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Ki Ok Ahn MD, PhD, Sang Do Shin MD, PhD, Won Chul Cha MD, Chulmin Jun PhD, Tae Sik Lee PhD & Ronald G. Pirrallo MD, MHSA

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A Model for the Association of the Call Volume and the Unavailable-for-Response Interval on the Delayed Ambulance Response for Out-of-Hospital Cardiac Arrest Using a Geographic Information System

Ki Ok Ahn, MD, PhD, Sang Do Shin, MD, PhD, Won Chul Cha, MD, Chulmin Jun, PhD, Tae Sik Lee, PhD, Ronald G. Pirrallo, MD, MHSA

Abstract

Background. An optimal ambulance response interval is desirable for emergency medical services (EMS) operations. Arriving on scene within a treatment time window is often delayed for many reasons, including overwhelming call volume. **Objective.** To determine whether an association exists between the ambulance call volume (ACV), the unavailable-for-response (UFR) interval, and the delayed ambulance response for out-of-hospital cardiac arrest (OHCA) patients. **Methods.** This was a retrospective observational study conducted in Seoul, Republic of Korea. The EMS ambulance logs from the metropolitan city's 22 EMS agencies, from January 1, 2006, to June 30, 2007, were obtained from the National Emergency Management Agency. These data included patient demographics and call location addresses. The addresses of the call locations and ambulance stations were geocoded and configured with a polygon expressing the optimal coverage areas in which an ambulance could travel within 4 minutes from their base station. The median ACV and mean UFR interval of each EMS agency were calculated. An actual response time interval greater than 4 minutes compared with the optimal coverage area was defined as a suboptimal response. Potential influencing factors on suboptimal response were analyzed using a multivariate logistic regression model to calculated the odds ratio (OR) and 95% confidence interval (95% CI). **Results.** Geocoding was successful for 255,961 calls, and 3,644 cardiac arrests occurred within the configured optimal response coverage areas. The response rate intervals for cardiac arrest patients, however, were optimal in only 22.6% of calls. Influencing factors for suboptimal response (occurring in 77.4% of the cases) were the median ACV and the mean UFR interval of each EMS agency. When the median ACV was seven or more, the OR of suboptimal response was 1.407 (1.142–1.734). If the mean UFR interval was 55 minutes or more, the OR for suboptimal response was 1.770 (1.345–2.329). **Conclusion.** The ambulance response time intervals in this study setting were associated with EMS agencies with higher ACVs and longer UFR intervals. **Key words:** emergency medical services; response time; cardiac arrest; time intervals

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Address correspondence and reprint requests to: Sang Do Shin, MD, PhD, Seoul National University Hospital, Emergency Medicine, 101 Daehak-Ro, Chongno-Gu, Seoul, 110-744 Republic of Korea. e-mail: shinsangdo@medimail.co.kr

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Introduction

Study Background

The American Heart Association (AHA) has been emphasizing the importance of the "chain of survival" since the 1990s to improve patient survival from out-of-hospital cardiac arrest (OHCA).[1] A prompt emergency medical services (EMS) response is an essential component in keeping the chain intact. The response interval, i.e., the time from the call for help until EMS arrives at the scene, has been shown to influence survival rates of victims with OHCA. Stiell et al. reported that when the response interval increased, patients' survival rate from OHCA was significantly decreased.[2] A recent study by Iwami et al. also showed that when the basic life support (BLS) response interval decreases from 9 minutes to 7 minutes, and the interval from scene arrival until first defibrillation decreases from 19 minutes to 10 minutes, the survival rate increases from 5% to 12%.[3]

For this reason, many EMS authorities in the United States recommend an EMS response interval within 4 minutes with a 90% success rate.[4] It has been reported that EMS systems that do not reach this goal have worse patient survival outcomes.[4,5] Regardless of the country, EMS systems are complex and vary in many elements such as communication infrastructure, education of providers, vehicle response configuration, human resources, and urbanization.[6,7] These EMS system design elements may be associated with the ambulance response interval and contribute to a suboptimal response. A suboptimal response can be influenced by an EMS agency's unavailable-for-response (UFR) interval or the ambulance call volume (ACV). The UFR interval is the time interval in which the ambulance is still assigned to a call and unable to accept or respond to an additional call. The UFR interval is associated with the road distance from the ambulance station to the patient location, the road distance from the patient location to the destination hospital, the timeliness of emergency department (ED) patient care transfer, and diurnal traffic conditions. The ACV may be affected by uneven regional call density, the time of day, and the total number of calls directed to that specific EMS agency.

If the intent is to redesign the EMS system to achieve an optimal response interval goal with 90% success, one should consider both those call locations that occur inside the optimal service coverage area (which can be expected to be responded to within the time interval goal) and those call locations that occur outside the optimal area (which may not be responded to within the time interval goal). For call locations outside the optimal service coverage area, additional resources may be necessary for an optimal response. However, for call locations inside the optimal service coverage area, the tolerable UFR intervals and adequate ACV for each EMS agency can be determined. To distinguish these two areas, geographic information system (GIS) software can be used to compare the actual response time intervals with the expected calculated intervals using electronic geographic information of the patient, the ambulance base station, and destination hospital locations.

Study Objective

This study was aimed at determining whether an association exists between the ACV, the UFR interval, and the delayed ambulance response for OHCA patients in a large metropolitan area using GIS software.

METHODS

Study Design

This was a retrospective observational study. It was approved through an abbreviated review by the study hospital institutional review board, as this study used data from an existing electronic database with limited, blinded patient demographic information and was not considered an intervention trial.

Study Setting

The study area was the Seoul, Republic of Korea, metropolitan area with more than 10 million residents. Prehospital care is provided by dual-trained emergency medical technician (EMT)-basic or EMT-intermediate firefighters responding from their fixed-position fire department base stations. The EMS system is a single-tiered system that responds to calls in patient-transport-capable ambulances. The Fire Department (FD) is divided into 22 districts (corresponding to the 22 EMS agencies), which operate and staff each headquarter base station (total 22) and 112 ambulance stations. The headquarter base stations are located in the same building as each EMS agency and have a specific mission, which is the control and coordination in multiple-casualty incidents. Eleven headquarter ambulance base stations among the 22 headquarter base stations have two dedicated ambulances each (total 22 ambulances), and the other remaining headquarter base stations have one ambulance each (total 11). Every one of the 112 ambulance stations have one ambulance (total 112) each. Thus, the total number of available ambulances is 134. A typical EMS response vehicle is staffed by three personnel, one EMT-basic, one EMT-intermediate, and one trained driver. The EMS personnel work a 24-hour shift. The EMS system operates one centralized call-dispatch center where direct medical direction is given if needed.

For a victim of cardiac arrest, EMT-basics are trained to provide chest compressions, bag–valve–mask ventilations, and automated external defibrillator (AED) use. In addition, EMT-intermediates are able to administer intravenous fluid under direct medical control. By system protocol, all patients found in cardiac arrest are transported to the closest hospital as soon as possible with ongoing cardiopulmonary resuscitation (CPR). In noncritical patients, the destination hospital is determined by patients' preferences.

All EDs are formally designated as level 1, 2, or 3 by the national and provincial government. The designation is based on the ED's human resources, essential instruments and equipment, and availability of specialty services. Most level 3 EDs are not well equipped and are usually served by general physicians. However, by law, level 1 and level 2 EDs must be staffed by emergency physicians 24 hours a day. In this metropolitan city, there are a total 60 EDs: one level 1 regional ED, 26 level 2 local EDs, 30 level 3 emergency rooms, and three specialty care centers (one trauma, one poison control, and one burn care ED). Most critical patients transported by EMS are taken to designated level 1 or 2 EDs according to EMT triage and decision making, taking into account distance, patients' preferences, and ED diversion status.

Study Population

Using the electronic patient care FD EMS database, patients were enrolled if they had a chief complaint of cardiac arrest or respiratory arrest, or received CPR prior to arrival at the hospital from January 1, 2006, to June 30, 2007 (18 months).

Data Collection

Data were collected from the electronic patient care ambulance log provided by the FD headquarters, National Emergency Management Agency (NEMA). The Seoul FD headquarters maintains the universal data-collection system for the country. A duty ambulance crew member (usually the EMT-intermediate) enters the information from the ambulance run sheet into a Web-based data-collection system prior to the end of the shift. These data are transferred to a central data management sever where patient demographic information is blinded and stored. The data elements included patient demographics, chief complaint, emergency patient care management, elapsed time variables, and the latitude and longitude of the patient and ambulance station locations.

The call time for help is automatically recorded in the electronic database at the centralized dispatch center. The ambulance on-scene arrival time is reported by the EMS provider to the dispatch center when the wheels are stopped at the scene. The ED arrival time is similarly reported to the dispatch center when the wheels are stopped at the hospital. Finally, the ready-for-duty time is also reported by the EMS provider when the vehicle returns to the ambulance station and is considered ready for the next call. The response time interval was defined as the time from the call for help to arrival at the scene. The UFR interval was defined as the time from the call for help to the return time at the ambulance station. During the UFR period an ambulance is considered unable to respond to a second call.

Outcome Measure

Primary outcome was the number of suboptimal responses, greater than 4 minutes, for patients with OHCA. The optimal response time interval for OHCA patients was defined as 4 minutes 0 seconds or less beginning at the time the call for help was received at the centralized dispatch center and ending when the ambulance arrived at the requested address.

Data Analysis

First, we coded geographic information of each patient's address and each fire station location on a map (*geocoding*). When the information was not sufficient to pinpoint the precise location, we used the representative point of the area. For example, if an address was written only with the street's name, we used the center location of the street as a representative point. After geocoding, we calculated the distance that an ambulance could be expected to travel within 4 minutes from each ambulance station to the patient's

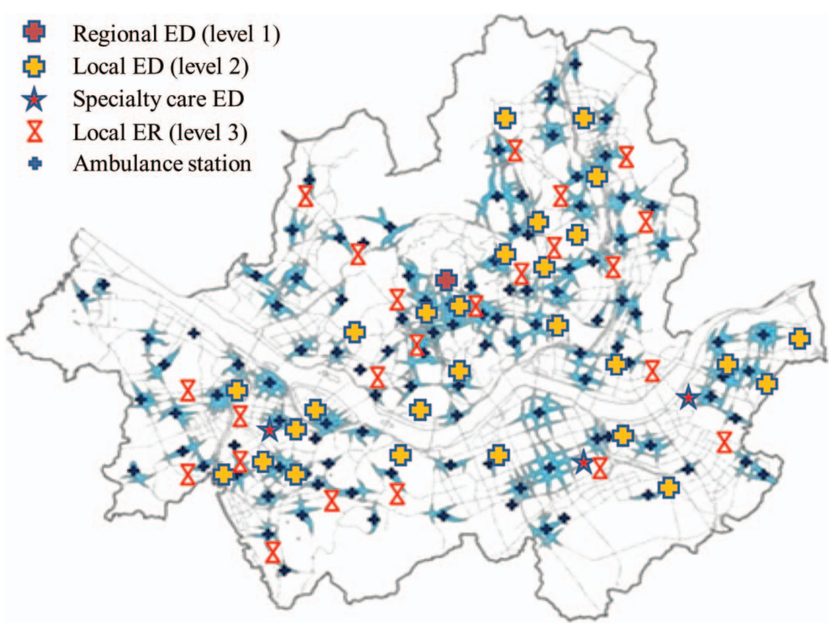

FIGURE 1. The location of the ambulance stations (black crosses) in the study metropolitan city. The one red cross denotes the regional emergency department (ED) (level 1). The 27 yellow crosses denote local EDs (level 2) and the red "dumbbells" denote local emergency rooms (ERs) (level 3). Three red stars symbolize specialty care EDs. Also illustrated are areas that could be reached within 4 minutes after the call (optimal service coverage, blue territories). ArcGIS 9.0 software for mapping and calculating the distance and territory was used.

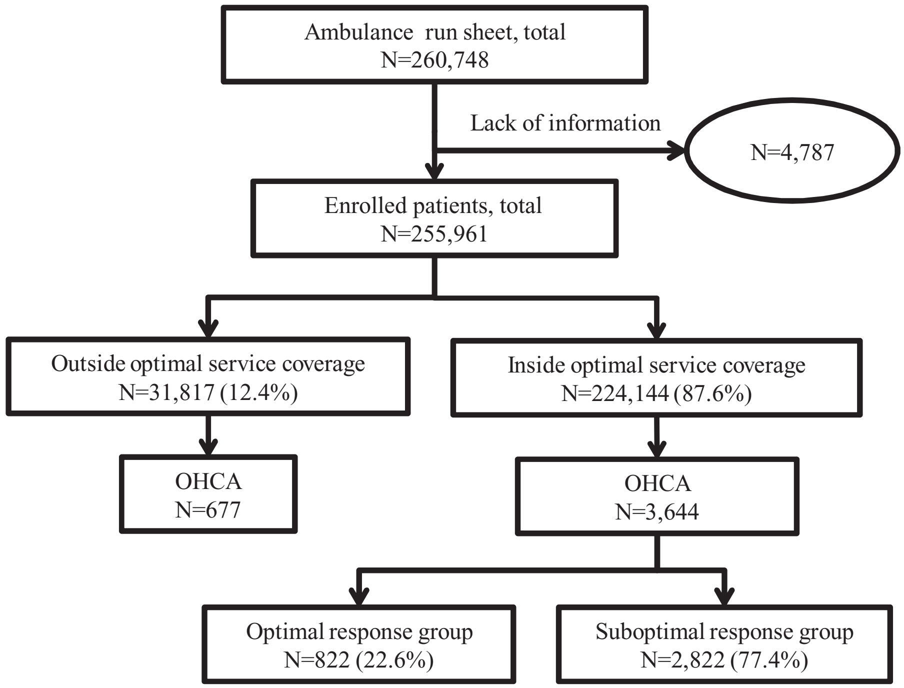

FIGURE 2. The distribution of total patients inside and outside the optimal service coverage and the number of patients in the optimal and suboptimal response groups with out-of-hospital cardiac arrest (OHCA).

address. The distance was calculated with consideration of the road network; that is to say, we calculated the distance between two points via street routes, not straight distance between two points. We also assumed the mean ambulance speed on the road to be 30 km/hour, which was the median velocity calculated from the ambulance log in the same duration. After a series of calculations, we built a map of possible 4-minute response intervals representing the optimal service coverage areas (Fig. 1). We excluded cases where the responding ambulance starting location was outside of the usual service coverage area.

We categorized the enrolled OHCA patients into two groups: Those patients whose response interval was 4 minutes 0 seconds or less were considered the *optimal response group* and those patients whose response interval was greater than 4 minutes were considered the *suboptimal response group*. We also calculated the daily median ACV of the EMS agency as a potential risk factor that could affect the response interval for cardiac arrest patients. The ACV was calculated as the sum of the number of all calls for all ambulances in an EMS agency divided by the number of ambulances in that EMS agency. The mean UFR interval of each EMS agency was calculated as an additional potential risk factor that may influence the next prompt response. Based on the time data for all individual ambulances, we computed the mean UFR interval for each EMS agency. It was assumed that an ambulance cannot take a new assignment from departure to the call until it returns to its base station.

The EMS agency was used as the unit for analysis because each agency has four to eight ambulance stations with one to two ambulances at each station that can be operated in a flexible manner. For example, if an ambulance has already been dispatched and a second ambulance is requested at nearly the same time, the EMS agency can dispatch the needed ambulance under its control for the second patient.

We used ArcGIS 9.0 (ESRI, Redlands, CA) for mapping and calculating the distance and territory. ArcGIS 9.0 software is not a real-time tracking GIS system, but a retrospective mapping method using address information. ArcGIS 9.0 software can convert address information such as a ZIP code to a geographic

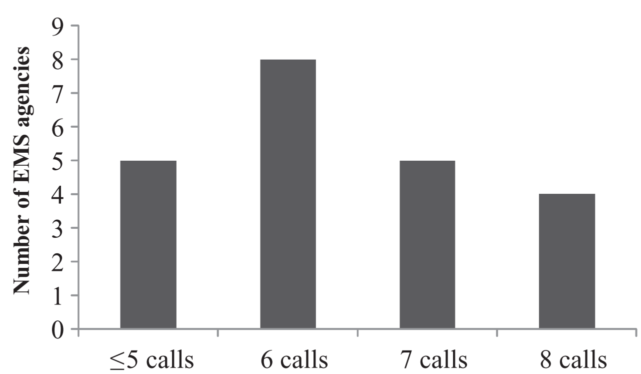

FIGURE 3. The numbers of emergency medical services (EMS) agencies according to the daily median ambulance call volume of the EMS agency.

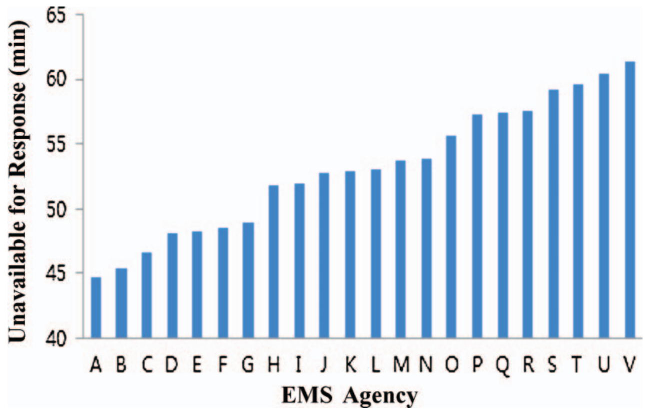

FIGURE 4. The mean unavailable-for-response (UFR) interval based on each emergency medical services (EMS) agency.

information data set and make a pinpoint corresponding to that address information on the map.

A Cochran-Armitage trend test was done for ordered variables. A multivariate logistic regression analysis was carried out to determine the effect of ACV and UFR interval on the suboptimal response adjusting for other covariates using 5-minute time intervals.

RESULTS

Demographic Findings

During the study period, a total of 260,748 EMS system ambulance responses were recorded. Of these, 4,787 (1.8%) were excluded because of lack of key data such as time variables, leaving 255,961 cases for analysis. Of these, 75.0% of patients' locations could be exactly geocoded, requiring 25.0% to be geocoded with representative points. All 112 FD ambulance stations operational at the time of the study could be geocoded to their exact locations.

Overall, of the 255,961 patients, 224,114 (87.6%) were located within the optimal service coverage area; 4,321 were identified as cardiac arrest patients. The number of OHCA patients located within the optimal service coverage was 3,644 (677 cases were located outside the optimal service coverage). Of the 3,644 OHCA cases located within the optimal service area, only 822 cases (22.6%) had an ambulance response interval of 4 minutes 0 seconds or less (Fig. 2). Figure 3 shows the distribution of the number of EMS agencies according to the daily mean ACV per ambulance. The shortest UFR interval (mean ± standard deviation) was 44.7 ± 25.4 minutes and the longest was 61.0 ± 34.20 minutes (Fig. 4). Figure 5 details the relationship of the mean ambulance UFR interval to call hour. At night, the UFR interval was shorter than during the day.

Logistic Regression Analysis

We analyzed the relationship between the median ACV and the rate of suboptimal responses per EMS agency. In general, the larger the ACV, the higher the suboptimal response rate became (p-value for trend <0.001 by Cochran-Armitage trend test) (Table 1). The 5-minute intervals for the mean UFR interval were also related to the suboptimal response rate. As the UFR interval increased, the suboptimal response rate increased significantly (p-value for trend <0.001 by Cochran-Armitage trend test) (Table 2).

When we analyzed the data for factors associated with a suboptimal response, the ACV and UFR interval showed significant effects (Table 3). When the median ACV increased from six (reference value) to seven or eight per day, the odds ratio for suboptimal

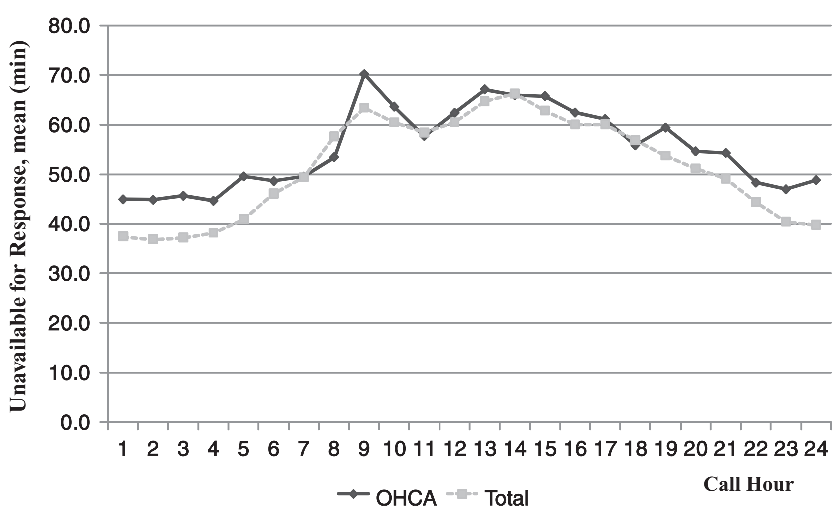

FIGURE 5. Mean unavailable-for-response (UFR) interval of ambulances according to call hour (numbers correspond to 24-hour time). OHCA = out-of-hospital cardiac arrest.

TABLE 1. The Relationship between Ambulance Call Volume and the Optimal Response Rate for Out-of-Hospital Cardiac Arrest

Daily Ambulance Call Volume (mean)	Total Number of Out-of-Hospital Cardiac Arrests	Suboptimal ($n = 2{,}822$)		Optimal ($n = 822$)		p-Value*
		n	%	n	%	
≤5.9	723	548	75.80	175	24.20	<0.001
6.0–6.9	1,324	964	72.81	360	27.19	
7.0–7.9	801	633	79.03	168	20.97	
8.0–8.9	796	677	85.05	119	14.95	

*The Cochran-Armitage trend test was used for statistical analysis.

response increased from 1.000 to 1.407 (95% CI 1.142–1.734) to 2.215 (95% CI 1.689–2.672), respectively. There was no significant effect for an ACV less than five (Table 3). The effect on the suboptimal response for the UFR interval was significantly increased only at 55 minutes or more (OR = 1.770, 95% CI 1.345–2.329). Finally, a multivariate logistic model adjusting for each variable (ACV for UFR interval or UFR interval for ACV) was performed. A very similar effect was found and the ACV and UFR interval were independent of the suboptimal response interval.

LIMITATIONS

Because of the unique geospatial characteristics of the study site, several limitations should be considered. First, we did not measure the additional time interval that was required to reach the patient's side, and the majority of the study population likely live in high-rise buildings. Thus, the response interval definition of 4 minutes or less is a conservative estimate of the time to treatment and may not reflect the actual time interval when patient care began. In regions with high-rise buildings and increased population density, the response interval tends to be delayed by the additional "vertical response time."[8–10] This model did not take into consideration the time of day or day of the week or traffic flow. The study site is known for its notorious traffic problem. Instead of adjusting the model by day of the week or time of day related to traffic flow, we uniformly applied the median vehicle speed (30 km/hour) based on historical data, which is, again, a conservative estimate of the actual response interval.

Exact addresses were not known for all call locations, and in these instances the midpoint of the street was used. It is likely that this overestimated the distance to be traveled as often as it underestimated the distance.[11] Taking into consideration that this occurred in 25% of the cases, it has the potential of skewing the data in an unknown direction, especially if some of the streets are several kilometers long.

Since patient hospital outcome data were not included in this study, our findings cannot be generalized to the effect of these risk factors on patient survival from OHCA. Thus, we could not estimate the effect of these risk factors on the potential to survive from OHCA.

This study was done in a single-tiered BLS system. Thus, there would be no difference in the expected optimal response interval for OHCA and simple back sprain patients. Emergency medical services systems that use priority-based dispatch protocols have reported shorter response intervals for cardiac arrest patients.[12]

For our model, we assumed that the ambulance cannot take a new assignment until it returns to its base station. This was an assumption for convenience only. The FD dispatch center does have two-way radio communication capabilities with the ambulance but not global positioning system (GPS) capability. If the EMS agencies adopted a GPS ambulance tracking system, more optimal responses intervals might be possible.

DISCUSSION

An optimal ambulance response interval is known to be one of the outcome measures of a high-quality

TABLE 2. The Relation between the Mean Unavailable-for-Response Interval and the Optimal Response Rate for Out-of-Hospital Cardiac Arrest

Unavailable-for-Response Interval (minutes)	Total Number of Cardiac Arrests	Suboptimal ($n = 2{,}822$)		Optimal ($n = 822$)		p-Value*
		n	%	n	%	
40–44	211	150	71.09	61	28.91	<0.001
45–49	1,052	772	73.38	280	26.62	
50–54	1,130	849	75.13	281	24.87	
≥55	1,251	1,051	84.01	200	15.99	

*The Cochran-Armitage trend test was used for statistical analysis.

TABLE 3. A Multivariate Logistic Regression Model for Suboptimal Response for Patients with Out-of-Hospital Cardiac Arrest

Risk	Value	Unadjusted Model			Adjusted Model*		
		Odds Ratio	95% Confidence Interval		Odds Ratio	95% Confidence Interval	
Daily ambulance call volume (number)	≤5.9	1.169	0.949	1.441	1.173	0.951	1.447
	6.0–6.9	1.000			1.000		
	7.0–7.9	1.407	1.142	1.734	1.455	1.109	1.909
	8.0–8.9	2.125	1.689	2.672	1.888	1.460	2.443
Unavailable-for-response interval (minutes)	40–44	1.000			1.000		
	45–49	0.863	0.670	1.11	1.551	0.920	2.358
	50–54	0.945	0.735	1.215	1.379	0.938	2.027
	≥55	1.770	1.345	2.329	2.169	1.492	3.152

*The adjusted model for the unavailable-for-response interval was made using the daily ambulance call volume as an adjusted factor. In reverse, the other adjusted model for daily ambulance call volume was made using the unavailable-for-response interval as an adjusted factor. The two risk factors will affect each other, independently.

EMS system, especially when considering its impact on OHCA patient survival. Although the optimal response interval is not standardized worldwide, 4 minutes 0 seconds has been promulgated in the literature as an optimal response.[4] The optimal response interval was achieved in only 22.6% of the cases in this study. Other authors have reported response time intervals as a mean of 5.8 minutes in Los Angeles[13] and as a median of 7 minutes for the 11 cities of North America from the Resuscitation Outcomes Consortium (ROC) project.[14] Though these studies reported the mean or median value of the response interval, we believe it is more appropriate to focus on the rate or percentage of the optimal response interval received. This approach is a recommended quality assurance protocol in the peer-reviewed EMS literature.[15]

Stiell et al. have reported that when BLS responders arrive with an AED within 8 minutes with 90% reliability, the adjusted OR of survival is 3.0 compared with the suboptimal group (those who did not reach a 90% success rate).[16] Additionally, De Maio et al. suggested that a response interval of less than 8 minutes is still not quick enough, since shorter response times were associated with better survival.[17]

One well-described reason for a delayed EMS response is the inability to identify and locate the ambulance that would have the shortest response interval when the vehicle is not at its base station.[18] In this study, we suggest that additional causes of delay are due to a large volume of calls and long UFR intervals. Based on the current allocation of ambulances in the Seoul metropolitan area, our findings imply that the number of ambulances available in the fire districts is not sufficient. A suboptimal response was significantly associated with the daily ACV of the EMS agency, which suggests that more ambulances may improve the rate of compliance with the 4-minute standard.

There were also significant differences in the UFR intervals for the EMS agencies (Fig. 4). The UFR interval consists of the response interval, the field interval (the time spent on the scene), the transport interval (from the scene until arrival at the hospital), and the returning interval (from the hospital until arrival at the station). The transport and returning intervals mainly rely on the distance to the destination hospital. When the patient is transported to a remote hospital or when the appropriate hospital is further away, the UFR interval tends to lengthen. In our system, destination hospital selection can be determined by the patient or his or her family, which may influence operational resources. We have discovered that when the UFR interval increased to 55 minutes or more, the rate of suboptimal response increased significantly. For critical conditions that require a prompt response interval such as OHCA, efforts to reduce the UFR interval and destination hospital selection policies would likely be needed. Figure 5 demonstrates that the UFR interval fluctuates according to a diurnal cycle; during the day, the mean UFR interval was longer than during the nighttime. This is a predictable event such that we can consider modifying the distribution of ambulance stations and the total number of available ambulances during a 24-hour period.

Geographic information system software is used mostly in the areas of exploration, environment analysis, city planning, and marketing, and is relatively new for EMS system analysis. It has been utilized to locate public-access defibrillation sites,[19] to build an air-transport system for emergency patients,[20] and to relocate ambulance standby locations to minimize response intervals.[21] We used GIS software and methodology to analyze locations and distances to determine the optimal and suboptimal ambulance response areas. We used the distance by roadway, instead of the straight distance, to reflect the real movement of an ambulance through city streets. As a result, our optimal response area of 4 minutes 0 seconds or less became polygons instead of circles. Therefore, GIS software can be useful in configuring the geographic response interval window, thus determining the optimal response coverage area. This new technology can identify the actual geographic optimal response area, whereas traditional methods provide only the optimal response rate, not the geographic location. This visual information can assist with identifying the geographically at-risk areas where emergency response and care may be delayed. Further, the GIS software can be programmed to perform ambulance reallocation model simulations to guide decision making on potential new ambulance base station locations and the effect of adding additional ambulances to the system. These simulation models may be useful in designing specialty regional care systems and identifying the optimal destination hospital for patient resuscitation and stroke and trauma care.

CONCLUSION

With the use of GIS technology for a metropolitan city with more than 10 million people, we found that the ambulance call volume and unavailable-for-response interval of each EMS agency was associated independently with the suboptimal response interval for OHCA patients.

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