

Outcome analysis of traumatic out-of-hospital cardiac arrest patients according to the mechanism of injury

A nationwide observation study

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Abstract

The variation in the outcome of traumatic out-of-hospital cardiac arrest (TOHCA) patients according to the mechanism of injury has been relatively unexplored. Therefore, this study aimed to determine whether the mechanism of injury is associated with survival to hospital discharge and good neurological outcome at hospital discharge in TOHCA.

The study population comprised cases of TOHCA drawn from the national Out-of-hospital cardiac arrest registry (2012–2016). Traumatic causes were categorized into 6 groups: traffic accident, fall, collision, stab injury, and gunshot injury. Data were retrospectively extracted from emergency medical service and Korean Centers for Disease Control and Prevention records. Multivariate logistic regression analysis was used to identify factors associated with survival to discharge and good neurological outcome.

The final analysis included a total of 8546 eligible TOHCA patients (traffic accident 5300, fall 2419, collision 572, stab injury 247, and gunshot injury 8). The overall survival rate was 18.4% (traffic accident 18.0%, fall 16.4%, collision 32.0%, stab injury 14.2%, and gunshot injury 12.5%). Good neurological outcome was achieved in 0.8% of all patients (traffic accident 0.8%, fall 0.8%, collision 1.2%, stab injury 0.8%, and gunshot injury 0.0%). In the multivariate analysis, injury mechanisms showed no significant difference in neurological outcomes, and only collision had a significant odds ratio for survival to discharge (odds ratio: 2.440; 95% confidence interval: 1.795–3.317) compared to the traffic accident group.

In this study, the mechanism of injury was not associated with neurological outcome in TOHCA patients. Collision might be the only mechanism of injury to result in better survival to discharge than traffic accident.

Abbreviations: CI = confidence interval, CPC = cerebral performance categories, CPR = cardiopulmonary resuscitation, EMS = emergency medical service, KCDC = Korean Centers for Disease Control and Prevention, OHCA = out-of-hospital cardiac arrest, OHCAS = out-of-hospital cardiac arrest surveillance, OR = odds ratio, ROSC = return of spontaneous circulation, TOHCA = traumatic out-of-hospital cardiac arrest.

Keywords: observational study, out-of-hospital cardiac arrest, prognosis, survival, trauma

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JGK and JL contributed equally to this work.

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1. Introduction

Traumatic cardiac arrest varies from a medical cardiac arrest regarding the causes and underlying pathophysiology.^[1] Compared to cardiac arrest of cardiac origin, traumatic cardiac arrest is generally associated with a poorer outcome. According to the historical observational studies on traumatic cardiac arrest, the rate of survival for traumatic out-of-hospital cardiac arrest (TOHCA) patients is extremely low.^[2,3] However, more recent publications, using data from modern trauma systems, have reported TOHCA survival rates comparable to those of out-of-hospital medical cardiac arrest.^[4–7]

The reported survival rate is 1% to 7%,^[8–11] and the reason underlying this variation is likely to be multifactorial, with varying sample sizes, different definitions of TOHCA, presence of different inclusion/exclusion criteria, and the specialty of the providing trauma service all likely to be contributing factors.

The improvement in survival in TOHCA is attributed to pre-hospital life-saving interventions.^[11–13] Basic pre-hospital trauma care comprises the external hemorrhage control, stabilization of spine, respiration and circulatory support, oxygen therapy, and advanced pre-hospital care, including intravenous fluid therapy. However, the efficacy of these treatments could be various according to the distance to the trauma center and available pre-hospital resources. The leading causes of TOHCA are traumatic brain injury and major hemorrhage,^[14] which its severity could be different according to the mechanism of injury of TOHCA.

Therefore, the mechanism of injury could be associated with patient outcome in traumatic cardiac arrest patients.^[15,16] However, the variation in the outcome of TOHCA patients according to the mechanism of injury has been relatively unexplored. Earlier studies focused on particular subgroups of injuries and mortality from bomb blasts, burns, and falls^[17,18] or reported inconsistent outcomes according to the mechanism of injury.^[10,19,20] Thus, the aim of this study was to evaluate survival to hospital discharge and good neurological outcome of TOHCA patients according to the mechanism of injury.

2. Methods

2.1. Study design and settings

This retrospective observational study included all adult TOHCA patients (aged ≥ 18 years) who were admitted to the emergency department between January 2012 and December 2016; nationwide data were obtained from the out-of-hospital cardiac arrest surveillance (OHCAS) of the Korean Centers for Disease Control and Prevention (KCDC).

The local ethics committee approved this study in 2020 (Institutional Review Board No. 2020-04-002), and the need to receive informed consent was waived because of the retrospective nature of the study and the use of anonymous clinical data for the analysis. The methodology of this study complied with the STROBE checklist for observational studies.

2.2. Data collection

The OHCAS, a national registry covering all of South-Korea, contains emergency medical service (EMS)-assessed cases of OHCA, including medical and traumatic cardiac arrest. The background characteristics of TOHCA patients were obtained

from the EMS records entered by EMS providers after the transport of TOHCA patients, and the data of TOHCA patients related to hospital care and outcomes at hospital discharge were provided by the KCDC. EMS personnel cannot declare death at the scene or terminate cardiopulmonary resuscitation (CPR) in South Korea. Therefore, all TOHCA patients are transported to the hospital. Medical record reviewers of the KCDC visited all emergency departments and hospitals that the TOHCA patients were transported to and reviewed the medical records.

The OHCAS included information such as basic characteristics of patients and place of CPR, cause of cardiac arrest, bystander CPR, management during transportation to the hospital, and outcomes at hospital discharge (survival and neurological status). The registry form was based on the Utstein style guideline and Resuscitation Outcome Consortium Project.^[21,22]

2.3. Study population

Between January 2012 and December 2016, a total of 142,905 OHCA patients were registered in the OHCAS. Among them, OHCA patients with any non-traumatic cause such as medical cause, hanging, and drowning; aged < 18 years; with a do not resuscitate order; or who were pronounced dead on arrival; with an unknown mechanism of trauma; with invalid data on survival or neurological outcome were excluded from this study.

2.4. Variables

Information on demographic factors such as age and sex, geographical factors of the OHCA (metropolitan city versus non-metropolitan city), bystander CPR, witnessed cardiac arrest, places of CPR (public places versus non-public places), prehospital return of spontaneous circulation (ROSC), initial cardiac rhythm (shockable versus non-shockable), time interval from EMS call to emergency department arrival, and mechanism of injury was collected. Metropolitan city is defined as any city with a population of > 1 million people and a first-level administrative division within South Korea.

TOHCA is defined as cardiac arrest directly caused by any external injuries at the scene including traffic accident, fall, collision, stab injury, and gunshot injury.^[8,23] The patients in this study were classified into 6 groups according to these mechanism of injury.

Traffic accident was defined as any damages caused by means of transportation, including automobile and motorbike. Collision was defined as any damage caused by colliding with an object. The detailed classification of the cause of traumatic cardiac arrest is described in Supplementary Table 1, <http://links.lww.com/MD/F147>.

Public places were defined as places that are generally open and near to people such as roads, public buildings, and commercial facilities. The detailed classification of cardiac arrest sites is summarized in Supplementary Table 2, <http://links.lww.com/MD/F147>. A shockable rhythm was defined as ventricular fibrillation and pulseless ventricular tachycardia. Sustained ROSC was defined as a spontaneous rhythm that was sustained for more than 20 min. The interval from cardiac arrest to ED arrival was defined as the time from EMS calling for TOHCA to the arrival of patients to the ED. Any patients with missing variables were excluded from the study population.

2.5. Outcomes

The primary outcome of this study was survival to discharge of TOHCA patients, and the secondary outcome was good neurological outcome at hospital discharge assessed using the Glasgow-Pittsburgh Cerebral Performance Categories (CPC) scale. CPC scores of 1-2 were categorized as good neurological outcome, and CPC scores of 3, 4, and 5 were categorized as poor neurological outcome. The outcome was based on medical records.

2.6. Statistical analysis

Categorical variables were expressed as frequencies and percentages, and differences between groups were compared using Pearson Chi-square test or Fisher exact test. Continuous variables were expressed as medians (interquartile range) or means and standard deviations and compared with the Kruskal-Wallis tests. The normality of each continuous variable was assessed using the Kolmogorov-Smirnov test.

The multivariate logistic regression model was stepwise backward elimination. The odd ratio of the traffic accident group was set as a reference in the multivariate analysis. A protocol for variable selection for multivariate logistic regression is described in Supplementary Table 3, <http://links.lww.com/MD/F147>. Any variables with p-values of <0.05 in the univariate analysis were included in the multivariate regression analysis. All statistical analyses were conducted using SPSS version 24.0 (IBM, Armonk, NY) and R package (R version 3.3.2), and P-values of <.05 were considered statistically significant.

3. Results

3.1. Characteristics and temporal trends among study subjects

Of 142,905 OHCA patients who were registered during the study period, we excluded patients with a non-traumatic cause (n=127,493), those aged <18 years (n=2857), those who were do not resuscitate or dead on arrival (n=3409), those with an

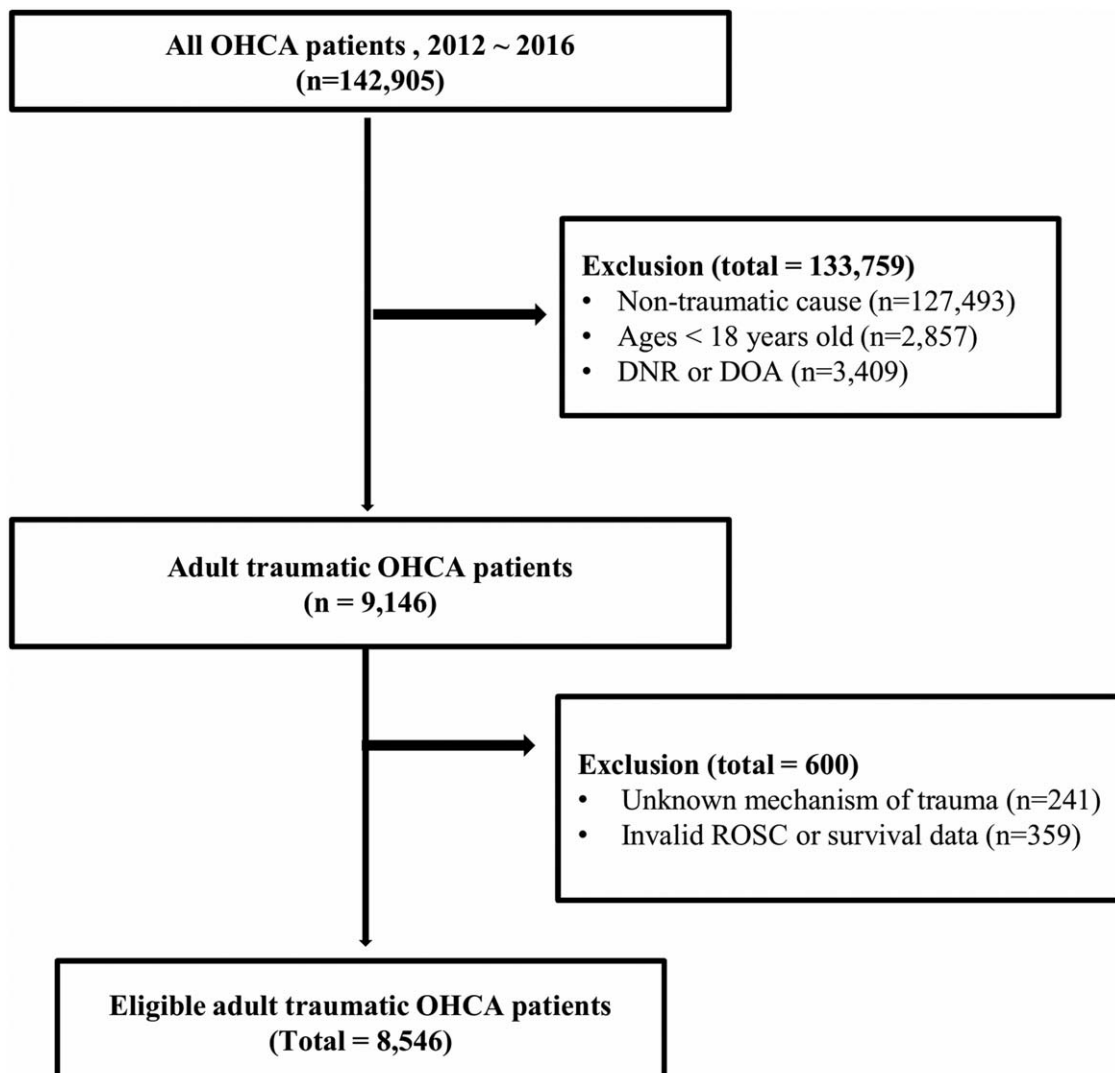


Figure 1. Flow diagram of the study population. DNR=do not resuscitate, DOA=dead on arrival, OHCA=out-of-hospital cardiac arrest.

unknown mechanism of trauma (n=241), and those whose survival or neurological outcome were unknown at hospital discharge (n=359) (Fig. 1). The remaining 8546 patients were finally enrolled in this study. The majority of TOHCAs were due to traffic accidents, falls, and collisions.

Table 1 summarizes the clinical characteristics of TOHCA patients according to the mechanism of injury. Of the enrolled patients, 1608 (18.6%) reached survival at discharge, and 70 (0.8%) patients were discharged with a good neurological outcome, with a CPC score of 1 or 2.

The six TOHCA groups, according to the mechanism of injury, had significantly different baseline characteristics (Table 1). The collision (56.6%) and gunshot groups (87.5%) were more likely to be witnessed by rescuers ($P < .001$) and TOHCAs due to traffic accidents (87.3%) and collisions (56.8%) were more likely to occur in a public location ($P < .001$). TOHCAs due to stab injury and gunshot were more likely to affect younger patients ($P < .001$). In contrast, TOHCAs due to traffic accidents were more likely to affect older patients ($P < .001$).

3.2. Multivariate logistic regression analysis of prognostic factors associated with survival to discharge and good neurological outcome

3.2.1. Prognostic factors for survival to discharge. Male sex (odds ratio [OR]: 1.574; 95% confidence interval [CI]: 1.235–2.006; $P < .001$), prehospital ROSC (OR: 17.926; 95% CI: 11.135–28.859; $P < .001$), and an initial shockable rhythm (OR:

3.416; 95% CI: 1.963–5.962; $P < .001$) were significantly associated with better survival to discharge. Among the mechanisms of injury, only collision (OR: 2.440; 95% CI: 1.795–3.317; $P < .001$) was associated with better survival to hospital discharge than traffic accidents (Table 2 and Fig. 2).

3.2.2. Prognostic factors for good neurological outcome. Prehospital ROSC (OR: 37.608; 95% CI: 16.683–84.780; $P < .001$) and an initial shockable rhythm (OR: 8.998; 95% CI: 3.381–23.941; $P < .001$) were significantly associated with good neurological outcome. However, none of the mechanisms of injury was associated with good neurological outcomes at hospital discharge (Table 2 and Fig. 2).

4. Discussion

We analyzed nationwide data to identify whether the mechanism of injury is associated with survival to discharge and good neurological outcome in adult TOHCA patients. Among the mechanisms of injury in this study, only collision was associated with better survival to discharge than traffic accident, and there were no significant associations among the mechanisms of injury and good neurological outcome at hospital discharge.

It is suggested that the resuscitation of TOHCA patients is futile, and the reported survival rate is generally low but variable.^[19,20] However, the relatively high rate (18.6%) of survival observed in this study may be due to the follow-up period of survival and rate of gunshot injury. The survival rate was only

Table 1
Basic characteristics of TOHCA patients according to mechanism of injury.

Variable	Total (n=8546)	Mechanism of injury					P
		Traffic accident (n=5300)	Fall (n=2419)	Collision (n=572)	Stab injury (n=247)	Gunshot injury (n=8)	
Age, yr	54 (41–67)	56 (43–69)	52 (38–63)	53 (43–60)	50 (39–58)	50 (36–54)	<.001
Sex							<.001
Male	6,198 (72.5%)	3845 (72.5%)	1,673 (69.2%)	505 (88.3%)	167 (67.6%)	8 (100.0%)	
Female	2,348 (27.5%)	1,455 (27.5%)	746 (30.8%)	67 (11.7%)	80 (32.4%)	0 (0.0%)	
Metropolitan city							<.001
Yes	2,966 (34.7%)	1,499 (28.3%)	1,174 (48.5%)	184 (32.2%)	107 (43.3%)	2 (25.0%)	
No	5,580 (65.3%)	3,801 (71.7%)	1,245 (51.5%)	388 (67.8%)	140 (56.7%)	6 (75.0%)	
Bystander CPR							<.001
Yes	368 (4.3%)	171 (3.2%)	141 (5.8%)	47 (8.2%)	9 (3.6%)	0 (0.0%)	
No	8,178 (95.7%)	5,129 (96.8%)	2,278 (94.2%)	525 (91.8%)	238 (96.4%)	8 (100.0%)	
Witnessed CA							<.001
Yes	3,573 (41.8%)	2,031 (38.3%)	1,111 (45.9%)	324 (56.6%)	100 (40.5%)	7 (87.5%)	
No	4,973 (58.2%)	3,269 (61.7%)	1,308 (54.1%)	248 (43.4%)	147 (59.5%)	1 (12.5%)	
Location of CA							<.001
Public places	5,606 (65.6%)	4,628 (87.3%)	586 (24.2%)	325 (56.8%)	64 (25.9%)	3 (37.5%)	
Non-public places	2,940 (34.4%)	672 (12.7%)	1,833 (75.8%)	247 (43.2%)	183 (74.1%)	5 (62.5%)	
Pre hospital ROSC							.705
Yes	309 (3.6%)	186 (3.5%)	94 (3.9%)	23 (4.0%)	6 (2.4%)	0 (0.0%)	
No	8,237 (96.4%)	5114 (96.5%)	2,325 (96.1%)	549 (96.0%)	241 (97.6%)	8 (100.0%)	
Initial cardiac rhythm							.001
Shockable	115 (1.3%)	52 (1.0%)	54 (2.2%)	7 (1.2%)	2 (0.8%)	0 (0.0%)	
Non-shockable	8,431 (98.7%)	5,248 (99.0%)	2,365 (97.8%)	565 (98.8%)	245 (99.2%)	8 (100.0%)	
Time interval, mins							.408
CA to ED arrival*	24 (17–33)	23 (15–33)	24 (18–32)	30 (20.5–40)	24 (13.5–36)	29.5 (10–40)	
Outcomes at hospital discharge							<.001
Survival	1,571 (18.4%)	956 (18.0%)	396 (16.4%)	183 (32.0%)	35 (14.2%)	1 (12.5%)	
Good neurological outcome	70 (0.8%)	41 (0.8%)	20 (0.8%)	7 (1.2%)	2 (0.8%)	0 (0.0%)	.673

CA=cardiac arrest, CPR=cardiopulmonary resuscitation, ED=emergency department, ROSC=return of spontaneous circulation, TOHCA=traumatic out of hospital cardiac arrest.

* Defined as time interval from emergency medical service calling for TOHCA to ED arrival of patients.

Table 2
Multivariate logistic analysis of survival to hospital discharge and good neurological outcome.

Outcomes	Factors	aOR (95% CI)*	P-value
Survival to hospital discharge	Male	1.574 (1.235–2.006)	<.001
	Prehospital ROSC	17.926 (11.135–28.859)	<.001
	Initial shockable rhythm	3.421 (1.963–5.962)	<.001
	Mechanism of injury		
	Traffic accident	Reference	
	Fall	1.019 (0.816–1.274)	.866
	Collision	2.440 (1.795–3.317)	<.001
Good neurological outcome at hospital discharge	Stab injury	1.035 (0.548–1.955)	.916
	Gunshot	0.000 (0.000–0.000)	.999
	Male	3.023 (0.848–10.781)	.088
	Prehospital ROSC	37.608 (16.683–84.780)	<.001
	Initial shockable rhythm	8.998 (3.381–23.941)	<.001
	Mechanism of injury†	N/A	N/A

aOR=adjusted odds ratio, CA=cardiac arrest, CI=confidence interval, ED=emergency department, N/A=not available, ROSC=return of spontaneous circulation.
 * Model of multivariate logistic regression analysis was backward stepwise and adjusted for age, sex, metropolitan city, bystander cardiopulmonary resuscitation, witnessed CA, location of CA, prehospital ROSC, initial cardiac rhythm, Time interval (CA to ER arrival).
 † Mechanism of injury was not selected as a factor in the final logistic regression model.

measured at hospital discharge in this study, rather than at ≥30 days after hospital discharge, and the rate of gunshot injury was very low (0.09%) compared to that reported in prior studies.^[19]

In terms of the mechanism of injury, traffic accident was the leading cause (61.3%) of TOHCA in this study. This corresponds to other TOHCA studies that identified traffic accident as the most common cause of trauma.^[19,20] However, the reported proportion of TOHCAs due to traffic accident was lower in a North American study (28%–24%). In addition, gunshot wounds (24%–26%) were the second leading cause of TOHCA in North America.^[19]

In the analysis for outcomes of TOHCA patients, the collision was associated with a higher possibility of survival to discharge than traffic accident. There is no clear explanation for why collision is associated with better survival. However, this result may be partially explained by the definition of collision in this study and the rate of bystander CPR, witnessed CA, and prehospital ROSC of collision-induced OHCA. The collision was defined as colliding with an object or being trapped between objects in this study. Even though the severity of the collision was not measured, it is more likely to have been caused by lower

energy than traffic accident. In the case of a collision to the chest wall, even if it is not strong enough to cause organ damage, fatal arrhythmia such as VF or airway obstruction can occur.^[24–27]

These conditions could have benefited from defibrillation and airway management by EMS. In addition, the cardiac arrest patient with collision showed a higher rate of bystander CPR (48.2% vs 3.2%) and witnessed cardiac arrest (56.6% vs 38.3%) compared traffic accident of injury, which is considered as of the crucial factors for survival in patients with OHCA.^[28–30] Therefore, we assumed that these natures of collision-induced TOHCA and a higher rate of pre-hospital factors favored better survival may have contributed to the higher rate of survival to hospital discharge than traffic accident observed in this study.

Lai et al and Evans et al reported that TOHCA caused by falls might have a higher survival to discharge rate than TOHCA caused by traffic accidents.^[10,19] In contrast, Irfan et al reported that falls were associated with lower survival to discharge than were traffic accidents.^[20] However, falls were not more strongly associated with survival to hospital discharge than traffic accidents in this study, and this finding is consistent with that of another study.^[8] This difference may be explained by differing

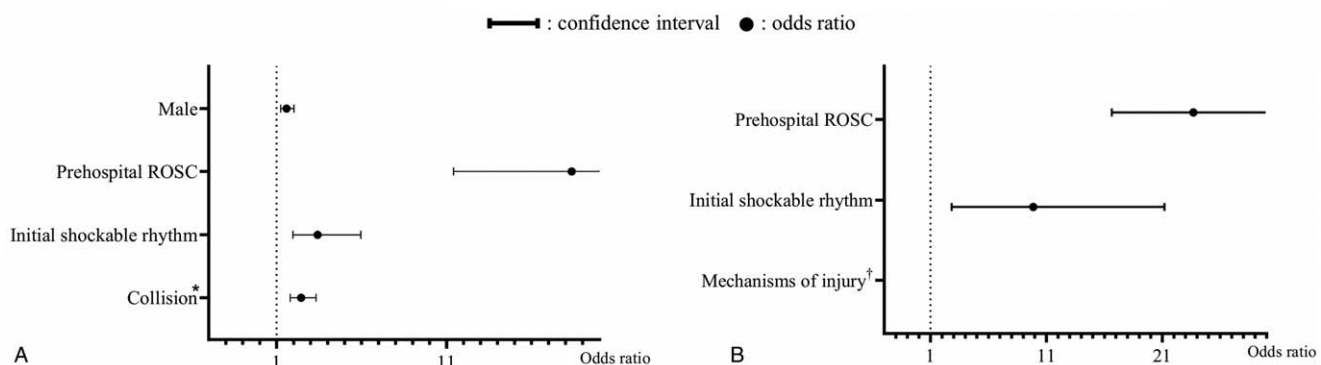


Figure 2. Independent predictors of survival to hospital discharge and good neurological outcomes in traumatic out-of-hospital cardiac arrest patients. (A) Survival to hospital discharge, (B) good neurological outcome. * Compared to traffic accident. † Mechanism of injury was not selected as a factor in the final logistic regression model. ROSC=return of spontaneous circulation.

rates of fall-induced TOHCAs among studies. Irfan et al evaluated a relatively smaller number of fall-induced TOHCA patients ($n=57$) than other previous studies including >300 fall-induced TOHCA patients.^[10,19] In this study, a relatively large number of fall-induced TOHCA patients ($n=2419$) were included. In addition to the variety in the medical system for trauma patients among countries, these differences in the incidence rates might have contributed to the inconsistent results among previous studies.^[8,10,20]

A systematic review of TOHCA reported good neurological outcome (CPC of ≤ 2) in 57% of survivors.^[10] Although the articles included in this systematic review were limited by the small number of survivors with neurological outcome data (median, $n=4$), this outcome rate differs from that observed in our study (4.3%, $n=70$). The lower rate of good neurological outcome of this study may be due to South Korea's EMS, which does not permit the provision of advanced cardiac life support to patients. Considering EMS-witnessed cardiac arrest is a well-known variables associated with favorable outcomes after trauma^[2] and immediate hemorrhage control or decompression of the chest in case of tension pneumothorax might be able to save the patients,^[3] this difference in the EMS could have resulted in greater TOHCA-related damage to the patients of this study than those of previous studies, which might have contributed to the poorer neurological outcome observed herein.

Our results also demonstrated that an initial shockable rhythm was strongly associated with survival to hospital discharge and neurological outcome. As in several previous studies, cardiac arrest patients with shockable rhythm had better survival than patients without.^[31,32] Wolbinski et al reported that OHCA patients with shockable presentations had a markedly higher survival rate than patients without (27% vs 1%).^[33] The underlying mechanism of how the shockable rhythm of TOHCA patients could contribute to survival to discharge remains unclear. However, Georgescu et al revealed that approximately 33% of TOHCA patients also presented with cardiovascular problems, which could be a reasonable explanation for our finding.^[34] It is highly possible that cardiac problems increased the rate of shockable rhythm among TOHCA patients. Consequently, the initial shockable rhythm played a major role in improving the outcomes of TOHCA patients in this study. However, this result should be interpreted cautiously, considering that the shockable rhythm could also be triggered by an underlying cardiac problem such as acute coronary syndrome, which could lead to real trauma such as vehicle accidents.

Similar to that for medical cardiac arrest, the pre-hospital ROSC was also a prognostic factor for both survival to hospital discharge and good neurological outcome in this study. Chest compressions only generate 25% to 30% of the normal cardiac output when they are performed under optimal conditions.^[35] Therefore, the prolonged CPR is related to a low likelihood of ROSC and increased cerebral damage.^[36] Hence, pre-hospital ROSC could contribute to survival to hospital discharge and good neurological outcomes.

Unlike previous TOHCA studies wherein sex had no or negative association with survival to discharge, male sex was a favorable factor for survival to discharge in this study.^[10,37] However, there are no appropriate studies providing clear evidence of this sex difference in the outcome of TOHCA. The association between male sex and a higher rate of survival to discharge could be partially explained by the result of a recent OHCA study that females are less likely than males to be

resuscitated by bystanders, and these sex differences are likely explained by the lower rate of shockable initial rhythm.^[38] To close the survival gap between sexes, further research is needed to clarify the causes of lower shockable initial rhythm rates in women.

Generally, older age is a predictor of poor outcome after CPR in trauma.^[39–41] However, in this study, age was not associated with the survival rate after TOHCA, which appears to be in contrast to previous studies but in line with 2 Taiwanese and Canadian studies.^[10,19] However, this could partially be explained by the lack of difference in TOHCA-related injury severity according to age in a recent USA study,^[39] and the fact that the average age of TOHCA patients was lower than that of non-traumatic OHCA patients.^[8,20,42,43]

5. Limitation

This study had some limitations. First, since this was a retrospective observational study, it may have been subject to selection bias relating to the survival to discharge and good neurological outcome. Second, we could not assess the neurological outcome beyond hospital discharge because the outcome was measured using data from the patients' medical records at hospital discharge. However, in this study, most patients did not survive at the hospital stage, and those with good neurological outcome at hospital discharge were only 0.8% of the total cases. Therefore, the outcome of traumatic cardiac arrest at hospital discharge could be more valuable than long term outcomes beyond hospital discharge. Third, our retrospective registry did not contain data about potential confounders, for example, underlying diseases, hemodynamic status, duration of hospital stay, and severity of the injury, which could affect outcomes. Thus, further studies, including more variables related to patient status, are required to corroborate our results. Finally, the generalizability of the study is limited by being specific to South Korea; the medical systems in this country do not provide pre-hospital advanced cardiac life support to patients. Therefore, the findings from this study should be interpreted with caution regarding their generalizability to other countries' medical systems that provide advanced cardiac life support to patients.

6. Conclusion

In this study, the mechanism of injury was not associated with neurological outcome in TOHCA patients. Collision might be the only mechanism of injury to result in better survival to discharge than a traffic accident. Nevertheless, these results should be interpreted cautiously considering the possible bias and undescribed potential confounders.

Author contributions

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