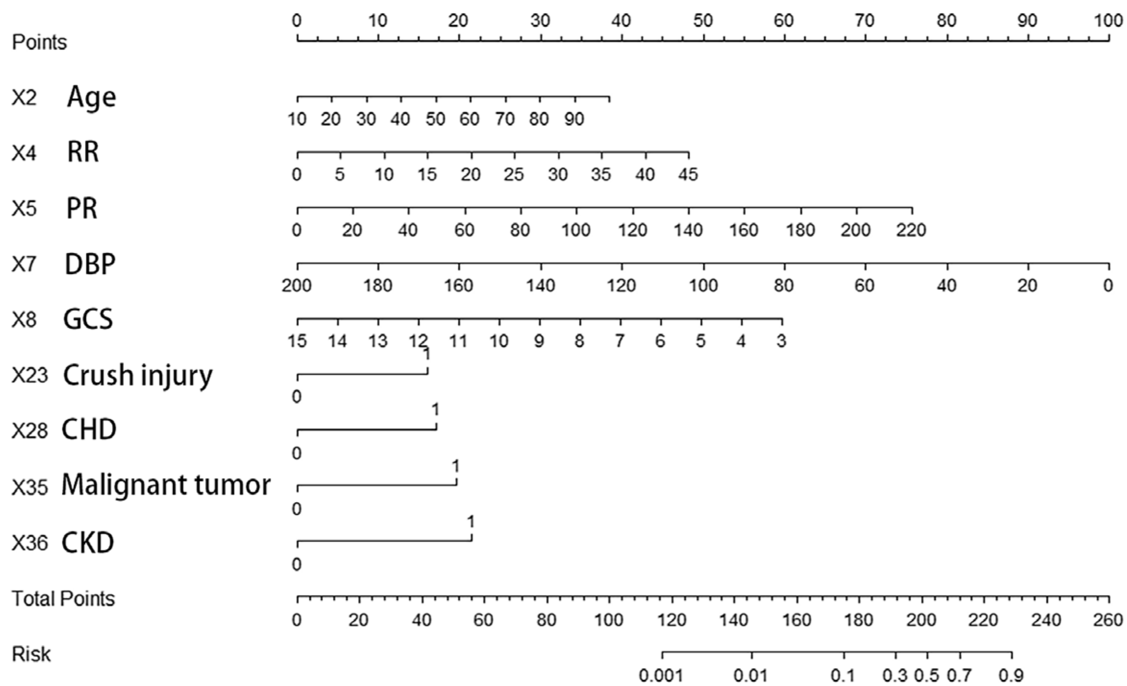

Figure 2. Nomogram for Assessing In-Patient Death of AETPs.
Note: The nomogram included nine variables, which were age (X2), respiratory rate (X4), pulse rate (X5), diastolic blood pressure (X7), Glasgow Coma Scale (X8), crush injury (X23), coronary heart disease (X28), malignant tumor (X35), and chronic kidney disease (X36). The nomogram summed the points from the scale for each variable. The total points indicated the probability of in-patient death of older adult trauma patients in an earthquake.
Abbreviations: RR, respiratory rate; PR, pulse rate; DBP, diastolic blood pressure; GCS, Glasgow Coma Scale; CHD, coronary heart disease; CKD, chronic kidney disease.

these scores to obtain a total point of 192, which corresponded to a risk of approximately 0.4.

Discussion

Early and rapid identification of fatal earthquake-related trauma in adult patients is crucial for delivering optimal care.[6] Exploring early related factors associated with AETPs could potentially be valuable for reducing mortality during an earthquake. Based on the LASSO regression, nine rapid and simple factors associated with the in-patient death risk of AETPs were selected. Factors such as age, RR, PR, DBP, GCS, crush injury, CHD, malignant tumor, and CKD could be quickly obtained when the patient arrived at the hospital with only inquisition and physical examination and without the need for laboratory or radiological results. Based on these factors, a nomogram was developed that included the above parameters and showed good discrimination and calibration to identify

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AETPs with a higher risk of in-patient mortality. Application of the model might allow emergency physicians to assess AETPs more effectively and allow medical decision makers to better utilize limited medical and transportation resources in the aftermath of a disaster.

Among the factors selected by LASSO regression, age was one of the high-risk factors. Generally, older patients have weaker bodies. Stonko's study,[21] which was based on the National Trauma Data Bank and included 614,496 geriatric trauma patients, showed that increasing age was associated with a 48% increase in overall mortality when holding ISS stable. Pant, et al studied patients in the Nepal earthquake (2015) and suggested that the earthquake-related impact on the older adult population was not only due to trauma, but also from the shortages of the medicine and medical facilities. This impact increased the adverse consequences of chronic diseases in these patients.[22] Another study on the Wenchuan earthquake (2008) also reported that the destruction of infrastructure such as road systems after the earthquake contributed to the supply shortage of medicines and equipment in hospitals.[23]

In this study, vital signs and the state of consciousness were also important risk factors. On arrival at the hospital, the RR, PR, and DBP of the vital signs and GCS were also related factors of AETP in-patient death. If the patient has increased RR, increased PR, decreased DBP, or lower GCS when arriving, it indicated that the patient had an increased risk of in-patient death and required urgent treatment.

This research also found that crush injury is a factor related to in-patient death for AETPs. Previous studies on earthquakes in Costa Rica, Turkey, Marmara, and Hanshin have reported similar results.[24–27] Pretto's study[24] on the Costa Rica earthquake (1991) showed that most injuries and deaths occurred in victims who were inside buildings or were pinned by rubble from building collapse; crush injury was the predominant cause of death. Ersoy's study[25] on the Marmara earthquake (1999) found that the mortality due to crush injury (21%) was much higher than the overall mortality (8%). Guner's research[26] reported that crush injuries require more medical resources to continuously monitor the complications that may emerge, such as dehydration and electrocardiography changes in hyperkalemia, to avoid disease progression. This is difficult and easily overlooked in disaster-stricken hospitals that lack human resources and medical supplies. Thus, the rapid institution of enhanced Emergency Medical Services, including professional personnel and material resources, may be associated with significant life-saving potential in earthquakes.

In environments requiring disaster management, such as earthquakes, many patients often have comorbidities, and the lack of medical resources for these comorbidities is likely to increase adverse outcomes in these patients. The current study screened three key comorbidities, including CHD, malignant tumors, and CKD. Some previous studies[28–32] on adult trauma reported similar results. The significance of these results was that the emergency supply of drugs or medical equipment for these chronic diseases should be considered in disaster preparedness strategies.

Limitations

This study had the following limitations. First, only the related factors were selected from a medical point of view, not from seismology, architecture, or sociology.[33–36] All of these could be factors related to earthquake-based in-patient death. The other was that all areas impacted by the earthquakes in the database were rural areas instead of urban regions. Compared with rural areas, urban regions are characterized by high population density and high variety and volume of medical services. Whether these results could be applied to urban earthquakes requires further exploration. It is necessary to study the potential factors associated with the in-patient mortality of AETPs in the future. Lastly, diagnostic criteria for existing comorbidities were not provided in the database, which may affect the definition of the variables of the existing comorbidities, which were extracted from the medical history and existing comorbidities fields of the database. Prospective studies on the existing comorbidities could be done in the future.

Despite these limitations, to the best of the authors' knowledge, this study is among the first to explore rapid and early related factors of in-patient deaths for AETPs using LASSO regression. In addition, the nomogram in the study is among the first to be constructed for predicting in-patient death in such patients.

Conclusion

To reduce the mortality of hospitalized AETPs, the rapid and simple related factors identified and analyzed by LASSO regression in this study included age, RR, PR, DBP, GCS, crush injury, CHD, malignant tumor, and CKD. Furthermore, by incorporating the above nine related factors, a nomogram for early warning of such patients was established.

Author Contributions

HH conceived the study, designed the trial, and obtained research funding. HH and XL supervised the conduct of the data collection from the database and managed the data, including quality control. HH and CT provided statistical advice on study design and analyzed the data. All the authors drafted the manuscript and contributed substantially to its revision. HH takes responsibility for the paper as a whole.

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Supplementary Materials

To view supplementary material for this article, please visit https://doi.org/10.1017/S1049023X22000693

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