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Research Article

Association between Disparity by Gini Coefficient for the Population Covered by Emergency Medical Service Rapid Response and Neurological Outcomes in Patients with Out-of-Hospital Cardiac Arrest in Japan

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Abstract

Background: Many studies have been conducted on return of spontaneous circulation (ROSC) from out-of-hospital cardiac arrest (OHCA). However, few studies have been conducted on the relation between ROSC from OHCA and the disparity by the Gini coefficient for the population covered by emergency medical service (EMS) rapid response. Gini coefficient is generally used as an indicator of disparity. This study aimed to assess the neurological and survival outcomes at 30 days of OHCA using the Gini coefficient.

Methods: This was a retrospective cohort study using the database from the All-Japan Utstein Registry of the Fire and Disaster Management Agency between 2015 and 2019. The Gini coefficient for the population covered by EMS rapid response was calculated with three-minute simulated driving on a map in each prefecture. The primary outcome was favourable neurological outcomes at 30 days.

Results: A total of 7,890 patients in the prefectures who had an initial shockable heart rhythm with cardiac origin and witnessed by bystanders were included. The Gini coefficient was associated with favourable neurological outcomes, a cerebral performance category score of 1 (good cerebral performance) or 2 (moderate cerebral disability) at 30 days, with an adjusted odds ratio of 0.378 (95% confidence interval: 0.129–0.650, p < 0.01). **Conclusion:** The Gini coefficient in prefectures affects the favourable neurological outcome at 30 days in patients with OHCA. Therefore, the Gini coefficient should be focused on to achieve better outcomes and corrective action should be required for the disparity, keeping chest compression and automated external defibrillator implementation.

Keywords: Cardiac Arrest; Gini Coefficient; Neurological Outcome; Survival Rate, Disparity of EMS Service

Introduction

Resuscitation for cardiac arrest has been reported to present favourable neurological outcomes and survival for patients with out-of-hospital cardiac arrest (OHCA) [1-4]. It is natural that most people want to live their life as it was before cardiac arrest. Because nobody knows when and where cardiac arrest occurs, the use of automated external defibrillators (AEDs) by non-medical people for patients with OHCA has been admitted since July 2004 in Japan. This contributes to the right to have equal access to fast medical treatment and becomes one of the major factors for resuscitation with chest compression [5,6]. Japanese emergency medical services (EMS) contribute to return of spontaneous circulation (ROSC) from OHCA. The first responders who provide basic life support within their vicinities have been trained by EMS, and their number has increased [7]. Moreover, the Japanese EMS system has conducted telephone-cardiopulmonary resuscitation (CPR) in all of Japan. When a fire dispatch centre receives an emergency call for cardiac arrest, if the caller does not know how to conduct CPR, the dispatcher verbally instructs callers on how to perform CPR before the arrival of the public emergency service on the scene. The telephone-CPR has shown 1-month survival with favourable neurological outcomes [8]. The discharge rate from OHCA has increased from 6.9% in 2010 to 7.5% in 2020 [9], which is higher than that of previous years, due to all efforts for cardiac arrest. To the best of our knowledge, no information is available on how the disparity in emergency medical services (EMS) provided to resident's influences the resuscitation rate. However, many studies have been conducted on resuscitation for OHCA to achieve better outcomes. Some of the factors studied include the effect of AEDs, CPR [10-12], and response time by EMS [13]. However, the survival rate still has room to increase. We hypothesize that the disparity in EMS rapid response in large prefectures with more than 5,000,000 population is one of the factors affecting outcomes for patients with OHCA. If the disparity exists in prefectures, the correction of the disparity might produce better outcomes. Therefore, this study calculated the Gini coefficient drawn from geographical EMS access and national databases. Then, the aim was to com-pare favourable neurological outcomes at 30 days and survival rates at 30 days using the Gini coefficient.

Materials and Methods

This was a retrospective cohort study. The data were obtained from the All-Japan Utstein Registry of the Fire and Disaster Management Agency, which is a prospective population-based registry of OHCA based on the standardized Utstein Style [14-16]. The data included patients' age, sex, type of bystander with witness status, initial cardiac rhythm, conduction of basic life support (chest compression and AEDs), advanced life support (airway management with medical equipment and epinephrine), time record for the cardiac event and intervention, and response time from EMS activation to patient arrival. Additionally, the data obtained included cardiac or non-cardiac, ROSC, 30-day survival, and cooperative patient classification. These data were collected between January 1, 2015, and December 31, 2019 because COVID-19 pandemic might influence the data as a bias. Initial shockable cardiac rhythm was defined as ventricular fibrillation or pulseless ventricular tachycardia, as determined by the EMS provider.

Objected Prefecture

Japan has 47 prefectures. In this study, nine prefectures were selected because they have a population of more than 5 million: Hokkaido, Saitama, Chiba, Tokyo, Aichi, Osaka, Hyogo, and Fukuoka. Overall, 54.6% (68,816,937/125,927,902) of the Japanese population resided in the studied prefecture."

Disparity in EMS rapid response

The population of Japan was about 120 million in 2022, which has been decreasing year by year since 2008 [17]. Tokyo Prefecture is one of the prefectures with the largest population size, approximately 14 million, and New York State has a population of about 20 million [18]. Tokyo EMS has 259 fire stations and covers a large area in Tokyo [19]. However, Tokyo has several rural areas. Hence, this paper used the Gini coefficient as an index of disparity for the population covered by EMS rapid response in each prefecture although the Gini coefficient with the Lorenz curve is known to be described as an index of economic disparity [20].

Lorenz curve and Gini coefficient

The Gini coefficient value ranges from "0" to "1" as a numerical value for disparity or inequality, with "1" denoting perfect inequality and "0" denoting perfect equality. This study defined the Gini coefficient as an independent variable and as a prefecture for the population within the areas, EMS responded to within three minutes in each municipality of the prefectures. The Gini coefficient was calculated based on the Lorenz curve as a graphical representation of a function of the cumulative proportion of services of ordered institutions mapped onto the corresponding cumulative proportion of their size based on the following formula [21,22]:

$$S_1 = 1/2 \sum_{i=0}^{i=1} (Y_i + Y_{i+1}) X_{i+1}$$

Gini coefficient $= 2\,(0.5 - S_1)$

Runtime setting for rapid response

The rapid response was defined as the response from a fire station to the emergency scene within three minutes of driving based on the Japanese AED guideline [23]. This denotes that the preferable time for AED deployment is within five minutes for patients with cardiac arrest. This time frame was broken down as follows: one minute was allocated for awareness via an emergency call, one minute was allocated for shifting from "AED's power on" to delivering the first shock, and the remaining 3 minutes were allocated for response time from the fire station to the emergency scene.

The Gini coefficient from the population covered by the EMS rapid response

EMS operates on a "first-come-first-serve" basis regardless of the nature of the complaint. Unfortunately, late emergency response occurs occasionally, even for patients with cardiac arrest. In response, when EMS dispatchers detect a patient under critical conditions, they activate not only ambulance vehicles but also fire trucks or other emergency vehicles for rapid response. In this study, we assume that emergency vehicles are available in all fire stations, and they include trained members who are supposed to perform CPR for cardiac arrest.

The data management proceeded in the following way to identify the population by EMS rapid response. First, all fire stations in prefectures [24] were plotted as starting points on the map. Then, each emergency vehicle was driven for 3 minutes from the starting points, using simulation on the map without traffic. The driving speed was based on each street limit because there were varying speed limits on each street in Japan based on the Japanese Road Traffic Act [25]. As a result of the simulation, the polygons were made by the reachable points within three-minute driving. The population was added to the polygon based on resident registration (Figure 1). Furthermore, several polygons overlapped the other polygons because of the nearby fire stations. In this case, those polygons were set at half distances to avoid overlapping. The population [26,27] was aggregated in each municipality of the prefectures. Then, the Gini coefficient was calculated with the population for the disparity in the prefectures. Data management for the population, which includes simulated network analysis on the map and added population in the polygons, was conducted via ArcGIS by ESRI, a geography software. Additionally, the Gini coefficient was calculated using Microsoft® Excel 2019.

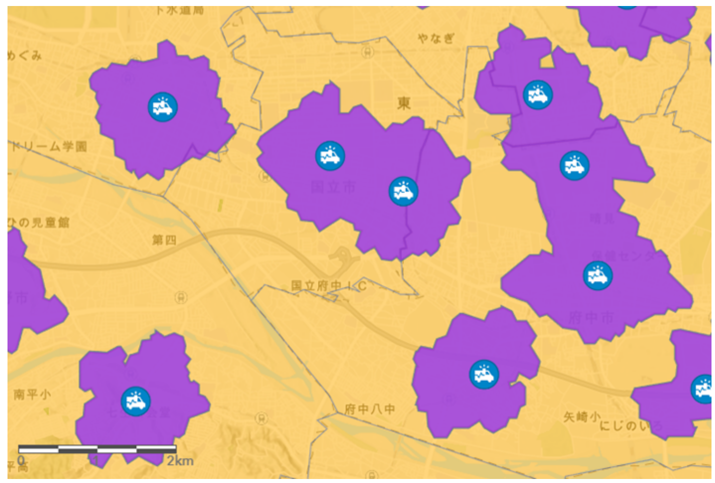

Figure 1: Covered area (purple polygon) by rapid (3min) EMS in Tokyo (as a sample) and the line indicating the governorate as an administrative division.

Outcomes

The primary outcome for patients with OHCA was favourable neurological outcomes at 30 days, which has a cerebral performance category score of 1 (good cerebral performance) or 2 (moderate cerebral disability) [14-16]. The secondary outcome was patient survival at 30 days.

Statistical analysis

Patient outcomes were divided into two groups: the favourable neurological outcomes at 30 days and the non-favourable neurological outcomes at 30 days. The factors of groups, which are chest compression and AED implementation, were compared using the chi-squared test. Other factors, including age, sex, response time, and Gini coefficient, were used in the statistical analysis by Mann–Whitney U test, as appropriate. The logistic regression model was used to calculate the adjusted odds ratio (OR) with a 95% confidence interval (CI) for favourable neurological outcomes at 30 days with Gini coefficient, chest compression only, bystander AED implementation, and response time. Similarly, patient survival at 30 days as a secondary outcome was analysed. All statistical analyses were performed using the SPSS statistical package version 25.0 J (IBM Corp, Armonk, NY, USA). A p-value less than 0.05 was considered significant.

Results

A total of 505,332 patients with OHCA were administered between January 1, 2015, and December 31, 2019 in Japan. Among them, 256,815 patients had OHCA in 9 prefectures: Hokkaido, Saitama, Chiba, Tokyo, Kanagawa, Aichi, Hyogo, and Fukuoka. The Gini coefficient calculated with the population covered by EMS rapid response is shown in Table 1.

	Population	Area (Km^2)	Number of fire stations	Number of municipalities	Percentage of Covered Population By EMS (%)	Gini's coefficient
Hokkaido	5,183,687	83,424	389	187	2,849,064/5,183,687 (55)	0.75
Saitama	7,385,848	3,798	210	72	2,139,086/7,385,848 (29)	0.55
Chiba	6,310,875	5,157	204	59	2,264,780/6,310,875 (36)	0.63
Tokyo	13,794,933	2,194	291	53	7,590,598/13,794,933 (55)	0.51
Kanagawa	9,215,210	2,416	265	58	4,325,027/9,215,210 (47)	0.43
Aichi	7,528,519	5,173	221	69	2,595,448/7,528,519 (34)	0.47
Osaka	8,800,753	1,905	248	72	4,371,012/8,800,753 (50)	0.44
Hyogo	5,488,605	8,401	176	49	2,088,251/5,488,605 (38)	0.62
Fukuoka	5,108,507	4,988	143	71	1,391,557/5,108,507 (27)	0.61

Table 1: Geographic characteristics in each prefecture.

The Gini coefficient value ranges from "0" to "1" as a numerical value for disparity or inequality, with "1" denoting perfect inequality and "0" denoting perfect equality. Of 256,815 patients, 159,240 were cardiac origin. Of the 159,240 patients, 93,730 were excluded: 1,033 patients were not witnessed by bystanders, 20 patients were witnessed by EMS, and 92,677 patients were of unknown witness status. Additionally, 54,026 patients were excluded because of pulseless electrical activity, asystole, and others. Additionally, patients with missing data for response time (15 patients), chest compression (2,088 patients), and public-access defibrillation (1,491 patients) were excluded. Finally, 7,890 patients who had an initial shockable heart rhythm were included in the analysis (Figure 2). Response time was defined as the time from the EMS call to EMS contact with the patient. The patients' characteristics are shown in Table 2.

N=7890	Favourable neurological outcomes at 30days	Non-Favourable neurological outcomes at 30days	P value
	CPC=1or2 (n=2208)	CPC=3or4or5 (n=5682)	
Age	61	69	P <0.001
	(25%quartile:50, 75%quartile:70)	(25% quartile:57, 75%quartile:79)	
Sex			P*=0.079
male	1787	4498	
female	421	1184	

Chest compression			P*<0.001
Bystander chest compression	1421	3128	
No Bystander chest compression	787	2554	
AED			P*<0.001
Bystander AED implementation	345	449	
No Bystander AED implementation	1863	5233	
Response time	7:59	8:00	P <0.001
	(25% quartile: 6:00, 75% quartile: 9:00)	(25% quartile: 7:00, 75% quartile: 9:59)	
Gini's coefficient	0.51	0.51	P =0.726
	(25% quartile: 0.47, 75%quartile:0.62)	(25% quartile: 0.47, 75% quartile: 0.61)	
P=Mann-Whitney U test, P*= chi-squared test			

Table 2: Patient characteristics.

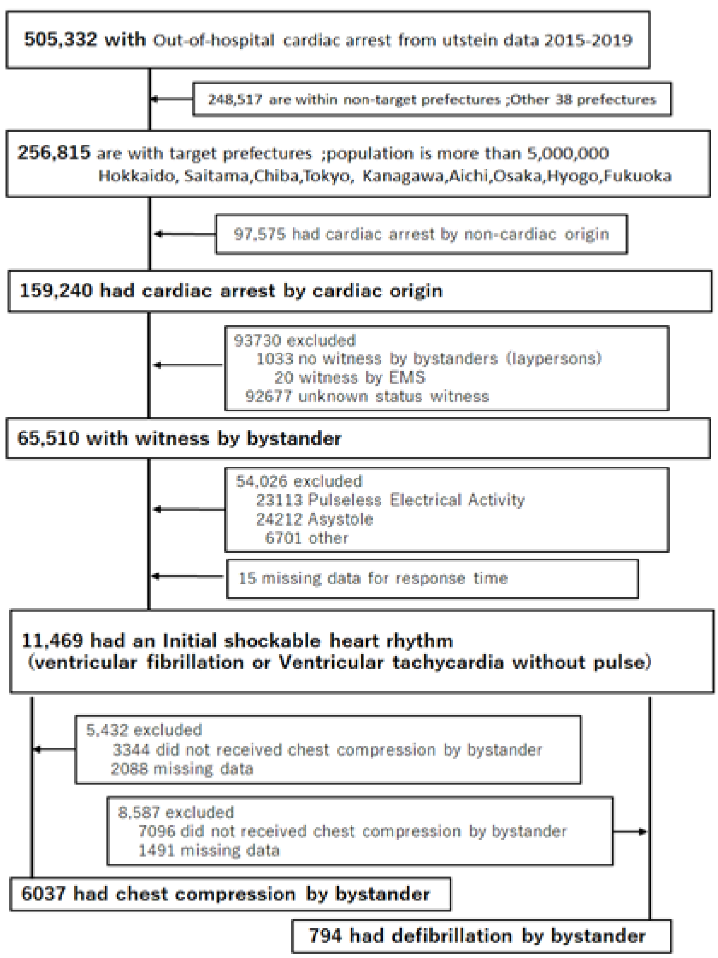

Figure 2: Patient flow chart.

Table 3 shows a comparison of outcomes among the Gini coefficient, chest compression only, bystander AED implementation, and response time. The Gini coefficient in prefectures was associated with a high risk of favourable neurological outcomes at 30 days, with an adjusted OR of 0.378 (95% CI: 0.129–0.650, p < 0.01). The Gini coefficient for patient survival at 30 days was an adjusted OR of 0.251 (95% CI: 0.152–0.416, p < 0.01). Furthermore, chest compression only, bystander AED implementation, or response time were associated with a high chance of favourable neurological outcomes, with an adjusted OR of 1.346 in chest compression (95% CI: 1.210–1.498, p < 0.01), of 2.013 in bystander AED implementation (95% CI: 1.719–2.358, p < 0.01), and of 0.378 in response time (95% CI: 1.001-1.002, p < 0.01). The variance expansion factor among each variable indicated no multicollinearity.

	Favourable neurological outcomes (CPC1 or CPC2) at 30 days	P value	Survival rates at 30 days	P value
	Odds ratio 95% CI		Odds ratio 95% CI	
Bystander chest compression only	1.346 (1.210-1.498)	<0.01	1.291 (1.172-1.422)	<0.01
Bystander AED implementation only	2.013 (1.719-2.358)	<0.01	1.659 (1.421-1.937)	<0.01
Response time	1.002 (1.001-1.002)	<0.01	1.002 (1.001-1.002)	<0.01
Gini's coefficient	0.378 (0.219-0.650)	<0.01	0.251 (0.152-0.416)	<0.01

Table 3: Primary and secondary outcome. The Gini coefficient value ranges from "0" to "1" as a numerical value for disparity or inequality, with "1" denoting perfect inequality and "0" denoting perfect equality.

Discussion

Many studies have been conducted on resuscitation to increase the survival rate [28,29]. For example, a recent cohort study reported that the number of patients who had public-access de-fibrillation was significantly higher than those who did not under the same status except for ROSC or not before EMS [30]. As expected, this paper confirmed that chest compression implementation by bystanders is effective for favourable neurological outcomes at 30 days and patient survival at 30 days. Similarly, the response time from EMS activation to EMS contact with patients with OHCA has been confirmed for better outcomes [31,32]. This study implies as a new finding that the high equality for cover population by EMS rapid response was significantly higher than the lower one in favourable neurological patients with an OHCA witnessed by a family member and an initial shockable cardiac rhythm with cardiac origin. The Gini coefficient as the equality of EMS rapid response might be one of the key factors for better outcomes of OHCA resuscitation. As mentioned above and according to Japan Resuscitation Council Guideline, patients with OHCA have to be resuscitated immediately with chest compression and AEDs [33]. In this study, the Gini coefficient is suggested to be one of the factors associated with favourable neurological outcomes at 30 days and patient survival at 30 days. In other words, better outcomes might be led by providing more EMS rapid response. Another point is that better outcomes for patients with OHCA in a prefecture require an equally rapid response by EMS because OHCA can occur to anyone at any time, although most of the OHCA occur in their residences [34]. The disparity might be due to the distribution of residence areas because of the nationwide population decline and the super-aging society in Japan [35]. Particularly, the population in rural areas inflow to urban areas because people who wanted to live in urban areas were 10 points more than those in rural areas, as shown in a questionnaire for 18 years old [36], because of more convenient areas for daily life and job opportunity. In the future, the disparity might be worse in each prefecture.

Corrections have been suggested to reduce the disparity, including adding fire stations to cover more population for rapid response or change of location of the fire stations. In fact, this kind of solution is unrealistic because of budget issues. However, another solution is the instalment of the community first responder system in a prefecture instead of EMS. According to Kurn [37], local neighbourhood volunteers can improve the response time to a simulated cardiac arrest. The Kashiwa City Fire Department initiates a rapid response system for community first responders through a mobile application [38]. Resuscitation by residents is expected to be the first response. The more rapid the response to the scene, the more the chance of survival for patients with cardiac arrest [39]. Hence, the present when the change of the times is intense need a broader perspective like the Gini coefficient for resuscitation from OHCA although focusing on bystander chest compression and AED implementation are essential. Also, because EMS has implemented maximum efforts within limited budget, the Gini coefficient combined with other factors for resuscitation might be one of the indexes to make a strategy to establish emergency medical response for residence.

Limitations

This study has several limitations. This is not a randomized controlled trial and employs a simulation of emergency settings in the prefectures with uniform data based on the Utstein Style guidelines. This study did not examine the data from all 47 prefectures in Japan. Particularly, the study did not discuss low-population prefectures. However, each prefecture in this study has a population of more than 5 million, and the percentage of the total population was 54.6% (68,816,937/125,927,902). Furthermore, the change in the night-to-daytime population was reflected because the Gini coefficient was calculated by resident registration and could not follow them. Furthermore, the Gini coefficient was calculated with the simulated results, which may only represent the best possible population covered by EMS. Thus, certain EMS cannot respond to emergencies due to the increasing number of emergency calls in Japan. Additionally, in real life, the response time is influenced by transportation conditions, such as vehicle accidents, road construction, and weather. These obstacles may minimize the areas and expand the area to improve the resuscitation rate. Further studies are needed to investigate EMS treatment in patients with OHCA.

Conclusion

This study suggested that the Gini coefficient for the population covered by EMS rapid response was one of the factors influencing the outcomes of patients with OHCA in the prefectures. Therefore, correcting the imparity might provide better outcomes. Furthermore, in a declining population in Japan, the Gini coefficient might help improving outcomes and establish a new EMS system in a prefecture. Moreover, the effect combined with public-access defibrillation could be expected for better outcomes.

Author Contributions: Conceptualization Methodology Writing- Original draft, K.N; Method-ology, K.S.; Study conception, K.F. and M.N; analysis, S.H; project administration, S.K. and R.S.; Supervision, S.O.

Disclosure

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Ethics Review Committee: This study was conducted after a review by the Ethics Committee of Nippon Sport Science University (Approval No. 023-H009).

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