

Emergency department crowding and cardiac arrest: A retrospective time-series study

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Abstract

Background

Emergency department (ED) crowding has been associated with adverse patient outcomes, but emergency department cardiac arrest (EDCA) remains understudied. We examined the association between daily ED crowding and EDCA rates and described temporal changes in EDCA before and after implementation of a fast-track model designed to reduce crowding.

Methods

We conducted a retrospective time-series study at a single emergency department from October 1, 2021, to December 31, 2024. Daily crowding was quantified using the maximum emergency department occupancy rate (EDOR), and daily EDCA counts were analysed using Poisson regression with the number of ED contacts as an offset. Models included calendar time, weekday, and season. EDOR was analysed both continuously and categorically ($< 100\%$, $100\text{--}129\%$, and $\geq 130\%$). A segmented time-series analysis was used to describe changes in EDCA rates around implementation of the fast-track model. Negative-binomial models were used as sensitivity analyses.

Results

During 1,188 observation days, there were 158,886 ED contacts and 72 EDCA events. The crude EDCA rate was 6.61 per 10,000 ED contacts before and 2.78 per 10,000 contacts after implementation of the fast-track model. Maximum EDOR $\geq 130\%$ occurred on 292 (53.4%) pre-intervention days and 126 (19.7%) post-intervention days. In the adjusted analysis, each 10-percentage-point increase in maximum daily EDOR was associated with a 22% higher EDCA rate (IRR 1.22, 95% CI 1.09–1.36; $p < 0.001$). Compared with days with EDOR $< 100\%$, days with EDOR $\geq 130\%$ had a higher EDCA rate (IRR 5.90, 95% CI 1.83–19.04; $p = 0.003$). Negative-binomial sensitivity analysis yielded similar estimates. The segmented time-series analysis did not demonstrate a statistically significant immediate change in EDCA rates at the start of the post-intervention period (IRR 0.90, 95% CI 0.37–2.16; $p = 0.810$).

Conclusion

Higher maximum daily ED occupancy was associated with higher EDCA rates in this single-centre retrospective study. EDCA rates and exposure to extreme crowding were both lower during the post-intervention period, but the temporal analysis did not demonstrate a statistically significant immediate change in EDCA rates following implementation of the fast-track model. These findings describe an association between ED crowding and EDCA but do not establish a causal relationship.

1.0 Introduction

Emergency Department (ED) crowding occurs when demand for emergency care exceeds available capacity. It is a widespread concern and has been associated with impaired clinical decision-making, increased medication errors, delays in time-sensitive treatment, and other adverse clinical outcomes [1–4]. ED crowding has also been associated with increased in-hospital mortality [4] and strained working conditions for ED staff [5].

In-hospital cardiac arrests (IHCA) can be divided into ED cardiac arrests (EDCA) and hospital ward cardiac arrests (HWCA). Several studies have reported an association between ED crowding and unexpected IHCA [6–9]. However, EDCA remain a relatively understudied subgroup of IHCA. As patients may spend substantial periods of time in the ED before cardiac arrest, early recognition of clinical deterioration is an important aspect of ED care [10]. EDCA has been reported to account for a substantial proportion of IHCA cases [11] while other studies have identified differences in patient characteristics and risk factors among patients experiencing EDCA [12]. EDCA has also been proposed as a distinct category of cardiac arrest because of differences in patient characteristics, outcomes, and clinical circumstances [13].

An operational measure of ED crowding is the emergency department occupancy rate (EDOR), defined as the number of patients present in the ED relative to the number of available ED beds [14]. EDOR provides a readily measurable measure of crowding that can be derived from routinely collected electronic health record data and may therefore be useful for monitoring crowding in clinical practice [14, 15].

We have previously reported a multifaceted fast-track approach aimed at improving ED patient flow and reducing crowding [16]. The intervention included nurse-led selection of eligible patients, allocation of a decision-competent physician, frontloading of standard blood tests, and streamlining of the patient pathway through the ED. In the previous study, the intervention was associated with an 84% reduction in the mean quarterly number of hours during which ED occupancy exceeded 130% [16].

Despite the growing literature linking ED crowding with IHCA and emerging evidence concerning EDCA, the association between the degree of ED crowding and cardiac arrest occurring specifically in the ED remains insufficiently studied. Furthermore, it is unclear whether temporal reductions in ED crowding are accompanied by corresponding changes in EDCA rates. Therefore, the aim of this study was (1) to examine the association between daily ED crowding and EDCA rates and (2) to describe temporal changes in EDCA rates before and after implementation of a fast-track model associated with reduced ED crowding.

2.0 Materials and Methods

2.1 Ethical approval

The data access responsible Vice President, on behalf of the Institutional Review Board at North Zealand Hospital, deemed individual patient consent unnecessary because the data were originally collected for departmental healthcare quality assessment. The aggregated quality data were anonymized and could subsequently be used for research purposes. This was in accordance with the Danish Health Care Act [17]. The study was conducted in accordance with the principles of the Declaration of Helsinki.

2.2 Study design and setting

This was a single-centre retrospective time-series study conducted at the Emergency Department (ED) of North Zealand Hospital in the Capital Region of Denmark. The study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [18].

The hospital serves a population of approximately 324,000 citizens. As previously described, patients are referred to the ED by general practitioners, an emergency service telephone line, or ambulance services [16]. The ED provides care for acute patients aged ≥ 18 years referred for evaluation, except for patients with gynaecological or obstetric conditions. Approximately 50,000 referred patients are treated annually.

The ED has dedicated nursing and medical staff. There were no changes in the overall numerical staffing between the two study periods, apart from the systematic competency assessment of nurses and physicians allocated to the fast-track pathway.

The study population comprised patients referred for evaluation of suspected medical, neurological, or surgical conditions, including stroke, appendicitis, myocardial infarction, pneumonia, and other conditions potentially requiring hospital admission. Patients presenting with minor injuries, approximately 35,000 annually, and patients referred to the out-of-hours general practitioner service, who are not assessed in the ED, were not included.

EDCA was defined as cardiac arrest occurring after arrival in the ED and before transfer to another hospital department. The available data did not allow reliable determination of the exact patient location, monitoring status, or clinical trajectory immediately preceding cardiac arrest.

2.3 Participants

Data from **158,886 ED contacts** recorded between October 1, 2021, and December 31, 2024, were included in the study. The observation period comprised **1,188 consecutive calendar days**, with no missing observation days.

All patients in the ED were registered through the Emergency Outpatient Incident Registration (EOIR). Patients with a documented do-not-resuscitate order and patients with cardiac arrest on arrival were excluded from the EDCA outcome analysis.

2.4 Variables

The primary exposure was EDOR. EDOR was calculated as the number of patients physically present in the ED divided by the number of designated treatment locations. The ED has 33 designated treatment locations, including gurneys, chairs, and beds; thus, 33 simultaneously present patients corresponded to an EDOR of 100%.

Patients physically present in the ED included patients in waiting areas, treatment areas, hallways, and monitored treatment spaces.

For each calendar day, the **maximum daily EDOR** was defined as the highest EDOR recorded during that day. Maximum daily EDOR was analysed primarily as a continuous exposure. For interpretability, the primary regression estimate was expressed per **10-percentage-point increase** in maximum daily EDOR.

In a secondary categorical analysis, maximum daily EDOR was categorized into three predefined operational levels: **<100%, 100–129%, and $\geq 130\%$** . An EDOR $\geq 130\%$ represents a clinically recognized level of crowding at the study site at which additional operational actions are initiated.

The study period was divided into two periods according to implementation of the crowding-reduction intervention. Period 1 comprised October 1, 2021, through March 31, 2023, and period 2 comprised April 1, 2023, through December 31, 2024. The multifaceted intervention was implemented on March 31, 2023, and included systematic fast-tracking of eligible low-risk patients, as previously described [16].

Patients presenting to the ED were triaged according to standard regional triage procedures (I-DEPT). HWCA within 72 hours of admission was evaluated as a secondary outcome. This analysis was exploratory and was intended to describe whether the temporal pattern observed for EDCA was associated with a change in early inpatient cardiac arrest. A 72-hour window was chosen to capture early post-admission cardiac arrest events following the index ED encounter.

2.4.1 Clinical data

Daily data included the number of patients physically present in the ED, maximum daily EDOR, the number of ED contacts, and the number of EDCA events.

EDCA events were identified from the hospital cardiac arrest registry and linked to the corresponding daily ED data.

2.5 Data sources

Data on ED activity and occupancy were extracted from the electronic health record (EHR) system Epic's data warehouse using SAP Web Intelligence and processed using the R statistical environment.

EDCA events were obtained from the hospital's quality reporting system (FLIS), which contributes data to the national Danish Cardiac Arrest Registry (DANARREST). Medical record review was performed to verify the classification and accuracy of identified cardiac arrest events.

2.6 Potential sources of bias

Several potential sources of bias were considered.

First, the study used **maximum daily EDOR**, defined as the highest occupancy recorded during the calendar day. This measure does not establish that the maximum occupancy occurred before an EDCA event. In addition, an EDCA event and the subsequent resuscitation may themselves temporarily increase occupancy and resource use within the ED. Therefore, reverse causation cannot be excluded.

Because individual event-level occupancy immediately preceding EDCA was not available for reliable analysis, the primary EDOR analysis should be interpreted as an **observational, contemporaneous ecological association at the calendar-day level**, rather than as evidence that crowding preceded or caused cardiac arrest.

Second, residual confounding cannot be excluded. The analyses accounted for calendar time, weekday, and seasonality, but other factors that may influence both ED occupancy and EDCA risk were not available in the dataset.

Third, EDCA events were identified from routinely collected hospital records. Assuming broadly consistent reporting procedures across the study period, changes in documentation or ascertainment practices over time could nevertheless introduce detection bias.

Finally, the retrospective study design and the use of aggregate daily data limit the ability to establish individual-level temporal relationships between ED crowding and cardiac arrest.

2.7 Study size

No formal a priori sample size or statistical power calculation was performed. The study size was determined by the number of eligible ED contacts and cardiac arrest events available during the predefined study period.

2.8 Statistical methods

All statistical analyses were performed using R statistical software (R Foundation for Statistical Computing, Vienna, Austria). A two-sided p-value <0.05 was considered statistically significant.

Continuous variables are presented as mean $\pm$ standard deviation (SD) or median with interquartile range (IQR), as appropriate, and categorical variables as counts and percentages. Crude EDCA rates were calculated as the number of EDCA events per 10,000 ED contacts.

Daily EDCA counts were analysed using Poisson regression with the number of ED contacts per day included as an offset:

The primary exposure-outcome analysis estimated the association between maximum daily EDOR and daily EDCA rate. EDOR was entered as a continuous variable and scaled per 10-percentage-point increase. Models were adjusted for continuous calendar time, weekday, and season. Incidence rate ratios (IRRs) are therefore interpreted as the relative difference in the daily EDCA rate associated with a 10-percentage-point difference in maximum daily EDOR, conditional on the covariates included in the model.

A secondary analysis examined maximum daily EDOR as a categorical variable using <100% as the reference category and categories of 100–129% and $\geq 130\%$.

Separately, a segmented time-series analysis was used to describe temporal changes in EDCA rates before and after implementation of the fast-track intervention. This model included calendar time, an indicator for the post-intervention period, and a post-intervention time variable, with daily ED contacts as the offset. **EDOR was not included in this intervention model**, because the "intervention" was designed to reduce ED crowding and EDOR may therefore lie on the pathway between the intervention and the observed outcome. The segmented model was used to describe changes in EDCA rates over time and was not interpreted as an estimate of a causal intervention effect.

Negative-binomial regression models were fitted as sensitivity analyses for both the EDOR association and the segmented time-series analysis.

Model estimates are reported as IRRs with 95% confidence intervals (CIs) and corresponding p-values. Crude rates are reported separately from adjusted regression estimates. Model dispersion was assessed by comparing residual deviance with residual degrees of freedom. Model fit was assessed using the Akaike Information Criterion (AIC). Residual autocorrelation was assessed using autocorrelation function (ACF) plots of Pearson residuals.

3.0 Results

3.1 Patient and crowding characteristics

A total of 284 in-hospital cardiac arrests (IHCAs) were screened, of which 72 were classified as EDCA (**Figure 1**). The mean age was 72 (14) years, and 65% of patients were male. No major differences in

demographic characteristics were observed between the two study periods.

A total of 1,188 consecutive observation days were included, comprising 547 days in period 1 and 641 days in period 2. During the study period, **158,886 ED contacts** were registered. There were 48 EDCA events in period 1 and 24 in period 2. The crude EDCA rate was **6.61 per 10,000 ED contacts** in period 1 and **2.78 per 10,000 ED contacts** in period 2 (**Table 1**).

Rates of HWCA within 72 hours of admission remained non-different between the two periods (0.062 vs. 0.056 events/day; rate ratio 0.90, $p = 0.67$).

Maximum daily ED occupancy was higher in period 1 than in period 2 (**Figure 2**). The mean maximum EDOR was 131% in period 1 and 112% in period 2. Days with maximum EDOR $\geq 130\%$ occurred on **292/547 days (53.4%)** in period 1 and **126/641 days (19.7%)**.

3.2 Association between crowding and EDCA rates

Across EDOR categories, 3 EDCA events occurred during 207 days with EDOR $<100\%$, 15 events during 563 days with EDOR 100–129%, and 54 events during 418 days with EDOR $\geq 130\%$ (**Figure 3, Table 2**).

In the adjusted Poisson regression model, **higher maximum daily EDOR was associated with higher EDCA rates** after adjustment for calendar time, weekday, and season. For each 10-percentage-point increase in maximum daily EDOR, the EDCA rate was **22% higher** (IRR 1.22, 95% CI 1.09–1.36; $p < 0.001$).

In the categorical analysis, days with EDOR $\geq 130\%$ had a higher EDCA rate compared with days with EDOR $<100\%$ (IRR 5.90, 95% CI 1.83–19.04; $p = 0.003$). The association for EDOR 100–129% was not statistically significant (IRR 1.56, 95% CI 0.45–5.39; $p = 0.48$) (**Table 4**). A gradual decrease in EDCA rates over calendar time was also observed in the adjusted continuous EDOR model (IRR per day 0.9992, 95% CI approximately 0.9985–0.9998; $p = 0.034$).

Negative-binomial sensitivity analysis produced similar estimates for the association between EDOR and EDCA (IRR 1.22, 95% CI 1.09–1.37; $p < 0.001$).

3.3 Temporal changes in EDCA rates following implementation of fast-track

A segmented time-series analysis was used to describe temporal changes in EDCA rates before and after implementation of the fast-track model. The analysis did not demonstrate a statistically significant immediate change in EDCA rates at the start of the post-intervention period (IRR 0.90, 95% CI 0.37–2.16; $p = 0.81$) (**Table 3**).

There was a non-significant tendency towards a steeper decline in EDCA rates during the post-intervention period (IRR per day 0.9973, 95% CI 0.9944–1.0002; $p = 0.071$).

Thus, although both maximum daily EDOR and the crude EDCA rate were lower during period 2, the segmented time-series analysis did not demonstrate a statistically significant immediate change in EDCA rates associated with the start of the post-intervention period.

4.0 Discussion

In this single-centre retrospective time-series study, higher maximum daily ED occupancy was associated with higher EDCA rates after adjustment for calendar time, weekday, and season. Each 10-percentage-point increase in maximum daily EDOR was associated with a 22% higher EDCA rate (IRR 1.22, 95% CI 1.09–1.36). Days with EDOR $\geq 130\%$ were also associated with higher EDCA rates compared with days with EDOR $< 100\%$. Negative-binomial sensitivity analyses yielded similar estimates.

These findings are consistent with previous studies reporting associations between ED crowding and cardiac arrest in or around the emergency department [6–9].

An important finding of the present study is that maximum daily EDOR and EDCA rates were both lower during the post-intervention period. The proportion of days with EDOR $\geq 130\%$ decreased from 53.4% to 19.7%, while the crude EDCA rate decreased from 6.61 to 2.78 per 10,000 ED contacts. However, the segmented time-series analysis did not demonstrate a statistically significant immediate change in EDCA rates at the start of the post-intervention period. There was a non-significant tendency towards a steeper decline in EDCA rates during the post-intervention period. Thus, the observed temporal reduction in EDCA rates should not be interpreted as evidence that the fast-track intervention caused a reduction in EDCA.

The association between crowding and EDCA may reflect several mechanisms. ED crowding can involve delayed assessment, prolonged waiting, reduced availability of monitoring, interruptions in workflow, and increased cognitive workload for healthcare professionals. These conditions may make recognition of clinical deterioration more difficult. However, the present study was not designed to investigate the mechanisms underlying the observed association, and these explanations should therefore be regarded as hypotheses rather than demonstrated causal pathways.

The fast-track model was associated with a substantial reduction in exposure to extreme crowding in the present setting. The model included several components intended to improve patient flow, including early nurse assessment, early blood sampling, allocation of appropriately qualified physicians, a redesigned physical patient pathway, use of chairs and gurneys for patients expected to have shorter stays, and separation of fast-track patients from patients requiring more extensive assessment or hospital admission. The present study cannot determine which, if any, of these components contributed to the observed changes in EDOR or EDCA rates. The findings therefore describe the temporal association between implementation of a multifaceted organisational model, reduced crowding, and changes in EDCA rates rather than an effect attributable to any individual component.

An important concern when interpreting a reduction in EDCA is whether cardiac arrests may instead have occurred shortly after admission to a hospital ward. In this study, the rate of HWCA within 72 hours of admission did not differ significantly between the two periods. This provides no evidence of a compensatory increase in early ward cardiac arrests corresponding to the lower EDCA rate. Nevertheless, this secondary analysis cannot exclude other changes in patient trajectories or clinical practice, and it should not be interpreted as demonstrating that adverse events were prevented.

The principal strength of this study is the complete daily observation series over 1,188 consecutive days, combined with prospectively recorded ED activity and verified EDCA events. The study also examines ED crowding using maximum daily EDOR, an operational measure that captures periods when the number of patients physically present exceeds the department's designated treatment capacity. The use of both continuous and categorical measures of EDOR, together with negative-binomial sensitivity analyses, produced consistent findings.

Several limitations should be considered. First, the study is retrospective and single-centre, and the relatively small number of EDCA events limits the complexity of statistical modelling and the precision of estimates. Second, maximum daily EDOR was defined as the highest occupancy recorded during the calendar day. Because the timing of maximum occupancy was not aligned to the timing of individual EDCA events in the present analysis, we cannot establish that the recorded crowding preceded the cardiac arrest. Reverse causation is therefore possible, as cardiac arrest and subsequent resuscitation may themselves temporarily increase occupancy and resource utilisation. Third, although models accounted for calendar time, weekday, and season, residual confounding by other changes in patient characteristics, clinical practice, staffing, or hospital organisation cannot be excluded. Finally, the analysis was performed at the daily aggregate level, limiting individual-level interpretation.

Overall, the findings indicate that higher maximum daily ED occupancy was associated with higher EDCA rates in this single-centre setting. The reduction in extreme crowding and the lower EDCA rate observed during the post-intervention period occurred concurrently, but the temporal analysis did not demonstrate a statistically significant immediate change in EDCA rates associated with implementation of the fast-track model. These findings therefore support an association between ED crowding and EDCA but do not establish a causal relationship.

5.0 Conclusions

In this single-centre retrospective time-series study, higher maximum daily ED occupancy was associated with higher EDCA rates after adjustment for calendar time, weekday, and season. Days with EDOR $\geq 130\%$ had substantially higher EDCA rates than days with EDOR $< 100\%$. Both exposure to extreme crowding and crude EDCA rates were lower during the post-intervention period; however, the segmented time-series analysis did not demonstrate a statistically significant immediate change in EDCA rates following implementation of the fast-track model.

These findings describe an association between ED crowding and EDCA but do not establish causality. Further multicentre studies using event-timed measures of ED crowding are needed to investigate the temporal relationship between crowding and EDCA and to determine whether interventions that reduce crowding are associated with changes in EDCA incidence.

Declarations

Consent for publication

All authors have consented for publication.

Availability of data and materials

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

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

HL, JJJ, TAS, AT, and JPH conceived and designed the original protocol. All authors were involved in amending the protocol. HL, JJJ, JPH, and TAS coordinated the study throughout. Data entry was carried out by HL, AT, and JPH. JPH cleaned the data and ran preliminary analysis with input from HL and TAS. HL and JPH analysed the data. JPH and HL wrote the first draft of the manuscript with input from all other authors. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

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Tables

Table 1
Characteristics of the study periods

Variable	Pre-intervention	Post-intervention
Observation days, n	547	641
ED contacts, n	72,586	86,300
EDCA events, n	48	24
EDCA rate per 10,000 ED contacts	6.61	2.78
Mean maximum EDOR, %	130.7	112.2
SD of maximum EDOR, %	24.8	18.5
Median maximum EDOR, %	130	112
IQR of maximum EDOR, percentage points	33	24
Days with EDOR $\geq$ 130%, n	292	126
Days with EDOR $\geq$ 130%, %	53.4	19.7
Characteristics of the study periods before and after implementation of the fast-track model. EDCA rates are calculated per 10,000 ED contacts. EDOR represents the maximum emergency department occupancy rate recorded during each calendar day. IQR, interquartile range; ED, emergency department; EDCA, emergency department cardiac arrest; EDOR, emergency department occupancy rate.		

Table 2
EDCA rates according to maximum daily EDOR category

Maximum daily EDOR	Observation days, n	ED contacts, n	EDCA events, n	EDCA rate per 10,000 ED contacts	95% CI
< 100%	207	23,924	3	1.25	0.26–3.66
100–129%	563	73,990	15	2.03	1.13–3.34
≥ 130%	418	60,972	54	8.86	6.65–11.56
Crude EDCA rates according to maximum daily EDOR category. Rates are expressed per 10,000 ED contacts. Confidence intervals are exact 95% Poisson confidence intervals. ED, emergency department; EDCA, emergency department cardiac arrest; EDOR, emergency department occupancy rate.					

Table 3
Segmented time-series analysis of daily EDCA rates

Variable	IRR	95% CI	P value
Calendar time	1.00	1.000–1.002	0.994
Post-intervention level	0.90	0.370–2.161	0.811
Post-intervention time trend	0.99	0.994–1.000	0.071
Segmented Poisson regression analysis of temporal changes in daily EDCA rates before and after implementation of the fast-track model. The model included calendar time, a post-intervention indicator, and time since implementation, with the number of daily ED contacts included as an offset. IRRs represent the relative change in EDCA rate associated with each model term. EDCA, emergency department cardiac arrest; IRR, incidence rate ratio; CI, confidence interval.			

Table 4
Association between EDOR category and EDCA rates

Maximum daily EDOR	IRR	95% CI	P value
< 100%	Reference	—	—
100–129%	1.56	0.45–5.39	0.483
≥ 130%	5.90	1.83–19.04	0.003
Calendar time	0.999	0.998–1.000	0.027

Association between maximum daily EDOR category and daily EDCA rates. EDOR < 100% was used as the reference category. The Poisson regression model was adjusted for calendar time, with the number of daily ED contacts included as an offset. IRRs represent the relative EDCA rate compared with the reference category. EDCA, emergency department cardiac arrest; EDOR, emergency department occupancy rate; IRR, incidence rate ratio; CI, confidence interval.

Figures

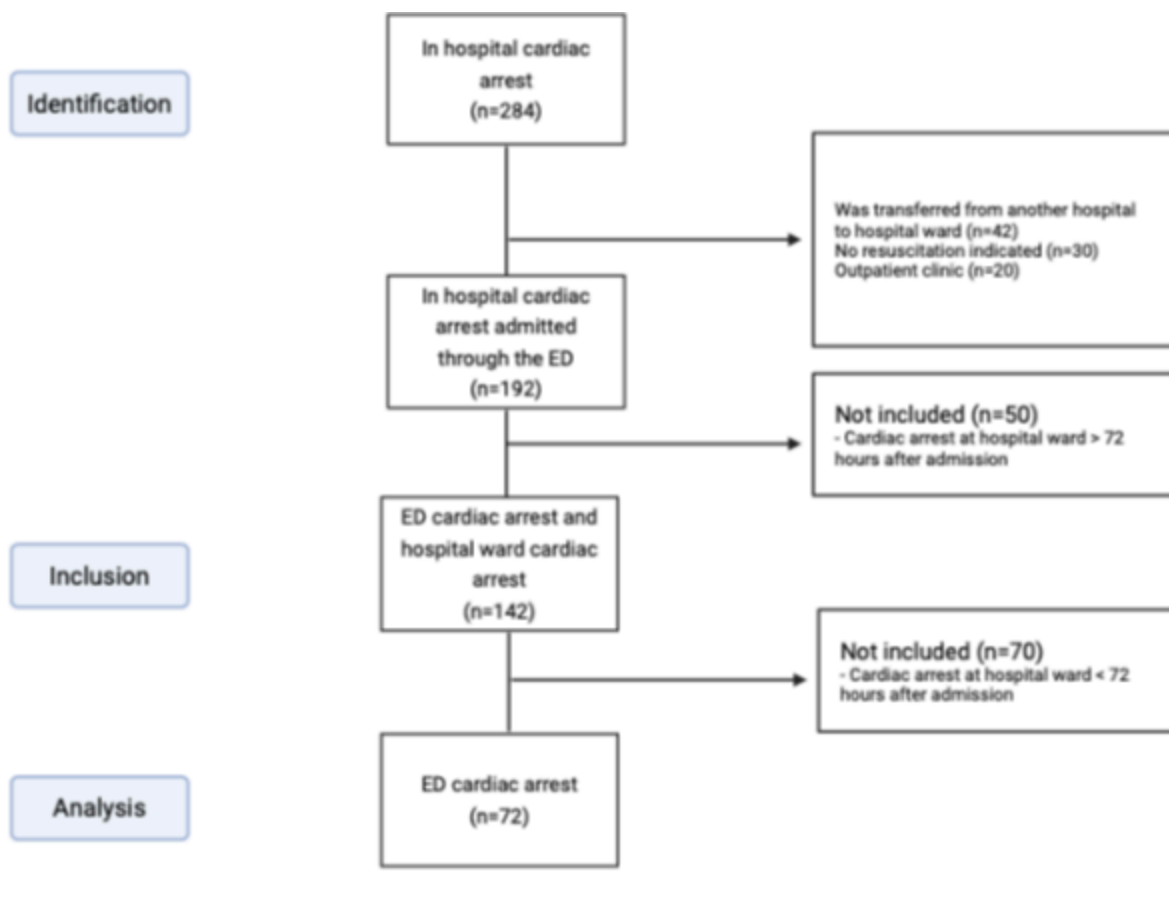


Figure 1

STROBE flow diagram of cardiac arrest cases screened and classified for inclusion in the study. Abbreviations: ED, emergency department; EDCA, emergency department cardiac arrest; IHCA, in-hospital cardiac arrest; n, number of cases. Created with BioRender.com.

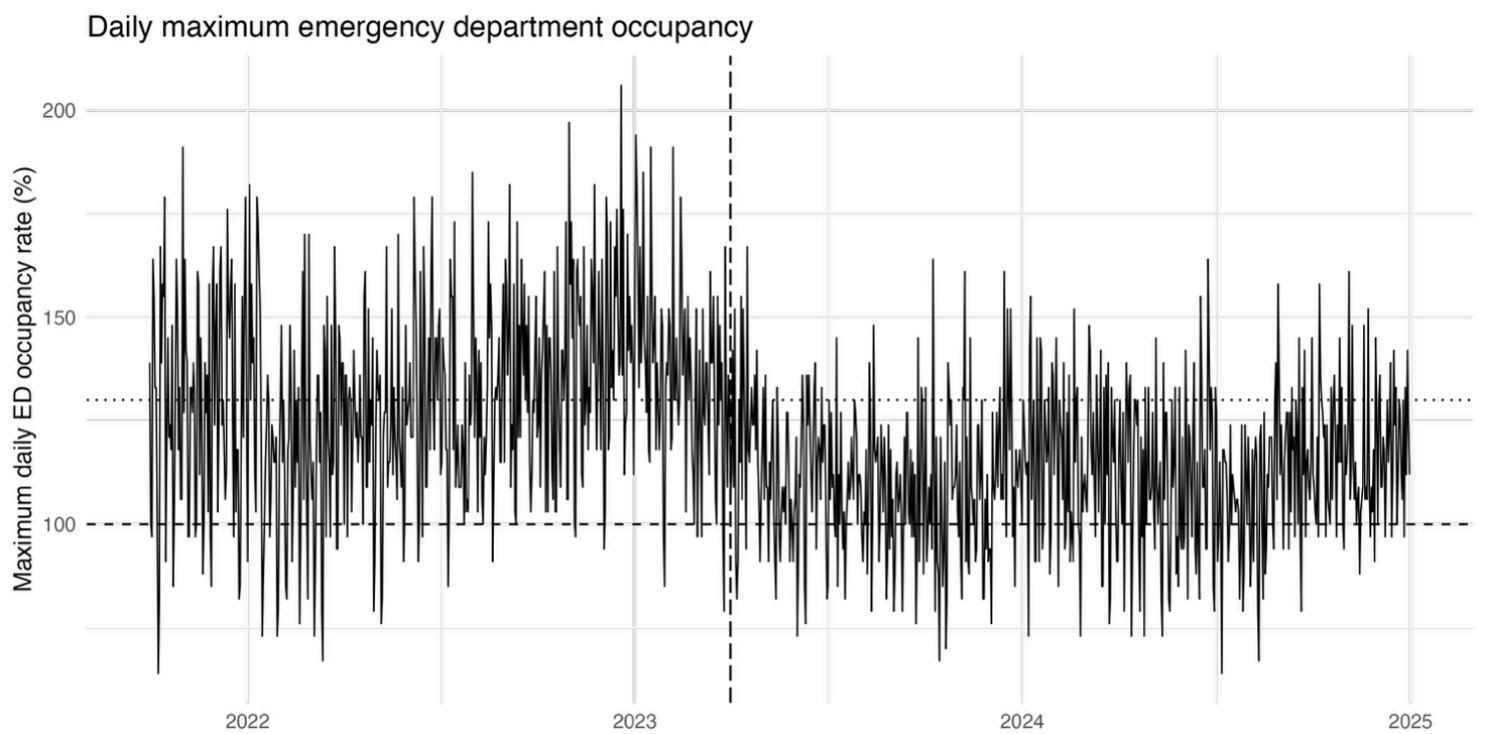


Figure 2

Daily maximum emergency department occupancy rate (EDOR) during the study period. The horizontal dashed lines indicate EDOR of 100% and 130%. The vertical line indicates implementation of the fast-track model on March 31, 2023. EDOR values represent the maximum occupancy recorded during each calendar day.

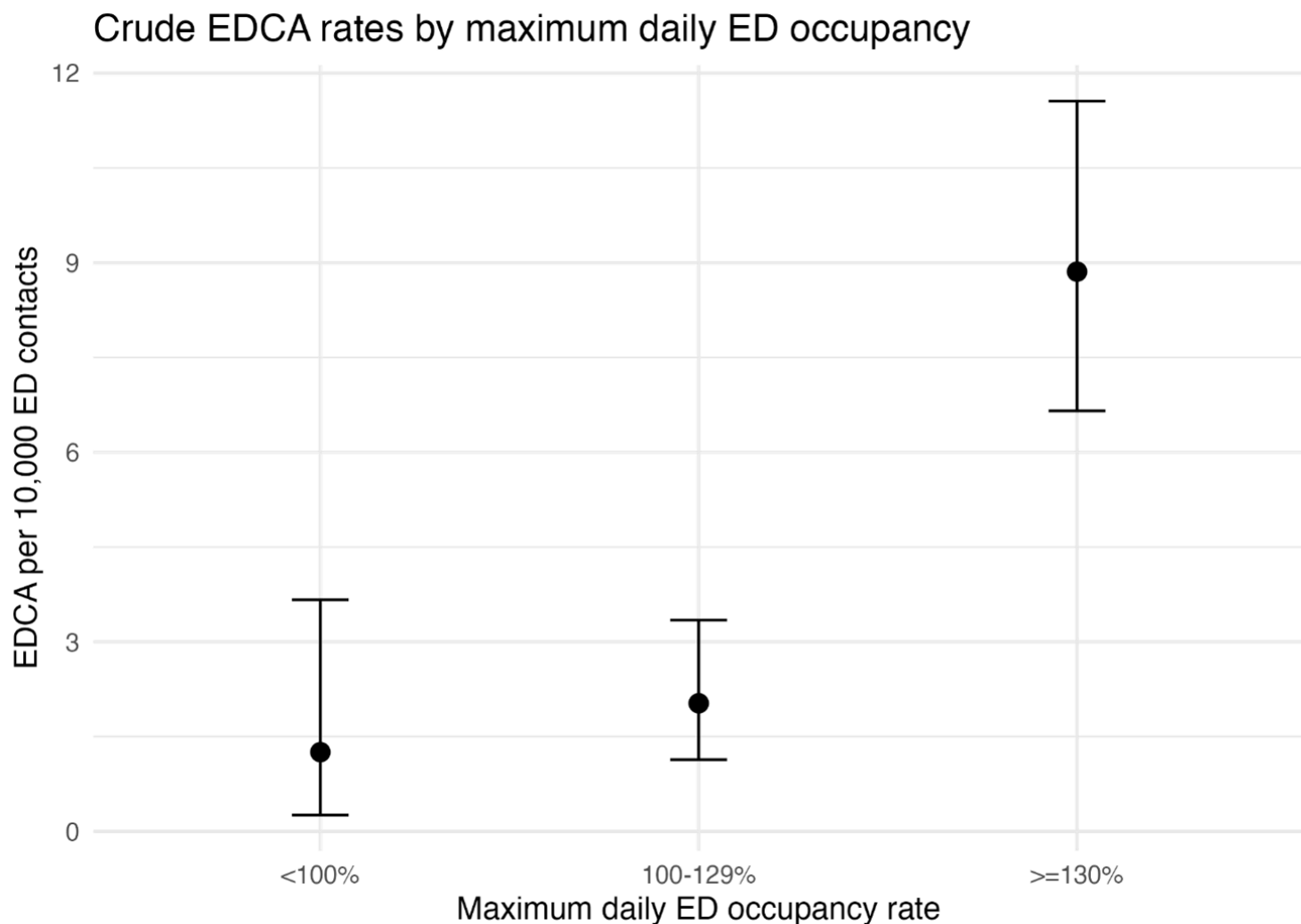


Figure 3

Crude emergency department cardiac arrest (EDCA) rates according to maximum daily emergency department occupancy rate (EDOR) category. Rates are expressed per 10,000 ED contacts, with exact 95% Poisson confidence intervals. EDOR categories were defined as <100%, 100–129%, and $\geq$ 130%