# Maximum emergency department overcrowding is correlated with occurrence of unexpected cardiac arrest

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# Abstract

Background Emergency department overcrowding negatively impacts critically ill patients and could lead to the occurrence of cardiac arrest. However, associations between emergency department crowding and occurrence of both in-hospital cardiac arrest and out-of-hospital cardiac arrest have not been thoroughly investigated. This study aimed to evaluate the correlation between emergency department occupancy rates and incidence of in-hospital and out-of-hospital cardiac arrest.

Methods A single-center, observational, registry-based cohort study was performed including all consecutive adult, non-traumatic cardiac arrest patients between January 2014 and June 2017. We used emergency department occupancy rates as a crowding index at time of presentation time of cardiac arrest and at the time of maximum crowding, and the average crowding rate for the duration of emergency department stay for each patient. To calculate incidence rate, we divided the number of arrest cases for each emergency department occupancy period by accumulated time. The primary outcome is association between the incidence of in-hospital cardiac arrest and out-of-hospital cardiac arrest and emergency department occupancy rates.

Results During the study period, 629 adult, non-traumatic cardiac arrest patients were enrolled in our registry. Among these, 187 patients experienced in-hospital cardiac arrest and 442 patients had out-of-hospital cardiac arrest. In-hospital cardiac arrest patients compared to out-of-hospital cardiac arrest patients had a significantly higher return of spontaneous circulation rates (16.5% vs. 4.8%; $P < .01$) and better neurologic outcomes at discharge (cerebral performance category scales 4.7 vs. 4.0; $P < .01$). Emergency department occupancy rates were positively correlated with in-hospital cardiac arrest occurrence. Moreover, maximum emergency department occupancy in the critical zone had the strongest positive correlation with in-hospital cardiac arrest occurrence (Spearman rank correlation $\rho = 1.0$, $P < .01$). Out-of-hospital cardiac arrest incidence was negatively correlated with emergency department occupancy ($\rho = -0.79$, $P = .04$).

Conclusion Maximum emergency department occupancy was strongly associated with in-hospital cardiac arrest occurrence, while occupancy rate was negatively correlated with out-of-hospital cardiac arrest incidence.


# Introduction

Emergency department (ED) overcrowding is a global phenomenon with complex causes that are not fully understood.[1, 2] The imbalance of supply and demand in ED capacity can result in hazardous effects both on physicians and patients,[3] and previous studies have found that overcrowded ED conditions increased physician decision-making time,[4, 5] led to more medication errors,[6] decreased quality of care,[7] and increased mortality during hospital stay.[8, 9] These potential dangers can be particularly detrimental for patients who needed time-critical interventions to effectively treat emergency conditions such as acute stroke,[4] acute respiratory failure,[10] and septic shock.[11]

Cardiac arrest is a critical situation requiring prompt intervention and continues to be a major public health burden.[12, 13] A previous study found that quality of out-of-hospital cardiac arrest (OHCA) was not associated with overcrowding because emergency medical services could alert the ED cardiopulmonary resuscitation (CPR) team of incoming OHCA patients, allowing time for the team to activate.[14] Compared to OHCA, many in-hospital cardiac arrests (IHCAs), especially during ED stay, are unexpected but considered to be preventable if early identification of at-risk patients and adequate interventions are possible.[15] However, there is limited evidence as to whether ED crowding influences the occurrence or outcomes of IHCA. We hypothesized that ED overcrowding correlates with IHCA occurrence.

# Method

1. **Study design**

This study was a single-center, observational, registry-based cohort study conducted at the ED of a university-affiliated teaching hospital in Seoul, Korea, which receives approximately 110,000 patients per year. We retrospectively analyzed prospectively collected registry data of all consecutive adult (age ≥ 18 years), non-traumatic IHCA and OHCA patients treated in the ED between January 2014 and June 2017. Patients were excluded if they were younger than 18 years, had do-not-resuscitate status, were dead upon arrival at the ED, or if return of spontaneous circulation (ROSC) occurred before arrival at the ED. Our institutional review board approved the study and waived the requirement for informed consent (study number S2017-1004).

Our ED had 7 zones with a total of 65 beds, including 2 beds in the CPR zone, 3 beds in the isolation rooms for airborne-transmitted disease, 37 beds in the intensive care zone, and 23 in the zone for boarding or ambulatory care. For simplification of analysis, we classified the ED zone into two zones: the critical zone for patients in need of CPR, isolation, or intensive care and the urgent zone for patients intended to be admitted to the hospital, discharged to home or another facility, or to receive ambulatory care. During the study period, the ED had an average of 16 board-certified emergency physicians, 24 residents, and 90 nurses. The study facility had 24-hour consultants including cardiologists, vascular surgeons, neurologists, neurosurgeons, interventional radiologists, and orthopedic surgeons.

2. **Data collection**

All patients presenting with OHCA and IHCA were registered in the CPR registry of our hospital. For each patient, an emergency physician on duty recorded a CPR report using the Utstein style, and the data were verified and entered into the web-based registry by the principal investigator.

Data included demographic characteristics, medical history, and characteristics of CPR, such as do-not-resuscitate (DNR) during or after CPR, if death occurred in the ED, whether the arrest was witnessed, the initially reported rhythm, time of first defibrillation, time of first epinephrine injection, time of intubation, total CPR duration, and whether ROSC occurred. Also, the registry contained information about hospital treatment and clinical outcomes, such as disposition of the hospital discharge, length of stay, and neurologic status at discharge. Achievement of sustained ROSC was declared when patients had a noticeable pulse for longer than 20 minutes. Neurologic status was quantified based on cerebral performance category (CPC) scales at the time of hospital discharge.[16]

We used ED occupancy rate as an overcrowding index. ED occupancy rate was defined as the ratio of the total number of ED patients to the number of beds in the ED.[17] Although there is no universal consensus on overcrowding measurement, ED occupancy rate is one of the most promising quantifiable methods.[18,19] It is essential that the ED occupancy rate is automatically updated periodically since this data has a time-series nature; our electronic medical record system automatically collects variables necessary for ED occupancy rate calculation at one-hour intervals. Previous studies using ED occupancy rate only measured occupancy at ED presentation.[20–22] To evaluate if other times during an ED cardiac arrest were associated with crowding levels, we measured ED occupancy rates of both IHCA and OHCA cases at presentation, at time of arrest, at time of maximum occupancy, and the average during ED stay. We then calculated the accumulated ED stay time of all patients. Finally, cardiac arrest occurrence at each specific ED occupancy rate time point was calculated based on the number of cardiac arrest patients at a certain range of ED occupancy rate (e.g., 0.9-1.1) divided by the accumulated time of each ED occupancy rate during the study period.

The primary outcome was the correlation between the four ED occupancy rate measurements and the occurrence rate of unexpected cardiac arrest during ED stay. The secondary outcome was comparing clinical outcomes of IHCA and OHCA.

3. **Statistical analysis**

All continuous variables were expressed as median with interquartile range (IQR). The Mann-Whitney U test was used to compare the values of continuous variables. Categorical variables were analyzed with the chi-square test or with the Fisher exact test. Normality of distribution was examined by the Kolmogorov–Smirnov test. Differences between means were calculated by one-way analysis of variance or Kruskal-Wallis test. We assessed the correlation between ED occupancy rate and cardiac arrest occurrence by calculating the Spearman rank correlation coefficient. For all analyses, a two-sided $P$ value of $< .05$ was considered to indicate a statistically significant difference. Statistical analyses were performed by using R version 3.5.0 (R Foundation for Statistical Computing, Vienna, Austria).

## Results

During the study period, 629 adult, non-traumatic cardiac arrest patients were enrolled in our registry. Of these, 187 patients experienced IHCA and 442 patients experience OHCA.

Demographic and clinical details of the study patients are summarized in Table 1. The mean patient age was 64.4 years and patients were predominantly male in both groups. Hypertension (7.0%) was the most common past medical illness in both groups. IHCA patients were more likely than OHCA patients to have arrhythmia (15% vs. n = 6.8%; P = < .01), heart failure (12.8% vs. 6.3%; P = .01), diabetes (29.9% vs. 22.2%; P = .04), chronic renal failure (11.8% vs. 6.1%; P = 0.02), and malignancy (31.6% vs. 11.5%; P < .01).

Table 1
Demographic data of cardiac arrest patients

| | **Total (N = 629)** | **IHCA (n = 187)** | **OHCA (n = 442)** | **P value** |
|---|---|---|---|---|
| Sex (Male) | 421 (66.9%) | 121 (64.7%) | 300 (67.9%) | .53 |
| Mean Age | 64.4 ± 16.4 | 65.2 ± 15.0 | 64.0 ± 17.0 | .58 |
| Medical history | | | | |
| Cardiac arrest history | 9 (1.4%) | 5 (2.7%) | 4 (0.9%) | .14 |
| Myocardial infarction | 36 (5.7%) | 12 (6.4%) | 24 (5.4%) | .71 |
| PCI history | 41 (6.5%) | 16 (8.6%) | 25 (5.7%) | .22 |
| CABG history | 19 (3.0%) | 7 (3.7%) | 12 (2.7%) | .46 |
| Arrhythmia | 58 (9.2%) | 28 (15.0%) | 30 (6.8%) | < .01 |
| Heart failure | 52 (8.3%) | 24 (12.8%) | 28 (6.3%) | .01 |
| Hypertension | 233 (37.0%) | 66 (35.3%) | 167 (37.8%) | .59 |
| Diabetes | 154 (24.5%) | 56 (29.9%) | 98 (22.2%) | .04 |
| Chronic lung disease | 53 (8.4%) | 16 (8.6%) | 37 (8.4%) | 1.0 |
| Stroke | 58 (9.2%) | 16 (8.6%) | 42 (9.5%) | .77 |
| Chronic renal failure | 49 (7.8%) | 22 (11.8%) | 27 (6.1%) | .02 |
| Liver cirrhosis | 24 (3.8%) | 9 (4.8%) | 15 (3.4%) | .37 |
| Malignancy | 110 (17.5%) | 59 (31.6%) | 51 (11.5%) | < .01 |

Abbreviations: CABG, coronary artery bypass graft; CPR, cardiopulmonary resuscitation; IHCA, in-hospital cardiac arrest; OHCA: out-of-hospital cardiac arrest; PCI, percutaneous coronary intervention.

Table 2 shows the variables associated with cardiac arrest. All IHCA events were witnessed, while only 66.5% of OHCA events were witnessed (P = < .01), and pulseless electrical activity was the most common initial documented rhythm (48.1%) among patients experiencing IHCA. The proportion of ROSC was higher in IHCA patients than in OHCA patients (66.8% vs. 41.9%; P < .01). In addition, the IHCA group had lower mortality than the OHCA group (42.2% vs. 65.6%; P < .01). Time to first epinephrine injection, endotracheal intubation, and duration of CPR were significantly shorter in IHCA group than in the OHCA group. Hypothermia was performed more frequently in OHCA patients (16.5% vs. 4.8%; P < .01), while extracorporeal membrane oxygenation was conducted more frequently in IHCA patients (13.4% vs. 4.8%; P = < .01). There was no difference in the declaration of DNR after ROSC in both groups. OHCA patients had longer average hospital length of stay (2.1 days vs. 1.5 days; P < .01) and worse CPC scores at discharge (4.7 vs. 4.0; P < .01) when compared to IHCA patients. ED occupancy rate at presentation was significantly higher for patients experiencing IHCA compared to those experiencing OHCA (0.93 vs. 0.83; P = < .01). Figure 1 shows the correlation between the occurrence of cardiac arrest patients and ED occupancy at specific times for each ED zone.

Table 2
Characteristics of CPR

| | Total (N = 629) | IHCA (n = 187) | OHCA (N = 442) | P value |
|---|---|---|---|---|
| DNR after ROSC | 106 (16.9%) | 37 (19.8%) | 69 (15.6%) | .20 |
| Disposition | 369 (58.7%) | 79 (42.2%) | 290 (65.6%) | < .01 |
| Witnessed | 481 (76.5%) | 187 (100.0%) | 294 (66.5%) | < .01 |
| Initial Rhythm[a] | | | | |
| VF | | 16 (8.6%) | | |
| Pulseless VT | | 3 (1.6%) | | |
| PEA | | 90 (48.1%) | | |
| Asystole | | 47 (25.1%) | | |
| Unknown | | 30 (16.0%) | | |
| ROSC | 310 (49.3%) | 125 (66.8%) | 185 (41.9%) | < .01 |
| Hypothermia | 82 (13.0%) | 9 (4.8%) | 73 (16.5%) | < .01 |
| PCI | 26 (4.1%) | 12 (6.4%) | 14 (3.2%) | .08 |
| ECMO | 46 (7.3%) | 25 (13.4%) | 21 (4.8%) | < .01 |
| Hospitalization days | 1.9 ± 0.9 | 1.5 ± 0.8 | 2.1 ± 1.0 | < .01 |
| CPC score at discharge | 4.5 ± 1.1 | 4.0 ± 1.5 | 4.7 ± 0.7 | < .01 |
| Time from cardiac arrest, minutes | | | | |
| First defibrillation | | 6.1 ± 14.2 | | |
| First epinephrine | 20.7 ± 17.3 | 1.2 ± 3.2 | 27.8 ± 14.7 | < .01 |
| Intubation | 23.6 ± 15.6 | 5.7 ± 8.3 | 28.5 ± 13.3 | < .01 |
| Duration of CPR | 36.6 ± 25.8 | 23.6 ± 32.5 | 42.1 ± 20.1 | < .01 |
| ED occupancy rate | | | | |

Abbreviations: CPC, cerebral performance category; DNR, do not resuscitate; ECMO, extracorporeal membrane oxygenation; ED, Emergency department; IHCA, in-hospital cardiac arrest; OHCA, out-of-hospital cardiac arrest; PCI: percutaneous coronary intervention; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; VF, ventricular fibrillation; VT, ventricular tachycardia.

[a] Initial documented rhythms of OHCA were not included in the registry.

[b] Maximum and average ED occupancy rate was measured during ED stay before arrest.

| | Total (N = 629) | IHCA (n = 187) | OHCA (N = 442) | P value |
|---|---|---|---|---|
| At presentation | 0.86 ± 0.26 | 0.93 ± 0.26 | 0.83 ± 0.26 | < .01 |
| At arrest | | 0.93 ± 0.25 | | |
| Maximum[b] | | 0.98 ± 0.26 | | |
| Average[b] | | 0.93 ± 0.25 | | |
| Abbreviations: CPC, cerebral performance category; DNR, do not resuscitate; ECMO, extracorporeal membrane oxygenation; ED, Emergency department; IHCA, in-hospital cardiac arrest; OHCA, out-of-hospital cardiac arrest; PCI: percutaneous coronary intervention; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; VF, ventricular fibrillation; VT, ventricular tachycardia. | | | | |
| [a] Initial documented rhythms of OHCA were not included in the registry. | | | | |
| [b] Maximum and average ED occupancy rate was measured during ED stay before arrest. | | | | |

IHCA occurrence was positively correlated with most of ED occupancy rate except occupancy rate at ED presentation and average during ED stay of urgent zone (Table 3). All ED occupancy rate in the critical zone was positively correlated with IHCA occurrence and maximum occupancy rate of IHCA was the most strongly correlated (Spearman's $\rho = 1$, $P < .01$). Maximum ED occupancy of the urgent zone also yielded a good positive relationship with IHCA occurrence. In the entire ED, all four occupancy rates including presentation, arrest, maximum, and average had strong positive correlations with IHCA occurrence. OHCA occurrence was negatively correlated with ED occupancy at initial presentation. Table 3 summarizes the results of Spearman rank correlation tests for the relationship between the cardiac arrest occurrence and ED occupancy.

Table 3
Correlation between ED occupancy rate and cardiac arrest occurrence

| | Critical zone ED occupancy rate | | Urgent zone ED occupancy rate | | Total ED occupancy rate | |
|---|---|---|---|---|---|---|
| | ρ | p | ρ | p | ρ | p |
| IHCA time point | | | | | | |
| At ED presentation | 0.86 | .01 | 0.35 | .33 | 1.0 | < .01 |
| At time of cardiac arrest | 0.89 | < .01 | 0.77 | < .01 | 0.96 | < .01 |
| Maximum ED occupancy rate[a] | 1.0 | < .01 | 0.94 | < .01 | 1.0 | < .01 |
| Average ED occupancy rate[a] | 0.96 | < .01 | 0.44 | .20 | 1.0 | < .01 |
| OHCA time point | | | | | | |
| At ED presentation | -0.86 | .01 | -0.70 | .03 | -0.79 | .04 |

Abbreviations: ED, Emergency department; IHCA, In-hospital cardiac arrest; OHCA, Out-of-hospital cardiac arrest

[a] Maximum and average ED occupancy rate was measured during ED stay before arrest.

# Discussion

In this study, we compared various types of ED occupancy rate (at presentation, at arrest, maximum, and average during ED stay for IHCA and at presentation for OHCA occurrence). We found that the maximum ED occupancy rate is most strongly associated with IHCA occurrence. The correlation between ED occupancy rate of the critical zone and IHCA occurrence was stronger than that of the urgent zone. However, OHCA incidence was inversely correlated with ED occupancy rate.

We found that higher maximum ED occupancy rates, which may indicate the most hazardous and chaotic times in the ED, were strongly associated with sudden IHCA occurrence. In a recent observational retrospective study conducted by Chang et al., ED crowding was roughly associated with IHCA occurrence.[24] In this study, ED bed occupancy rate (EDBOR) was used as an overcrowding index by calculating the ratio of the total number of filled beds divided by the total number of licensed ED beds. However, EDBOR is an index that has never been used before and it is difficult to compare with other studies. Moreover, the EDBOR might lead to substantial selection bias because filled beds may not reflect the proportion of critically-ill patients at risk of experiencing IHCA in the ED, such as patients waiting for a bed. Liu et al. recently found that there was no association between IHCA events and EDBOR when they calculated the IHCA incidence rate.[25]

We also questioned the value of only measuring ED occupancy rate only at ED presentations, which is done in most ED occupancy rate studies, as it might not be sufficient to evaluate the types of overcrowding that ED patients may experience during their ED stay. Other measurements, such as at time of presentation, arrest, or maximum occupancy, or average ED occupancy rate during ED stay may be better parameters for reflecting overcrowding. To the best of our knowledge, this study is the first study that compared the relationship between IHCA occurrence and ED occupancy rate at these times. Chang's study used three arbitrary cut-off values of the bed occupancy rate,[23] but ED occupancy rate crowding measures should be dealt with as a continuous variable because there is no standard threshold. In our study, we normalized with IHCA incidence per hour for each ED occupancy rate interval (0.2 increment for critical zone and 0.4 increment for urgent zone) and found there was a strong association between unexpected IHCA and ED occupancy rate. Meanwhile, our study also proved that not only overall crowding but the portion of critically ill patients dramatically impacts on the occurrence of IHCA. In the Spearman rank correlation test, all rho values of critical zone were higher than that of urgent zone. Moreover, critical zone showed definite positive correlation with IHCA occurrence at sub-maximal level of ED occupancy rate ($\leq 0.9$). These trends would imply that even small number of critical patients could compromise the quality of ED services and surveillance ability at risk patients.

In contrast to IHCA, OHCA occurrence had an inverse relationship with ED occupancy rate. Kang et al. measured ED occupancy rate of each OHCA cases at arrival and found the incidence of OHCA was a negatively correlated with ED occupancy rate, which was similar to the trend observed in our study.[14] We think that one plausible reason for this result is ambulance diversion. In South Korea, emergency medical services notify the nearest hospital that they are transporting an OHCA patient, but the hospital may divert ambulances when if the ED is at capacity. Similar to previous reports, our study found that OHCA patients had worse clinical outcomes than IHCA cases, including higher mortality, higher CPC score at discharge, lower ROSC rates, and shorter hospitalization stays, even though IHCA patients had more comorbidities.[26,27] This might be because IHCA was usually witnessed, and had shorter times to first epinephrine injection and intubation, and shorter duration of CPR when compared to OHCA events.[24, 25]

# Limitations

Our study had several limitations. First, the retrospective cohort design imposes intrinsic limitations on the study, making it difficult to generalize the findings. Second, we could not exclude various confounding factors, including the different proportions of underlying diseases between IHCA and OHCA patients in our study. Malignancies, arrhythmia, and heart failure were more common in IHCA patients than in OHCA patients, which may impact risk of sudden cardiac arrest. In cases of OHCA, we could not collect the initial rhythm and first defibrillation time because of the retrospective design. Lastly, this study included a relatively small number of patients at a single center.

# Conclusion

We found that maximum ED occupancy rate is strongly associated with the IHCA occurrence. OHCA is inversely correlated with ED occupancy rate.

# Abbreviations

CPC, cerebral performance category

CPR, cardiopulmonary resuscitation

DNR, do-not-resuscitate

ED, emergency department

EDBOR, emergency department bed occupancy rate

IHCA, in-hospital cardiac arrest

IQR, interquartile range

OHCA, out-of-hospital cardiac arrest

ROSC, return of spontaneous circulation

# Declarations


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None.


## Authors' contribution

J.S.K. and H.J.B. participated in drafting, data analyzing. C.H.S. and S.E.C. participated in conceptualizing and data collecting. J.E.H. and W.Y.K. read and revised the manuscript. N.K.K. and D.W.S. supervised, read, and approved the final manuscript.


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None.


## Availability of data and materials

The datasets generated analyzed during the current study are available from the corresponding author on reasonable request.

### Ethics approval and consent to participate

Reviewed and approved by Asan Medical Center IRB with waiver of written consent.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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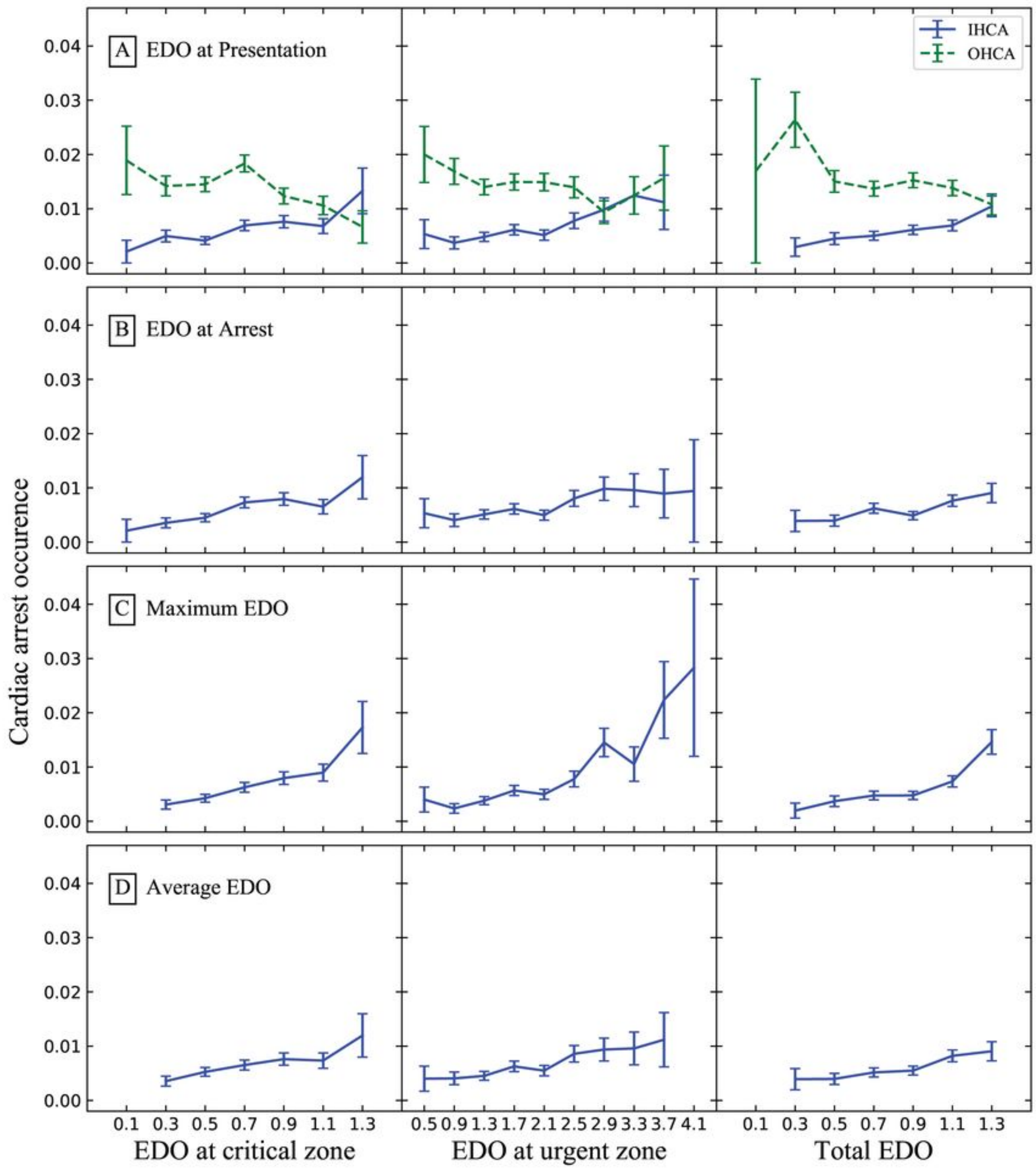
## Figures




## Figure 1

Comparison of the association of ED occupancy rate at critical and urgent zone and cardiac arrest occurrence for four different timings; at presentation, at arrest, maximum, and average on ED stay.