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ORIGINAL RESEARCH

Interaction effect between prehospital hydration and initial cardiac rhythm in traumatic out-of-hospital cardiac arrest: a nationwide observational study

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Abstract

Traumatic cardiac arrest (TCA) is different in etiology compared to medical cardiac arrest. In case of TCA, it is important to initiate early fluid resuscitation. Initial cardiac rhythm serves as an indicator of outcomes in case of cardiac arrest. We aimed to find the association between prehospital hydration and outcomes of TCA according to initial cardiac rhythm. This is a retrospective, observational, cross-sectional study. An examination was undertaken involving patients afflicted with TCA within the timeframe of 2014 to 2019. Exposure was defined to encompass prehospital hydration; interactive exposure was categorized by initial cardiac rhythm (non-shockable *vs.* shockable); the primary outcome was defined as good neurological status at discharge, whereas the secondary outcome was defined as survival to discharge. Multivariable logistic regression analysis was used to calculate adjusted odds ratios (AORs) with 95% confidence intervals (CIs). A comprehensive analysis was conducted on a cumulative of 20,247 patients. Rates of good neurological status and survival to discharge were 0.2% and 8.3% (non-shockable rhythm group) and 3.0% and 16.7% (shockable rhythm group), respectively. However, rates of good neurological status and survival to discharge were 0.2% and 7.9% (non-prehospital hydration group) and 0.3% and 10.0% (hydration group), respectively. Compared to the non-hydration group, the AORs for good neurological status at discharge was 1.44 (95% CI: 0.77–2.69) for the hydration group. Moreover, compared to the non-shockable rhythm group, the AORs for good neurological status at discharge was 19.74 (95% CI: 10.46–27.26) in the shockable rhythm group. The interaction analysis conducted between prehospital hydration and initial rhythm unveiled the efficacy of prehospital hydration in promoting favorable survival to discharge outcomes in the non-shockable rhythm group. Therefore, prehospital hydration is recommended for those with TCA characterized by a non-shockable rhythm before transport from the incident location.

Keywords

Traumatic cardiac arrest; Prehospital hydration; Initial cardiac rhythm

1. Introduction

Out-of-hospital cardiac arrest (OHCA) is a leading cause of mortality globally [1]. The majority of OHCA cases are presumed to have a cardiac etiology, whereas traumatic cardiac arrest (TCA) accounts only for a small proportion [2]. However, previously reported mortality rates in cases of TCA were higher than those observed in OHCA cases with a medical etiology [3]. The survival rate of TCA has been reported to range from 1% to 12% according to the research settings [4, 5].

The mechanism of TCA primarily involves decompensated hypovolemic and hypoxic shock after the initial injury [6]. Distinct etiological differences necessitate varied approaches for presumed medical causes and trauma. For instance, strategies include early chest compressions with electro-cardioversion for medical causes, in contrast to addressing acute reversible causes. Reversible causes of TCA encompass several factors. Hypoxia arising from airway obstruction attributed to severe traumatic brain injury (treated by airway protection), hypovolemia due to major vessel injuries or pelvic fractures (treated by hydration, blood products transfusion and hemostasis), and obstructive shock stemming from cardiac tamponade or pneumothorax (treated by needle thoracotomy) [7]. In case of TCA, the utmost priority lies in establishing a substantial intravenous (IV) access point and initiate a rapid transfusion of blood products. However, many prehospital emergency medical services (EMS) encounter challenges in obtaining blood products due to difficulties in storage and transportation involving temperature control, as well as product expiry issues [8]. Therefore, instead of blood transfusion, immediate fluid resuscitation can be administered during the prehospital phase to restore circulating volume and maintain organ perfusion in TCA [9–11]. However, there remains an insufficiency of comprehensive evidence regarding the effect of prehospital hydration on TCA.

The initial cardiac rhythm serves as a well-known prognostic indicator not only in presumed cardiac OHCA but also in TCA [6, 12, 13]. This significance arises from the recognition that an initial shockable rhythm has been linked to short no-flow time (time between patient collapse and start of cardiopulmonary resuscitation (CPR)) in previous studies [14, 15]. Nevertheless, this concept has been proposed mainly in presumed cardiac arrest cases and has not been investigated in TCA. As aforementioned, differences in cardiac arrest etiologies require different interpretations and strategies even when the initial cardiac rhythm remains consistent.

We hypothesized that prehospital hydration would have a different effect according to initial cardiac rhythms on outcomes of TCA. We aimed to evaluate the association between prehospital hydration and clinical outcomes based on initial cardiac rhythm in cases of TCA.

2. Materials and methods

This study was conducted as a retrospective, observational, cross-sectional study, using the Korean national OHCA registry. South Korea has a population of nearly 50 million and a land of 99,000 km^2. The EMS is based on a single-tiered, fire-based and government-sponsored system operated by the National Fire Agency. For emergency assistance, the telephone number of the EMS is "119" across the entire country. EMS providers adhere to the EMS CPR protocol, which is based on the 2020 American Heart Association guidelines. Moreover, this protocol is followed at the scene and during transportation of the patient [16, 17]. A Korean EMS provider holds a role similar to that of an intermediate emergency medical technician (EMT-I) in the United States. These providers can perform CPR with basic life support at the scene and during transportation, coupled with the utilization of automatic external defibrillation. Additionally, IV fluid administration and advanced airway management, such as supraglottic airway and endotracheal intubation performed under direct medical control, are also allowed to be executed by the EMS providers. They can also call doctors from the scene using a smartphone for direct medical oversight. There is no definite protocol or guideline about EMS IV hydration in South Korea. We defer to the judgement of the on-scene EMS providers to determine whether to administer hydration before transportation or while in transit. Patients with OHCA must be transported to an emergency department (ED). Advanced cardiac life support medications are available at an ED; however, their availability is limited in most prehospital areas. Furthermore, in cases involving major trauma, EMS providers are not authorized to perform needle thoracotomy for tension pneumothorax. The nationwide OHCA registry, which includes the basic EMS run sheet, prehospital EMS cardiac arrest registry, and hospital record review, was employed in this study [18–21]. The EMS run sheet and prehospital EMS cardiac arrest registry, including Utstein factors, such as demographics and prehospital EMS management variables, are recorded by the on-duty EMS provider.

All EMS-treated TCA cases from 2014 to 2019 were initially enrolled for analysis. Patients with OHCA of medical etiology; those with non-traumatic cardiac arrest owing to reasons such as burns, fire and suffocation; those that did not receive CPR at the scene; and those of unknown age, exposures and outcomes were excluded.

The main exposure was defined as "prehospital hydration status at the scene". Prehospital hydration was considered positive when EMS providers successfully administered IV fluid at the scene. The interactive exposure was characterized as "the initial cardiac rhythm first checked at the scene". Shockable rhythm included pulseless ventricular tachycardia and ventricular fibrillation, whereas non-shockable rhythm encompassed pulseless electrical activity and asystole. Various factors were considered including Utstein factors, demographic variables, community factors, as well as prehospital and hospital variables. These encompassed age, sex, weekends, EMS call time (day or night), response time interval (RTI), scene time interval (STI), transport time interval (TTI), EMS time interval, place of arrest (public or private), metropolitan area (with a population of more than one million), witnessed status, bystander CPR, mechanism of trauma (traffic accident, fall, blunt, penetrating or gunshot), intent of trauma (accidental or intentional), prehospital airway management (endotracheal intubation, combitube, laryngeal mask airway, king airway, I-gel, others or none), prehospital adrenaline (epinephrine) administration, prehospital restraint (cervical, whole spine, extremity splint or head), prehospital wound management (hemostasis or dressing), multi-tiered response status, referred hospital level (regional level 1 ED, local level 2 ED, local level 3 ED or local level 4), death on arrival at ED, prehospital return of spontaneous circulation (ROSC), and ED ROSC were collected. RTI was characterized as the span between the moment when the emergency call was received by a call-taker in the 119 dispatch center and the point when the ambulance arrived at the OHCA scene. Similarly, STI was defined as the duration commencing from the instance the ambulance arrived at the scene to the time when the ambulance departed from the same location. TTI was defined as the span starting from the point when the ambulance departed the scene to the time when the ambulance arrived at the ED. However, EMS time interval was defined as the duration commencing from the moment the emergency call was received by a call-taker in 119 dispatch center to the time when the ambulance arrived at the ED.

The primary outcome was a good neurological status at discharge, and the secondary outcome was survival to discharge. Good neurological status was constructed to be the attainment of a cerebral performance category (CPC) score of 1 or 2 at hospital discharge.

Patient demographics and several factors related to TCA, such as place of arrest, witness status, bystander, time of arrest, mechanism of trauma, and prehospital EMS management, were compared between the variables of "prehospital hydration" and "initial cardiac rhythm". The categorical variables were described using counts and proportions and compared using the chi-square test. The continuous variables were presented as the mean and standard deviation (SD) or median and interquartile range (IQR) using the Mann-Whitney U test. Additionally, a multivariable logistic regression analysis was performed to test the association between prehospital hydration and initial cardiac rhythm and the resultant outcomes. Potential confounders, such as age, sex, year, weekend, time of arrest, place of arrest, witness, bystander, mechanism of trauma, intent of trauma, metropolitan and RTI were adjusted. The AORs and 95% CIs were calculated for outcomes. An interaction analysis was performed to compare the effect of the initial cardiac rhythm and the prehospital hydration on the outcomes. All of the analyses were performed using SAS version 9.4 (SAS©, Cary, NC, USA). p-values of 0.05 were considered to be statistically significant.

3. Results

From 181,495 eligible OHCA patients, 20,247 patients were finally assessed after excluding patients with medical etiology (n = 145,787), non-TCA owing to reasons such as burns, fire and suffocation (n = 13,392), those that did not receive CPR at the scene (n = 2036), and those with unknown age (n = 26), exposures (n = 0) and outcomes (n = 7) (Fig. 1).

A cumulative of 6413 patients, constituting 31.7% of the overall 20,247 patient cohort, received prehospital hydration; 6.4%, 10.7%, 16.3%, 15.8%, 25.5% and 25.3% of the patients were administered prehospital hydration from 2014 to 2019, respectively. The median STI was 7 (IQR 5–10) min for the no prehospital hydration group and 9 (IQR 6–11) min for the prehospital hydration group. TCA occurred in a metropolitan region in 25.5% of patients of the no prehospital hydration group and 44.9% of the prehospital hydration group. The proportion of prehospital airway management was 27.1% in the no prehospital hydration group and 73.3% in the prehospital hydration group. I-gel was the most frequently used in both groups: 14.9% in the no prehospital hydration group and 39.8% in the prehospital hydration. The proportion of patients with initial shockable rhythm was 2.7% in the no prehospital hydration group and 3.0% in the prehospital hydration group. The proportion of patients with outcomes of good neurological status at discharge and survival to discharge were 0.2% and 7.9% in the no prehospital hydration group and 0.3% and 10.0% in prehospital hydration, respectively (Table 1).

The number (percentage) of patients with initial shockable rhythm was 569 (2.8%). The median STI was 8 (IQR 5–10) min in the non-shockable rhythm group and 8 (IQR 5–10.5) min in the shockable rhythm group. The rate of witnessed arrest and bystander CPR were 41.9% and 31.9%, respectively, in the non-shockable rhythm group and 46.7% and 39.7%, respectively, in the shockable rhythm group. The proportions of patients with statuses of death on arrival at ED, prehospital ROSC and ED ROSC were 48.8%, 1.5% and 14.5% in the non-shockable rhythm group and 38.7%, 8.6% and 16.5% in the shockable rhythm group, respectively. The proportion of patients with outcomes of good neurological status at discharge and survival to discharge were 0.2% and 8.3% in the non-shockable rhythm group and 3.0% and 16.7% in the shockable rhythm group, respectively (Table 2).

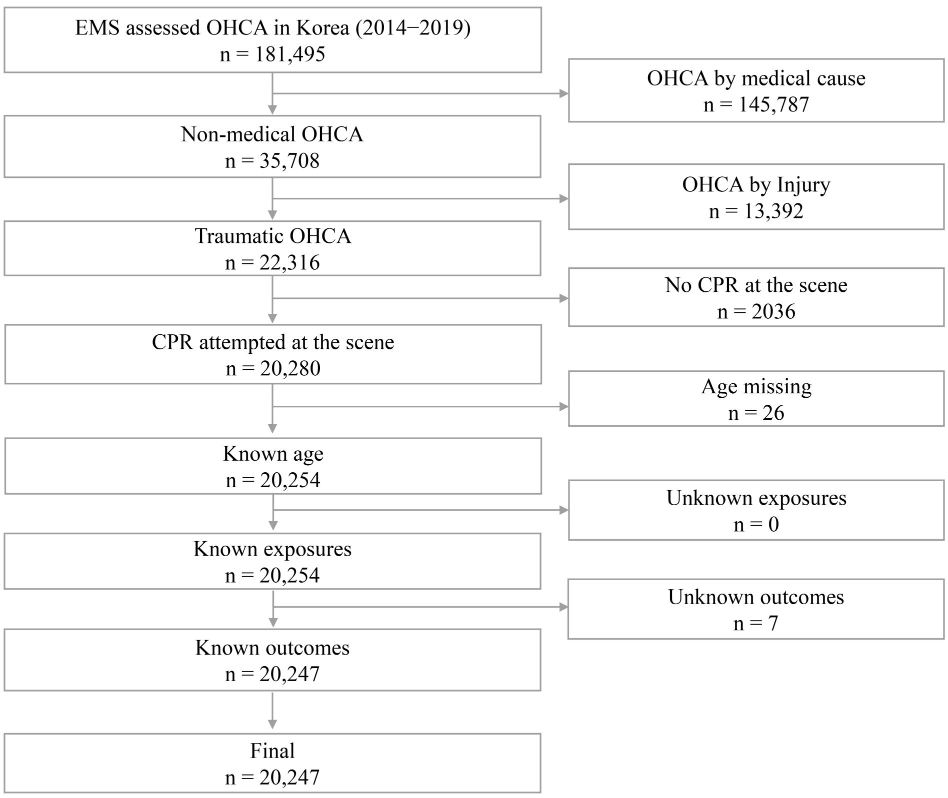

FIGURE 1. Study flow chart. EMS: emergency medical service; OHCA: out-of-hospital cardiac arrest; CPR: cardiopulmonary resuscitation.

TABLE 1. Demographic findings of patients included in the study according to prehospital hydration status.

		Prehospital hydration status						*p*-value
				Hydration (−)		Hydration (+)		
		All	%	n	%	n	%	
All	N	20,247	100.0	13,834	100.0	6413	100.0	
Year								
	2014	3204	15.8	2792	20.2	412	6.4	<0.001
	2015	3443	17.0	2760	20.0	683	10.7	
	2016	3299	16.3	2252	16.3	1047	16.3	
	2017	3267	16.1	2252	16.3	1015	15.8	
	2018	3513	17.4	1880	13.6	1633	25.5	
	2019	3521	17.4	1898	13.7	1623	25.3	
Age								
	0∼18	766	3.8	545	3.9	221	3.4	0.11
	19∼65	13,491	66.6	9166	66.3	4325	67.4	
	>66	5990	29.6	4123	29.8	1867	29.1	
	Median (IQR)	55 (40∼68)		55 (40∼68)		54 (40∼67)		0.30
Sex	Male	14,573	72.0	9915	71.7	4658	72.6	0.16
Weekend	Yes	5569	27.5	3828	27.7	1741	27.1	0.44
Daytime	8A∼8P	11,853	58.5	8072	58.3	3781	59.0	0.41
RTI (call∼contact)								
	≤4	2206	10.9	1560	11.3	646	10.1	<0.001
	4∼8	8243	40.7	5399	39.0	2844	44.3	
	>8	8546	42.2	5783	41.8	2763	43.1	
	Median (IQR)	8 (6∼12)		8 (6∼12)		8 (6∼12)		0.38
STI (contact∼depart)								
	≤8	11,360	56.1	8229	59.5	3131	48.8	<0.001
	8∼16	6215	30.7	3641	26.3	2574	40.1	
	>16	1500	7.4	931	6.7	569	8.9	
	Median (IQR)	8 (5∼10)		7 (5∼10)		9 (6∼11)		<0.001
TTI (depart∼ED arrival)								
	≤6	8546	42.2	5880	42.5	2666	41.6	0.35
	6∼12	6450	31.9	4368	31.6	2082	32.5	
	>12	5177	25.6	3549	25.7	1628	25.4	
	Median (IQR)	8 (5∼13)		8 (5∼13)		8 (5∼13)		0.06
EMS TI (call∼ED arrival)								
	≤15	2524	12.5	1975	14.3	549	8.6	<0.001
	15∼25	8035	39.7	5468	39.5	2567	40.0	
	>25	9688	47.8	6391	46.2	3297	51.4	
	Median (IQR)	25 (19∼35)		24 (18∼34)		26 (20∼35)		<0.001
Distance (km)	Median (IQR)	3 (1.5∼5.8)		3 (1.7∼6)		2.5 (1.5∼5)		<0.001
Place of arrest								
	Public	12,297	60.7	8592	62.1	3705	57.8	<0.001
	Private	6191	30.6	4033	29.2	2158	33.7	
	Others	1759	8.7	1209	8.7	550	8.6	
Metropolitan		6412	31.7	3534	25.5	2878	44.9	<0.001
Witness		8505	42.0	5617	40.6	2888	45.0	<0.001
Bystander		6498	32.1	4257	30.8	2241	34.9	<0.001
EMS AED		20,055	99.1	13,661	98.7	6394	99.7	<0.001

TABLE 1. Continued.

		Prehospital hydration status						*p*-value
				Hydration (−)		Hydration (+)		
		All	%	n	%	n	%	
All	N	20,247	100.0	13,834	100.0	6413	100.0	
Mechanism of trauma								
	TA	11,668	57.6	8265	59.7	3403	53.1	
	Fall	6892	34.0	4448	32.2	2444	38.1	
	Blunt	1203	5.9	817	5.9	386	6.0	<0.001
	Penetrating	473	2.3	296	2.1	177	2.8	
	Gun shot	11	0.1	8	0.1	3	0.0	
Intent								
	Accident	14,346	70.9	10,040	72.6	4306	67.1	
	Intentional	3177	15.7	2079	15.0	1098	17.1	<0.001
	Assault	305	1.5	200	1.4	105	1.6	
Prehospital Airway								
	None	10,417	51.4	8707	62.9	1710	26.7	
	Endotracheal Tube	552	2.7	197	1.4	355	5.5	
	Combitube	16	0.1	6	0.0	10	0.2	
	LMA	873	4.3	481	3.5	392	6.1	<0.001
	King Airway	259	1.3	207	1.5	52	0.8	
	I-gel	4613	22.8	2062	14.9	2551	39.8	
	Others	3234	16.0	2017	14.6	1217	19.0	
Prehospital Adrenaline use		77	0.4	2	0.0	75	1.2	<0.001
Restraint								
	Cervical	15,234	75.2	9781	70.7	5453	85.0	<0.001
	Whole spine	9775	48.3	5903	42.7	3872	60.4	<0.001
	Extremity splint	3651	18.0	1959	14.2	1692	26.4	<0.001
	Head	6504	32.1	3579	25.9	2925	45.6	<0.001
Wound management								
	Hemostasis	5469	27.0	3153	22.8	2316	36.1	<0.001
	Dressing	4009	19.8	2224	16.1	1785	27.8	<0.001
Initial shockable rhythm		569	2.8	375	2.7	194	3.0	0.21
Hydration amount	Mean (SD)	500 (1000)		0 (0)		500 (1000)		N/A
Multi-tiered response		9350	46.2	5393	39.0	3957	61.7	<0.001
Transported hospital level								
	1	4834	23.9	2918	21.1	1916	29.9	
	2	8842	43.7	5945	43.0	2897	45.2	<0.001
	3	5617	27.7	4193	30.3	1424	22.2	
	4	614	3.0	526	3.8	88	1.4	
DOA at ED		9823	48.5	7096	51.3	2727	42.5	<0.001
Prehospital ROSC		340	1.7	179	1.3	161	2.5	<0.001
ED ROSC		2957	14.6	1895	13.7	1062	16.6	<0.001
Good CPC at discharge		51	0.3	31	0.2	20	0.3	0.25
Survival to discharge		1738	8.6	1094	7.9	644	10.0	<0.001

IQR: interquartile range; RTI: response time interval; STI: scene time interval; TTI: transport time interval; EMS TI: emergency medical service time interval; AED: automated external defibrillator; TA: traffic accident; LMA: laryngeal mask airway; SD: standard deviation; DOA: death on arrival; ED: emergency department; ROSC: return of spontaneous circulation; CPC: cerebral performance category.

TABLE 2. Demographic findings of patients included in the study according to initial cardiac rhythm.

		Initial cardiac rhythm						*p*-value
				Shockable (−)		Shockable (+)		
		All	%	n	%	n	%	
All	N	20,247	100.0	19,678	100.0	569	100.0	
Year								
	2014	3204	15.8	3100	15.8	104	18.3	0.08
	2015	3443	17.0	3337	17.0	106	18.6	
	2016	3299	16.3	3197	16.2	102	17.9	
	2017	3267	16.1	3196	16.2	71	12.5	
	2018	3513	17.4	3418	17.4	95	16.7	
	2019	3521	17.4	3430	17.4	91	16.0	
Age								
	0∼18	766	3.8	743	3.8	23	4.0	0.94
	19∼65	13,491	66.6	13,114	66.6	377	66.3	
	≥65	5990	29.6	5821	29.6	169	29.7	
	Median (IQR)	55 (40∼68)		55 (40∼68)		54 (40∼66)		0.58
Sex	Male	14,573	72.0	14,150	71.9	423	74.3	0.20
Weekend	Yes	5569	27.5	5419	27.5	150	26.4	0.54
Daytime	8A∼8P	11,853	58.5	11,496	58.4	357	62.7	0.04
RTI (call∼contact)								
	≤4	2206	10.9	2129	10.8	77	13.5	0.05
	4∼8	8243	40.7	8020	40.8	223	39.2	
	>8	8546	42.2	8328	42.3	218	38.3	
	Median (IQR)	8 (6∼12)		8 (6∼12)		8 (5∼11)		0.01
STI (contact∼depart)								
	≤8	11,360	56.1	11,064	56.2	296	52.0	0.45
	8∼16	6215	30.7	6033	30.7	182	32.0	
	>16	1500	7.4	1459	7.4	41	7.2	
	Median (IQR)	8 (5∼10)		8 (5∼10)		8 (5∼10.5)		0.49
TTI (depart∼ED arrival)								
	≤6	8546	42.2	8316	42.3	230	40.4	0.4
	6∼12	6450	31.9	6272	31.9	178	31.3	
	>12	5177	25.6	5018	25.5	159	27.9	
	Median (IQR)	8 (5∼13)		8 (5∼13)		8 (5∼13.5)		0.22
EMS TI (call∼ED arrival)								
	≤15	2524	12.5	2446	12.4	78	13.7	0.06
	15∼25	8035	39.7	7836	39.8	199	35.0	
	>25	9688	47.8	9396	47.7	292	51.3	
	Median (IQR)	25 (19∼35)		25 (19∼35)		26 (19∼34)		0.98
Distance (km)	Median (IQR)	3 (1.5∼5.8)		3 (1.6∼5.9)		2.9 (1.5∼5)		0.10
Place of arrest								
	Public	12,297	60.7	11,940	60.7	357	62.7	0.49
	Private	6191	30.6	6030	30.6	161	28.3	
	Others	1759	8.7	1708	8.7	51	9.0	
Metropolitan		6412	31.7	6227	31.6	185	32.5	0.66
Witness		8505	42.0	8239	41.9	266	46.7	0.05
Bystander		6498	32.1	6272	31.9	226	39.7	<0.001
EMS AED		20,055	99.1	19,486	99.0	569	100.0	0.02

TABLE 2. Continued.

			Initial cardiac rhythm				*p*-value
			Shockable (−)		Shockable (+)		
	All	%	n	%	n	%	
All N	20,247	100.0	19,678	100.0	569	100.0	
Mechanism of trauma							
TA	11,668	57.6	11,338	57.6	330	58.0	
Fall	6892	34.0	6694	34	198	34.8	
Blunt	1203	5.9	1168	5.9	35	6.2	0.13
Penetrating	473	2.3	468	2.4	5	0.9	
Gun shot	11	0.1	10	0.1	1	0.2	
Intent							
Accident	14,346	70.9	13,928	70.8	418	73.5	
Intentional	3177	15.7	3104	15.8	73	12.8	0.08
Assault	305	1.5	301	1.5	4	0.7	
Prehospital Airway							
None	10,417	51.4	10,134	51.5	283	49.7	
Endotracheal Tube	552	2.7	534	2.7	18	3.2	
Combitube	16	0.1	15	0.1	1	0.2	
LMA	873	4.3	838	4.3	35	6.2	0.03
King Airway	259	1.3	245	1.2	14	2.5	
I-gel	4613	22.8	4495	22.8	118	20.7	
Others	3234	16.0	3138	15.9	96	16.9	
Prehospital Adrenaline Use	77	0.4	75	0.4	2	0.4	0.91
Restraint							
Cervical	15,234	75.2	14,823	75.3	411	72.2	0.09
Whole spine	9775	48.3	9519	48.4	256	45.0	0.11
Extremity splint	3651	18.0	3572	18.2	79	13.9	0.01
Head	6504	32.1	6333	32.2	171	30.1	0.28
Wound management							
Hemostasis	5469	27.0	5346	27.2	123	21.6	0.003
Dressing	4009	19.8	3923	19.9	86	15.1	0.004
Prehospital Hydration							
Yes	6413	31.7	6219	31.6	194	34.1	0.21
Mean (SD)	500 (1000)		0 (0)		500 (1000)		0.02
Multi-tiered response	9350	46.2	9112	46.3	238	41.8	0.03
Transported hospital level							
1	4834	23.9	4704	23.9	130	22.8	
2	8842	43.7	8592	43.7	250	43.9	0.91
3	5617	27.7	5453	27.7	164	28.8	
4	614	3.0	596	3.0	18	3.2	
DOA at ED	9823	48.5	9603	48.8	220	38.7	<0.001
Prehospital ROSC	340	1.7	291	1.5	49	8.6	<0.001
ED ROSC	2957	14.6	2863	14.5	94	16.5	0.19
Good CPC at discharge	51	0.3	34	0.2	17	3.0	<0.001
Survival to discharge	1738	8.6	1643	8.3	95	16.7	<0.001

IQR: interquartile range; RTI: response time interval; STI: scene time interval; TTI: transport time interval; EMS TI: emergency medical service time interval; AED: automated external defibrillator; TA: traffic accident; LMA: laryngeal mask airway; SD: standard deviation; DOA: death on arrival; ED: emergency department; ROSC: return of spontaneous circulation; CPC: cerebral performance category.

Compared with the no prehospital hydration group, the unadjusted ORs and AORs (95% CIs) for good neurological status at discharge of the prehospital hydration group were 1.39 (0.79–2.45) and 1.44 (0.77–2.69), respectively, and those for survival to discharge were 1.30 (1.17–1.44) and 1.32 (1.18–1.48), respectively. Compared with the non-shockable rhythm group, the unadjusted ORs and AORs (95% CIs) of the shockable rhythm group for good neurological status at discharge were 17.79 (9.88–32.05) and 19.74 (10.46–37.26), respectively, and for survival to discharge, they were 2.20 (1.76–2.76) and 2.06 (1.61–2.63), respectively (Table 3).

In the interaction analysis for good neurological status at discharge according to initial rhythm, AORs (95% CIs) of the prehospital hydration group were 1.49 (0.70–3.17) among those with non-shockable rhythm and 1.08 (0.36–3.30) among those with shockable rhythm. AORs (95% CIs) for survival to discharge of prehospital hydration group were significantly different according to initial cardiac rhythm: 1.27 (1.13–1.42) in the non-shockable rhythm group and 1.52 (0.93–2.47) in the shockable rhythm group (Table 4).

4. Discussion

We found that prehospital hydration was associated with higher survival to discharge rate in patients with TCA with initial non-shockable rhythm. However, prehospital hydration had no effect, regardless of initial cardiac rhythm, on good neurological status at discharge. To the best of our knowledge, this is the first study to evaluate the interaction analysis between prehospital hydration and initial cardiac rhythm in TCA.

TCA can be caused by several reversible factors, such as hypoxia, tension pneumothorax, cardiac tamponade or hypovolemia [22]. In this study, hypovolemia was the cause of interest. It is known that TCA due to hypovolemia does not occur immediately after traumatic events. As the patient's blood volume decreases, blood flow is diverted to vital organs, such as the brain and heart. Lactic acid accumulates within cells over time due to organ ischemia, leading to TCA [23]. In a previous study, Xavier *et al*. [14] have stated that shockable rhythms are associated with no-flow duration. Considering the pathophysiology of TCA, initial non-shockable rhythms indicate prolonged no-flow duration and less intravascular volume. We think that prehospital hydration was effective in patients with TCA with non-shockable rhythm because it restored effective circulatory volume, which led to an increase of survival to discharge rate. In future research, the relationship between prehospital fluid amounts and electrocardiogram rhythms will need to be analyzed.

TCA is a time-dependent condition that requires a well-coordinated chain of events for survival from prehospital management to specialized trauma center care [24, 25]. TCA management must focus on the correction of reversible causes soon after prioritized life support has been administered. Herein, we selected patients with blunt and penetrating trauma, which was consistent with other studies on this topic [26–29]. Prehospital hydration has been considered as one of the basic treatment factors to restore circulating blood volume in previous studies [30, 31]. However, Evans *et al*. [32] have stated that prehospital hydration—including IV and intraosseous administration—was ineffective for survival to discharge. Contrarily, our results show that prehospital hydration was associated with higher survival to discharge after adjusting for confounders in the logistic regression analysis. This may be attributed to the fact that the database used in Evans *et al*.'s [32] study was the North American EMS system, where paramedics could

TABLE 3. Association between exposures and outcomes by logistic regression.

	Outcomes				
	All	n	%	Unadjusted OR (95% CI)	Adjusted OR (95% CI)*
Good CPC at discharge					
Hydration (−)	13,834	31	0.2	1.00	1.00
Hydration (+)	6413	20	0.3	1.39 (0.79∼2.45)	1.44 (0.77∼2.69)
Total	20,247	51	0.3		
Shockable (−)	19,678	34	0.2	1.00	1.00
Shockable (+)	569	17	3.0	17.79 (9.88∼32.05)	19.74 (10.46∼37.26)
Total	20,247	51	0.3		
Survival to discharge					
Hydration (−)	13,834	1094	7.9	1.00	1.00
Hydration (+)	6413	644	10.0	1.30 (1.17∼1.44)	1.32 (1.18∼1.48)
Total	20,247	1738	8.6		
Shockable (−)	19,678	1643	8.3	1.00	1.00
Shockable (+)	569	95	16.7	2.20 (1.76∼2.76)	2.06 (1.61∼2.63)
Total	20,247	1738	8.6		

OR: odds ratio; CI: confidence interval; CPC: cerebral performance category.
**Adjusted for age, sex, year, weekend, daytime, place of arrest, witness, bystander, mechanism of injury, intent, metropolitan and response time interval.*

TABLE 4. Interaction analysis between prehospital hydration and initial cardiac rhythm.

Outcomes	Shockable (−)			Shockable (+)		
Good CPC at discharge	AOR	95% CI		AOR	95% CI	
Hydration (−)		1.00			1.00	
Hydration (+)	1.49	0.70	3.17	1.08	0.36	3.30
Survival to discharge	*AOR	95% CI		AOR	95% CI	
Hydration (−)		1.00			1.00	
Hydration (+)	1.27	1.13	1.42	1.52	0.93	2.47

AOR: adjusted odds ratio; CI: confidence interval; CPC: cerebral performance category.
**Adjusted for age, sex, year, weekend, daytime, place of arrest, witness, bystander, mechanism of injury, intent, metropolitan and response time interval.*

select which patients to provide interventions based on existing protocols and clinical judgement. In our study, the EMS providers should perform high-quality CPR to patients with all causes of arrest, unless the signs of death (*i.e.*, decapitation, trunk amputation or rigor mortis) were evident. This selection bias could have led to the contrary results. Another reason may be that there is a difference in the EMS provider procedure levels between different countries. In our study, the EMS providers could perform advanced airway management techniques and administer fluid intravenously; however, they could not perform needle thoracotomy and blood product transfusion, which is possible in some North American regions. These differences in prehospital procedure level may have functioned as confounders in logistic regression and affected the outcomes. Further studies are therefore required to determine the effectiveness of prehospital hydration in patients with TCA.

The mechanism of injury in this study was mainly blunt trauma, including traffic accidents, falls and blunt injuries, consisting of up to 97.5% of all TCAs. In a previous study, the proportions of cases with blunt trauma and gunshot injuries were nearly 67% and 25%, respectively [32]. As civilian gun ownership is legally prohibited in South Korea, there have been rare instances of TCAs caused by firearm-related penetrating injuries. Keizer *et al*. [33] found that penetrating injuries required a higher rate of surgical intervention in major trauma cases compared to blunt injuries, even though there were no differences in mortality and complication rates. This implies that differences in the mechanism of injuries contribute to different pathophysiologies and consequently require different treatment plans. The homogenous mechanism of injury in our study population requires caution in terms of interpretation of the results. Further research requires stratified analysis that includes the mechanism of injury.

In our study, IV hydration was not administered in 68.3% of TCA cases (Table 1). The proportion of those who received hydration increased from 6.4% in 2014 to 25.3% in 2019 because a multi-tiered response (MTR) protocol was started with a pilot study in 2013 and has been implemented nationwide since 2015 [34]. The implementation of the MTR protocol has been accompanied by education on procedures, which was mandatory for EMS providers, including IV hydration and airway management. The prehospital procedure affects STI, and in this study, we found a median of a 2 min delay of departure of the ambulance from the scene in the hydration group. The optimal STI in TCA is still controversial, but the AOR of the hydration group on survival to discharge may allude to the fact that prehospital hydration is required, even though it delays transportation to the hospital from the scene. In case of poor peripheral condition because of extremity fractures or collapsed venous vessels, a maximum of 2 min of additional IV hydration attempts on the scene can be acceptable according to this study.

The effect of shockable rhythm as a good prognostic factor in OHCA of all causes was observed again in our study. Unlike prehospital hydration, initial shockable rhythm was associated with higher outcomes in both survival to discharge and good neurological status. However, the effect of initial shockable rhythm in TCA needs further discussion because it is difficult to distinguish true TCA from a case of major trauma followed by medical cardiac arrest. For example, if the driver collapsed while driving because of acute coronary syndrome, the resulting diagnosis will be major trauma caused by road traffic injury. In-depth surveys, such as injury severity score and evaluation of first injury severity by EMS providers on the scene, must be reviewed together to confirm true TCA. In the interaction analysis, prehospital hydration was not associated with better outcomes in shockable rhythm. This implies that early transportation is recommended for patients with initial shockable rhythm, rather than spending time on the scene in the prehospital phase. Further research must be followed by randomized control trials to determine the effect of prehospital hydration in patients with TCA with shockable rhythm.

This study had some limitations. First, patient data from 2020 to 2022 were not included because during this period, prehospital EMS protocol was affected by the coronavirus disease pandemic, and inclusion of this data may have introduced a bias. Second, the prehospital hydration amount was not fully recorded in many cases; although it was recorded in the EMS run sheet, it was not easy to record CPR situations exactly on the scene while performing high-quality CPR. Furthermore, the EMS run sheet was routinely recorded after the transport is over. A possible recall bias could have been incorporated by the EMS providers in recording exact prehospital hydration amounts, which in turn could have affected the outcomes. Third, this nationwide OHCA registry does not specify trauma information and therefore lacks information on injury severity scores. Further research must include the injury severity score as a potential confounder in association analyses. Fourth, data on post-arrest care and in-hospital treatment, such as hemodynamic support, emergency operation, angio-intervention and targeted temperature management, is missing; these interventions might have affected the outcomes. Fifth, the traumatic etiology (*e.g.*, hypovolemia, hypoxia, tension pneumothorax and cardiac tamponade), which caused TCA, was not clear in this database. Further research requires association analysis according to specified populations. Sixth, this study setting involved a nationally operated EMS by the National Fire Agency of Korea. CPR protocols and available medications at the prehospital stage were different compared to those of other countries, as these are determined according to the local EMS act. The difference in the EMS environment along with that of other resources can limit the generalizability of our findings.

5. Conclusions

The interaction analysis between prehospital hydration and initial cardiac rhythm revealed that prehospital hydration was effective in improving the survival to discharge outcome in patients with TCA with non-shockable rhythm. Prehospital hydration was not associated with better survival to discharge in patients with shockable rhythm and good neurological status at discharge, regardless of the initial cardiac rhythm. Therefore, prehospital hydration is recommended for patients with TCA with non-shockable rhythm before transport from the scene. For those with shockable rhythm, early transportation is recommended.

ABBREVIATIONS

OHCA, Out-of-hospital cardiac arrest; TCA, Traumatic cardiac arrest; IV, Intravenous; EMS, Emergency medical services; CPR, Cardiopulmonary resuscitation; ED, Emergency department; RTI, Response time interval; STI, Scene time interval; TTI, Transport time interval; ROSC, Return of spontaneous circulation; SD, Standard deviation; IQR, Interquartile range; AOR, Adjusted odds ratio; CI, Confidence interval; MTR, Multi-tiered response.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

DKK, YSR and SDS—designed the research study. DKK and KJH—performed the formal analysis and wrote the manuscript. KJS and JJ—performed the data curation, validation and methodology. SDS and YSR—were responsible for the project administration. All of the authors contributed to editorial changes in the manuscript and read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Seoul National University Hospital Institutional Review Board with a waiver of informed patient consent (IRB No. 1103-153-357).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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