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ORIGINAL RESEARCH

Effect of age on the interaction between heart rate and mortality in prehospital trauma care

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Abstract

Objectives: The association between tachycardia and age in prehospital trauma mortality has not been thoroughly studied. The purpose of this study was to evaluate the interaction effects of age between prehospital tachycardia and mortality in adult trauma patients.

Methods: Adult trauma patients during 2012, 2013, and 2015 who were treated and transported by emergency medical services (EMS) were analyzed. Main exposure was tachycardia (>90 beat/min) measured at the scene. The primary outcome was mortality, the secondary outcome was worsened disability. Multivariable logistic regression with interaction models between tachycardia and age was used to calculate the adjusted odds ratio (AOR) with 95% confidence intervals after adjusting for confounders.

Results: A total of 35,542 patients were analyzed. Tachycardia had a significant association with mortality and worsened disability: 1.41 (1.28–1.54) for mortality and 1.25 (1.15–1.36) for worsened disability. In the interaction analysis, the AOR for mortality by tachycardia in age over 84 years was insignificant: 1.2 (1.11–1.3) for 15–64 years, 1.4 (1.29–1.52) for 65–84 years, 1.14 (0.92–1.42) for age over 85 years, respectively ($p < 0.01$ for interactions).

Conclusion: Tachycardia had a significant association with mortality and worsened disability in prehospital trauma patients and age over 85 years old had a significantly different interaction effect. Prehospital trauma care protocol should include recognizing severe cases based on the patient's heart rate and age. It would be helpful in the decision-making at the scene such as trauma center transfer and advanced treatment.

Keywords

Major trauma; Prehospital vital sign; Tachycardia; Mortality

1. Introduction

Trauma is major public health issue, and burden of disease is tremendous [1, 2]. Victims suffer from a significant economic burden, especially in severe traumatic injuries [3]. Prehospital emergency medical system providers play important roles in the early phase of trauma management to evaluate the severity and need for specialized trauma care [4]. Many trauma severity evaluation tools have been developed and validated to assess more severely injured patients [5, 6].

Prior studies assessed prehospital vital signs to predict trauma severity and possibilities of deterioration [7, 8]. The Shock Index and Reverse Shock Index have been fully evaluated for their predictive performance in many clinical settings [9, 10]. Heart rate variability also demonstrated higher predictive power toward mortality based on 120 million integer data [11]. Heart rate has been also used with other predictors such as pulse pressure to demonstrate trauma patient status or anticipate advanced management [12]. But accurate measurement of parameters such as blood pressure or heart rate variability have been known to be difficult in ambulance [13, 14].

Tachycardia is considered an important early sign of shock in trauma [15]. An association with mortality has been found [16], and some studies demonstrated low performance as an indicator of the need for interventions or severity predictor [17, 18]. It is related to cardiovascular responsive capacity and predominantly depends on patient organ function, comorbidity, and medications [19–21]. As a physiologic parameter of autonomic compensation, tachycardia is well known for various degree according to patient age [22]. Previous studies have attempted to elucidate better indicators considering age, such as Age Shock Index [23]. However, the relationship between age and tachycardia in trauma patients has not been fully studied. We assumed that prehospital tachycardia has different associations with mortality by patient age in trauma. The purpose of this study was to evaluate the interaction effects of age between prehospital tachycardia and mortality in trauma patients who were treated and transported by emergency medical services providers.

2. Materials and methods

2.1 Study design and setting

The Korea Central Fire Services operates the prehospital emergency medical system (EMS) exclusively for trauma care and regional fire headquarters manages the system in each 17 provinces. Emergency medical service providers performed basic to intermediate levels of services. Basic procedures including oxygen supplement from nasal cannula to back-valve masks, spinal immobilization, splints, and wound care can be conducted based on standing orders. Korean emergency medical technicians (EMTs) are divided into level 1 (equivalent to EMS-Intermediate) and level 2 (equivalent to EMS-Basic). Level 1 EMTs can provide intravenous fluid administration for hypotensive patient and advanced life support for traumatic cardiac arrest including endotracheal intubation under direct medical control [24].

Korean EMS operates ground ambulance response systems in most cities and helicopter EMS can be activated in some rural areas. All trauma patients are transported to nearby emergency departments (EDs), which are categorized as level 1, 2 and 3. Level 1 or 2 EDs can provide definite care including surgery and embolization followed by critical care in intensive care units. Level 1 EDs operates emergency board physicians 24/7. Level 3 EDs can provide appropriate care by general physicians. There are about 30 Level 1 EDs, 120 Level 2 EDs, and 300 Level 3 EDs. Level 1 trauma centers are designated separately for each province, but most overlap with Level 1 ED. Trauma centers require independent facilities and trauma team. The designation varies according to annual performance and quality evaluations conducted by the Ministry of Health and Welfare.

In 2012, Korea Prehospital Trauma Triage and Scheme (KPTTS), which has 4 triage categories modified from the U.S. CDC's triage guidelines, was implemented for prehospital protocol for destination hospitals [25, 26]. For severe trauma cases recognized by EMS personnel, the protocol encourages transport to level 1 or 2 EDs or level 1 trauma centers. Regional level 1 trauma centers covered by emergency physicians or trauma surgeons should provide a specialized trauma team, independent operating rooms, and trauma intensive care units from general ED space. The Korean government has designated regional level 1 trauma center in each province. A total of 13 institutions were designated from five institutions from 2012 to 2015.

2.2 Data source

This multicenter cross-sectional observational study was conducted using the Korean Emergency Medical Services-Severe Trauma Registry (EMS-STR) database. It was constructed in 2012 through a collaboration between the Korean Central Fire Service and the Korean CDC. Three data resources including EMS run sheets, the EMS trauma registry, and the hospital trauma record review registry were merged to construct the EMS-STR. All EMS-transported traumatic injuries were screened and severe trauma cases were selected according to KTPPS criteria. EMS run sheets and the EMS trauma registry were recorded by EMS providers after transport. The EMS run sheet includes demographic findings, EMS operational variables, time elapse variables, destination hospital levels, and transport-related information for all trauma patients. EMS providers fill out the EMS trauma registry, which includes in-depth information such as clinical findings and prehospital procedures, for patients with positive KTPPS criteria [26]. A hospital trauma record review was conducted by professional medical record reviewers hired by the Korea CDC. They collected clinical information about patient status, procedures, and outcomes from hospital medical records by visiting the hospitals where EMS providers transport patients. A medical record review was conducted in 6 provinces in 2012 and 10 in 2013, and all of the provinces were surveyed in 2015.

The data quality managed by the committee consisted of epidemiologists, biostatistics experts, emergency medicine physicians, and trauma surgeons. It holds monthly meetings for education and feedback to medical record reviewers.

2.3 Study population

Adult severe trauma patients who were treated and transported by EMS from 2012 to 2015 were screened. Since the surveillance was not conducted in any area in 2014, data for 3 years were enrolled. Prehospital cardiac arrest cases, transfer cases, and patients without heart rate data or hospital outcomes were excluded.

2.4 Data variables

The main exposure was tachycardia, and the interaction variable was age. We defined tachycardia as the heart rate measured by pulse oximetry or electrocardiogram monitor by EMS providers higher than 90 beats per minute, which was frequently used for the Shock Index cut-off value [27]. The Korean EMS trauma standard operation protocol recommend measuring vital signs at least 3 times during EMS transport, immediately after encountering the patient, during ambulance transport, and at the time of ED arrival. We used the first recorded heart rate if multiple measurement was conducted.

We selected confounders including age, sex, Charlson Comorbidity Index, residential area, mechanism of injury, Injury Severity Score (ISS), mental status, shock status in the field, and alcohol consumption status. Age was categorized into 3 groups: 15–64 years, 65–84 years, and over 85 years. We categorized the Charlson Comorbidity Index into 3 groups: two or more according to the number of comorbidities as the high-risk group [28, 29], one or none. The mechanisms of injury were traffic accidents, falls, other blunt force trauma, other penetrations, and other mechanisms. Injury severity was categorized into 2 groups: severe (ISS 16 or higher) and not severe (ISS 1–15) [30]. We divided prehospital shock status and mental status into 2 groups: based on systolic blood pressure measured with the heart rate simultaneously by EMS providers, shock status was defined as less than 90 mmHg, and mental status which was not alert on AVPU scale (alert, response to verbal stimulation, response to pain, and unresponsiveness) was defined as altered mental status. Hospital management and clinical outcome data included surgery under general anesthesia, transfusion in the first 24 hours, emergent embolization for traumatic bleeding, discharge from ED, admission to the intensive care unit, disability, and mortality. The Glasgow Outcome Scale (GOS) was used to measure disability including death, vegetative status, severe disability, moderate disability, and good recovery [31]. It was retrospectively measured from medical records before the time of injury and at the time of discharge.

2.5 Outcomes measures

The primary outcome was hospital mortality includes ED death or death after hospitalization. Secondary outcome was worsened disability, which was used to assess the impact of current trauma on a patient's disability in a previous study [32]. It was defined as a 2-point decline in the Glasgow Outcome Scale (GOS) score between discharge and the time before injury. The tertiary outcome was intensive care unit (ICU) admission from ED. All of the outcomes were identified by medical record reviews.

2.6 Statistical analysis

A descriptive analysis was conducted to compare the distribution of risk factors between main exposure and interaction variables. Chi-squared tests for categorical variables and Wilcoxon's rank sum tests for continuous variables were used.

To evaluate the association between tachycardia and mortality, a multivariable logistic regression analysis was conducted before and after adjusting for multiple confounders. The confounders included age, gender, Charlson Comorbidity Index, residential area, mechanism of trauma, Injury Severity Score, prehospital shock status, prehospital altered mentality, and alcohol consumption status. The adjusted odds ratios (AOR) with 95% confidence intervals (95% CIs) were calculated to measure the effects of tachycardia and age. To compare the effect size of tachycardia according to age, we conducted an interaction analysis using interaction terms (tachycardia*age) added to the multivariable logistic regression model.

Additional sensitivity analyses were conducted for specific study participants. We divided entire cohort according to shock status and ISS score greater than or equal to 16, which was used to define severe trauma. Multivariable logistic regression was conducted for the association between tachycardia and outcomes adjusted for confounders in the main analysis. An interaction analysis with same model in the main analysis for subgroups was used to evaluate the interactive association between tachycardia and age for outcomes.

2.7 Ethical statements

This study complied with the Declaration of Helsinki, and its protocol was approved by the Seoul National University Hospital's Institutional Review Board with a waiver for informed consent (IRB No. H-1206-024-412).

3. Results

3.1 Demographic findings

A total of 81,910 trauma patients were treated and transported by EMS in the study period. After excluding 7561 pediatrics, 8721 prehospital cardiac arrests, 6732 who lacked heart rate values, and 23,354 who were transferred to other hospitals or lacked clinical outcomes, 35,542 patients were analyzed (Fig. 1). The tachycardia group demonstrated higher mortality than the non-tachycardia group (11.5% vs 6.6%) and also showed higher worsened disability (15.3% vs 9.9%) and ICU admission rates (26.1% vs 19.7%), respectively (all p values $<$ 0.01). The tachycardia group was more likely to be male, under 65 years old, involve alcohol consumption, and have higher ISS and altered mental status. Unlike transfusion, surgery was more likely to occur in the non-tachycardia group (Table 1).

Age over 85 years group demonstrated higher mortality than the other groups (19.7% vs 15.6% vs 6%) and higher worsened disability (24.7% vs 20.4% vs 9.1%), respectively (all p values $<$ 0.01). The ICU admission rate was similar between the age over 85 years and 65–84 years groups. There was no specific pattern of tachycardia proportion according to aging. The age over 85 years group was more likely to be female and injured by falling. Low blood pressure and higher Charlson Comorbidity Index values were found in the age over 85 years group (Table 2).

3.2 Main analysis and subgroup analysis

The multivariable logistic regression analysis showed significant associations between tachycardia and mortality; AOR (95% CIs) for tachycardia was 1.41 (1.28–1.54). For worsened disability and ICU admission, the AORs and 95% CIs were 1.25 (1.15–1.36) and 1.04 (0.97–1.12), respectively (Table 3). C statistics for discrimination of the final models were calculated: 0.903 for mortality, 0.895 for worsened disability, and 0.890 for ICU admission. Hosmer and Lemeshow Goodness-of-Fit Test were conducted to evaluate calibration and found that p-value were under 0.01 for all final models.

The same statistical model was used for tachycardia with interaction terms (age group), AORs, and 95% CIs for mortality were 1.2 (1.11–1.3) for the 15–64 years group, 1.4 (1.29–1.52) for the 65–84 years group, and 1.14 (0.92–1.42) for the age over 85 years group (p for interaction $<$0.01). For worsened disability, similar results were found: 1.16 (1.07–1.24) for the 15–64 years group, 1.38 (1.28–1.48) for the 65–84 years group, and 1.1 (0.9–1.35) for the age over 85 years group. No significant interaction effect was found in ICU admissions (Table 4).

3.3 Sensitivity analysis

We conducted a sensitivity analysis for mortality according to the patients' initial shock status. The same multivariable logistic regression analysis with interaction terms was used for each subpopulation. For the prehospital shock cohort, AORs and 95% CIs for mortality were 1.29 (1.02–1.62) for the 15–64 years group, 1.26 (1–1.6) for the 65–84 years group, and 1.56 (0.82–2.95) for the age over 85 years group. For the prehospital

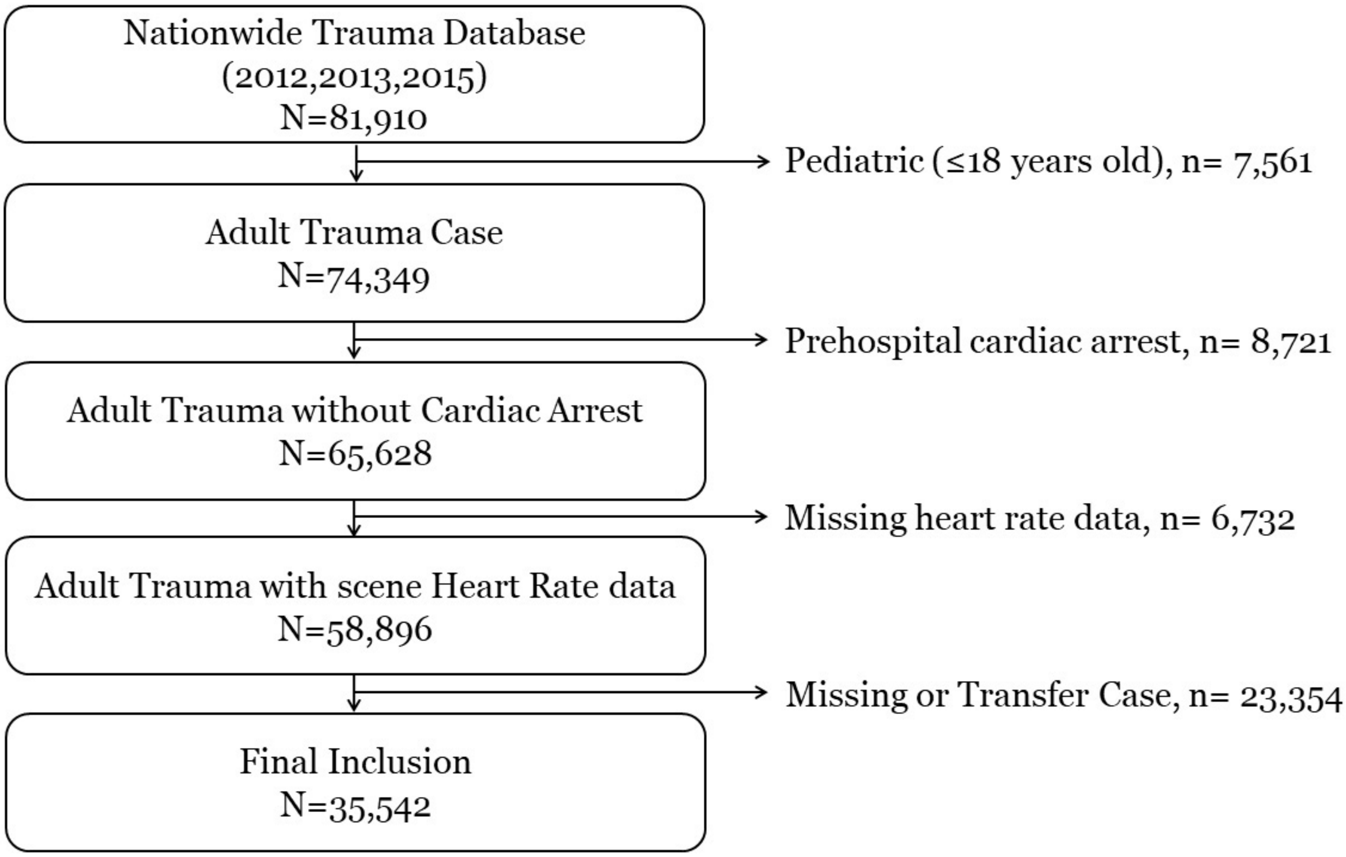

FIGURE 1. Patient flow.

non-shock cohort, AORs and 95% CIs for mortality were 1.21 (1.12–1.32) for the 15–64 years group, 1.4 (1.29–1.53) for the 65–84 years group, and 1.17 (0.93–1.46) for the age over 85 years group (p for interaction <0.01) (Table 5).

4. Discussion

We found a significant association between tachycardia with a heart rate over 90 beats per minute measured at the trauma scene and mortality in EMS-treated adult trauma patients. Associations with worsened disability were also demonstrated. Age over 85 years old had a significant negative interaction effect with tachycardia in mortality and worsened disability.

In trauma research, tachycardia has been known as predictor of early signs of shock. For the past decade, a normal heart rate was considered to have no association with significant blood loss, even in advanced trauma life support (ATLS). But tachycardia alone is not usually used in prehospital trauma patient evaluations. Numerous factors including the circulating blood volume, pain, autonomic response, prescribed drugs, and reflex control can determine whether or not tachycardia occurs at the trauma scene. More advanced indexes for evaluating trauma patients have been developed combining other physiological parameters such as the Shock Index or heart rate variability. Although the Shock Index is usually considered a good predictor of mortality or the need for intervention in many studies [33, 34], blood pressure is not enough to adjust the effect of tachycardia when evaluating patients. Victorino demonstrated poor correlation between tachycardia and hypotension in trauma in a clinical study [17]. More complicated methods of adjusting surrogate marker such as serial measurement of Shock Index or Reverse Shock Index have also been attempted [35, 36]. Heart rate variability has been known for its high performance in predicting mortality or the need for intervention, demonstrating that transportable monitors are needed in prehospital settings [37]. But the noise and shake of the ambulance limits non-invasive blood pressure or accurate measurement of complex parameters [13]. Heart rate measurement is relatively simple and reliable which can improve the EMS field patient-assess protocol. Autonomic control is essential for critical patients. Differences in the Cardiac Index during hemodialysis were demonstrated as potent predictors of cardiovascular outcomes in a small-sized cohort [38]. In geriatrics, autonomic response can be insufficient in major stimulation such as general anesthesia [39], which can cause discrepancies between vital signs and trauma severity. Shibahashi conducted a retrospective cohort study that indicated poor performance for predicting mortality in an older cohort using the Shock Index [40]. The mechanism of how age-associated changes, which includes reduction of autonomic sensitivity and mechanisms intrinsic to pacemaker cells, were also studied [41] that could explained the discrepancy of cardiac responses. Negative chronotropic medications such as beta blockers, which are mostly prescribed to older patients, can affect this association and lead to poor outcomes [42].

In our study, trauma scene tachycardia had significant associations with clinical outcomes including mortality and wors-

TABLE 1. Demographics of the study population according to tachycardia.

Variable	Total	Non-tachycardia	Tachycardia	
	N (%)	N (%)	N (%)	*p*-value
Total	35142 (100)	23298 (66.3)	11844 (33.7)	
Age group, year				<0.01
15–64	27258 (77.6)	17668 (75.8)	9590 (81)	
65–84	7093 (20.2)	5087 (21.8)	2006 (16.9)	
>84	791 (2.3)	543 (2.3)	248 (2.1)	
Gender, male	22365 (63.6)	14566 (62.5)	7799 (65.8)	<0.01
Charlson's comorbidity index				<0.01
0	30711 (87.4)	20402 (87.6)	10309 (87.0)	
1	3547 (10.1)	2357 (10.1)	1190 (10.0)	
2-	884 (2.5)	539 (2.3)	345 (2.9)	
Residential area, metropolitan	13830 (39.4)	8901 (38.2)	4929 (41.6)	<0.01
EMS data assessed				
Mechanism				<0.01
Traffic accident	19991 (56.9)	13545 (58.1)	6446 (54.4)	
Fall	10973 (31.2)	7368 (31.6)	3605 (30.4)	
Blunt	2172 (6.2)	1235 (5.3)	937 (7.9)	
Penetrating	1437 (4.1)	770 (3.3)	667 (5.6)	
Other	569 (1.6)	380 (1.6)	189 (1.6)	
Injury severity score				<0.01
<16	30941 (88.0)	20978 (90.0)	9963 (84.1)	
16~	4201 (12.0)	2320 (10.0)	1881 (15.9)	
Shock status	3048 (8.7)	1751 (7.5)	1297 (11.0)	<0.01
Altered mental status	15353 (43.7)	9513 (40.8)	5840 (49.3)	<0.01
Alcohol consumption	7708 (21.9)	4890 (21.0)	2818 (23.8)	<0.01
Hospital data				
Operation	28366 (80.7)	19263 (82.7)	9103 (76.9)	<0.01
Transfusion	3594 (10.2)	1879 (8.1)	1715 (14.5)	<0.01
Embolization	131 (0.4)	63 (0.3)	68 (0.6)	<0.01
Outcome data				
Mortality	2900 (8.3)	1542 (6.6)	1358 (11.5)	<0.01
Worsened disability	4125 (11.7)	2308 (9.9)	1817 (15.3)	<0.01
ICU admission	7693 (21.9)	4597 (19.7)	3096 (26.1)	<0.01

EMS, emergency medical service; ICU, intensive care unit.
p-values of the chi-squared test were all under 0.01.

ened disability after adjusting for multiple confounders. ICU admission may have differed since patients who survived until hospital admission were included. Age group categorization was conducted considering deterioration of cardiac-autonomic compensation, even without clear reference values in previous studies. In patients over 85, the effect size on the association between tachycardia and clinical outcomes was insignificant. It may have been caused by weakened autonomic compensation, and several factors may have included prescribed medication, comorbidities, or injured anatomic lesions. In contrast, the effect size was lower in the 15–64 years group, which was explained by sufficient circulating blood volume compensating for hypovolemia. These findings were consistent in the additional sensitivity analysis. We tested interactive associations between tachycardia and age for the subgroup population with or without prehospital shock status. The interaction effect was significant and showed significantly different effect sizes for the age over 85 years group.

In prehospital trauma research, single physiological parameters have not been fully elucidated, primarily depending on the significance of performance. Time is critical for patient outcomes, and advanced procedures or intensive monitoring

TABLE 2. Demographics of the study population according to the age groups.

	Total	15–64 years	65–84 years	>85 years	
	N (%)	N (%)	N (%)	N (%)	*p*-value
Total	35142 (100)	27258 (77.6)	7093 (20.2)	791 (2.3)	
Gender, male	22365 (63.6)	18031 (66.1)	4036 (56.9)	298 (37.7)	<0.01
Charlson's comorbidity index					<0.01
0	30711 (87.4)	25053 (91.9)	5145 (72.5)	513 (64.9)	
1	3547 (10.1)	1744 (6.4)	1583 (22.3)	220 (27.8)	
2-	884 (2.5)	461 (1.7)	365 (5.1)	58 (7.3)	
Residential area, metropolitan	13830 (39.4)	11089 (40.7)	2437 (34.4)	304 (38.4)	<0.01
EMS data assessed					
Mechanism					<0.01
Traffic accident	19991 (56.9)	16010 (58.7)	3767 (53.1)	214 (27.1)	
Fall	10973 (31.2)	7542 (27.7)	2899 (40.9)	532 (67.3)	
Blunt	2172 (6.2)	1939 (7.1)	207 (2.9)	26 (3.3)	
Penetrating	1437 (4.1)	1276 (4.7)	144 (2.0)	17 (2.1)	
Other	569 (1.6)	491 (1.8)	76 (1.1)	2 (0.3)	
Injury severity score					<0.01
<16	30941 (88.0)	24246 (89.0)	6006 (84.7)	689 (87.1)	
16∼	4201 (12.0)	3012 (11.0)	1087 (15.3)	102 (12.9)	
Tachycardia	11844 (33.7)	9590 (35.2)	2006 (28.3)	248 (31.4)	<0.01
Shock status	3048 (8.7)	2300 (8.4)	648 (9.1)	100 (12.6)	<0.01
Altered mental status	15353 (43.7)	11778 (43.2)	3202 (45.1)	373 (47.2)	<0.01
Alcohol consumption	7708 (21.9)	6741 (24.7)	950 (13.4)	17 (2.1)	<0.01
Hospital data					
Operation	28366 (80.7)	21941 (80.5)	5730 (80.8)	695 (87.9)	<0.01
Transfusion	3594 (10.2)	2582 (9.5)	922 (13.0)	90 (11.4)	<0.01
Embolization	131 (0.4)	96 (0.4)	33 (0.5)	2 (0.3)	0.34
Outcome data					
Mortality	2900 (8.3)	1638 (6.0)	1106 (15.6)	156 (19.7)	<0.01
Worsened disability	4125 (11.7)	2482 (9.1)	1448 (20.4)	195 (24.7)	<0.01
ICU admission	7693 (21.9)	5545 (20.3)	1930 (27.2)	218 (27.6)	<0.01

EMS, emergency medical service; ICU, intensive care unit.
p-values of the Kruskal-Wallis test for all discrete variables were under 0.01.

are limited based on EMS levels in prehospital trauma care [43, 44]. Evaluating patient severity using one simple parameter can be more practical in noisy and imminent prehospital environments. Blood pressure is often limited to use with heart rate since non-invasive methods can be inaccurate and require a lengthy confirmation time. Measurement may fail if patient cooperation is insufficient due to pain, alcohol consumption, or traumatic head injury. Heart rate is generally easier and faster to measure even using portable pulse oximetry. It also can be monitored continuously during management and EMS transport compared to blood pressure measurement.

Prehospital trauma evaluation is fundamentally important for patient survival and neurologic outcomes. There is no universal standard prehospital triage tool for trauma using only simple and reliable parameters such as heart rate and age. The results of this study can be applied to EMS from basic to advanced levels around the world. Our study suggests that EMS providers should pay attention to progression during transport in geriatrics, even without tachycardia at the trauma scene. Education and training to monitor tachycardia status through intravenous access in certain age groups are also important. Further research on the impact of EMS protocol changes including proper interventions for tachycardia or old age is necessary.

This study has several limitations. Database was constructed based on severe trauma according to KTPPS criteria, and patients recognized as minor injuries in the field were not included. We excluded pediatrics, prehospital cardiac arrest, and unknown main exposure and outcomes. Our study's exclusion criteria could also have influenced the final results

TABLE 3. Multivariable logistic regression analysis for clinical tachycardia outcomes.

	Outcomes	Crude OR (95% CIs)	Adjusted OR (95% CIs)
	n/N (%)		
Mortality			
Total	2900/35142 (8.3)		
Non-tachycardia	1542/23298 (6.6)	1.00	1.00
Tachycardia	1358/11844 (11.5)	1.83 (1.69–1.97)*	1.41 (1.28–1.54)*
Worsened disability			
Total	4125/35142 (11.7)		
Non-tachycardia	2308/23298 (9.9)	1.00	1.00
Tachycardia	1817/11844 (15.3)	1.65 (1.54–1.76)*	1.25 (1.15–1.36)*
ICU admission			
Total	7693/35142 (21.9)		
Non-tachycardia	4597/23298 (19.7)	1.00	1.00
Tachycardia	3096/11844 (26.1)	1.44 (1.37–1.52)*	1.04 (0.97–1.12)

OR, odds ratio; CI, confidence interval; ICU, intensive care unit.
**p-value of model is under 0.05.*
Age groups, gender, Charlson comorbidity index, residential area, mechanism of injury, injury severity score, prehospital shock status, prehospital altered mentality and alcohol consumption status were adjusted in multivariable logistic regression model.

TABLE 4. Multivariable logistic regression analysis with interaction term between tachycardia and age.

	Mortality		Worsened disability		ICU admission	
	n (%)	aOR (95% CIs)	n (%)	aOR (95% CIs)	n (%)	aOR (95% CIs)
Age <65 years old						
Non-tachycardia (N = 17831)	900 (5.0)	1.00	1350 (7.6)	1.00	3215 (18.0)	1.00
Tachycardia (N = 9686)	854 (8.8)	1.20 (1.11–1.30)*	1132 (11.8)	1.16 (1.07–1.24)*	2411 (24.9)	1.0 (0.93–1.08)
Age between 65 and 84 years old						
Non-tachycardia (N = 5175)	660 (12.8)	1.00	835 (16.4)	1.00	1322 (25.5)	1.00
Tachycardia (N = 2047)	520 (25.4)	1.40 (1.29–1.52)*	613 (30.6)	1.38 (1.28–1.48)*	655 (32.0)	0.99 (0.82–1.07)
Age over 85 years old						
Non-tachycardia (N = 548)	97 (17.7)	1.00	123 (22.7)	1.00	148 (27.0)	1.00
Tachycardia (N = 255)	67 (26.3)	1.14 (0.92–1.42)	72 (29.0)	1.10 (0.90–1.35)	77 (30.2)	0.98 (0.80–1.21)

aOR, adjusted odds ratio; CI, confidence interval; ICU, intensive care unit.
*Age groups, gender, Charlson comorbidity index, residential area, mechanism of injury, injury severity score, prehospital shock status, prehospital altered mentality, alcohol consumption status and interaction term (tachycardia*age groups) were adjusted in the model.*
**p-value of model is under 0.05.*

of the analysis.

The heart rate measurement was conducted by EMS personnel (basic to intermediate level EMTs) using different measurement devices, so any measurement bias could not be fully corrected. Heart rates can fluctuate even during measurement, which makes it impossible to consistently record the correct rates. Since EMS personnel can confirm the sufficient shape of pulse waves using portable monitors, we assume that the measurement bias was minimal. Portable monitoring devices for transcutaneous measurement in this study were recommended by the Korea Food and Drug Agency (FDA) for reliability and validity. Accuracy of heart rate could be impaired in patients with arrhythmia or pacemaker, which is more frequent in elderly, especially. Although this study was conducted based on actually measured heart rate data, this could be a significant limitation.

Also, we used 90 beats per minute as a reference value, which itself overestimated 89.5% of survived patients and underestimated 6.6% of mortality. Nevertheless, combining a simple and reliable physiological parameter with other variables can advance the prehospital trauma evaluation by EMS providers.

As previously described, further studies with prescribed medications or detailed diagnostic information might demon-

TABLE 5. Sensitivity analysis for prehospital shock status, interaction analysis between tachycardia and age in mortality.

	Prehospital shock cohort		Prehospital non-shock cohort	
	n (%)	aOR (95% CIs)	n (%)	aOR (95% CIs)
Age <65 years old				
Non-tachycardia (N = 1295)	163 (12.6)	1.00	737 (4.5)	1.00
Tachycardia (N = 1043)	218 (20.9)	1.29 (1.02–1.62)*	636 (7.4)	1.21 (1.12–1.32)*
Age between 65 and 84 years old				
Non-tachycardia (N = 427)	98 (23.0)	1.00	562 (11.8)	1.00
Tachycardia (N = 245)	87 (35.5)	1.26 (0.99–1.60)	433 (24.0)	1.40 (1.29–1.53)*
Age over 85 years old				
Non-tachycardia (N = 64)	11 (17.2)	1.00	86 (17.8)	1.00
Tachycardia (N = 36)	9 (25.0)	1.56 (0.82–2.95)	58 (26.5)	1.17 (0.93–1.46)

aOR, adjusted odds ratio; CI, confidence interval.
*Age groups, gender, Charlson comorbidity index, residential area, mechanism of injury, injury severity score, prehospital shock status, prehospital altered mentality, alcohol consumption status and interaction term (tachycardia * age groups) were adjusted in the model.*
**p-value of model is under 0.05.*

strate different results. Our database has limited information on prescribed medications affecting autonomic compensation. Considering aspects of EMS personnel at the trauma scene, assessing prescribed medications was not unavailable. Predicting diagnoses was also improper to practically apply to prehospital protocols.

The hospital care and outcome data were measured by a trained medical record reviewer. Although data quality management was conducted regularly and rigorously, and the simulation tests assessing the reliability and validity showed no measurement bias, the medical record reviewers may have caused differences in measurements, especially GOS.

Korea has an intermediate EMS level. The protocols recommend transporting patients to the hospital as quickly as possible and do not encourage intensive care in the field. The results of our study may not be generalizable for countries with different EMS prehospital trauma protocols.

5. Conclusions

Tachycardia over 90 beats per minute, measured in the field, had a significant association with mortality and worsened disability in prehospital trauma patients. This findings could not be applied to people over 85 years old. Prehospital trauma care protocol recognizing severe cases based on the patient's heart rate and age should be considered. EMS providers will be able to make more precise decisions about destinating hospital or advanced procedures.

AUTHOR CONTRIBUTIONS

KJS, SDS designed the research study. KHK, KJH, JJ, JHP performed the research. YSR analyzed the data. KHK, KJS wrote and revised the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study complied with the Declaration of Helsinki, and its protocol was approved by the Seoul National University Hospital's Institutional Review Board with a waiver for informed consent (IRB No. H-1206-024-412).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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