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Short paper

Data-driven classification of arrest location for emergency department cardiac arrests

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Abstract

Background: Resuscitation research is inconsistent in how emergency department (ED) arrests are classified. We tested whether clinical features of ED arrests more closely resembled out-of-hospital cardiac arrest (OHCA) or in-hospital cardiac arrest (IHCA).

Methods: We performed a retrospective study including all patients resuscitated from cardiac arrest at a single academic medical center from January 2010 to December 2019. We abstracted clinical information from our prospective registry. We used unsupervised learning (k-prototypes) to identify clusters within the OHCA and IHCA cohorts. We determined the number of subgroups using scree plots. We assigned individual ED arrest patients the nearest OHCA or IHCA cluster based on the shortest Gower distance from that patient to the nearest cluster center. In our secondary analysis, we determined the optimal number of clusters in each of the 3 arrest cohorts, and then calculated the mean Gower distances with the standard deviation (SD) between cluster centers (ED-IHCA, ED-OHCA, IHCA-OHCA).

Results: We included 2723 patients: 372 (14%) ED arrests, 1709 (63%) OHCA, and 642 (23%) IHCA. We identified 3 clusters of OHCA patients, and 4 clusters of IHCA patients. Of ED arrest cases, 292 (78%) most closely resembled an IHCA cluster and 80 (22%) most closely resembled an OHCA cluster. Mean (SD) Gower distance between ED arrest and IHCA centers was 0.33 (0.2). Mean Gower distances between ED arrest-OHCA centers and between IHCA-OHCA centers were 0.41 (0.11).

Conclusion: Across multiple aggregated measures, ED arrests resemble IHCA more than OHCA.

Keywords: Cardiac arrest, Unsupervised learning, Clustering

Introduction

Cardiac arrest is common and occurs both out-of-hospital (OHCA) and after hospital admission (IHCA). Since OHCA and IHCA have epidemiological and clinical differences, classification of arrest location is important in clinical research.[1,2] Cardiac arrest may also occur in outpatient healthcare settings such as the emergency department (ED).[3] Past classification of ED arrests as IHCA or OHCA is typically based on expert opinion rather than data. We used unsupervised learning to compare clinical characteristics of ED arrests to IHCA and OHCA.

Methods

Study design

We performed a retrospective analysis of a prospective registry that includes consecutive patients treated after resuscitation from cardiac

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arrest at a single academic medical center in Western Pennsylvania. Our center is a large tertiary care hospital that receives via interfacility transfer OHCA patients who were initially transported to other hospitals as well as patients resuscitated from IHCA in other hospitals. Trained abstractors enter registry data after structured review of prehospital and hospital medical records.[4–6] We included all patients treated from January 2010 to December 2019 without any exclusions. The University of Pittsburgh Human Research Protection Office approved this study.

Data collection

We extracted clinical information from our registry. This included arrest location, which was assigned based on the initial location of collapse (ED arrest, OHCA or IHCA); age; sex; initial arrest rhythm (ventricular tachycardia or fibrillation; pulseless electrical activity; asystole; or, unknown); number of standard doses of epinephrine (adrenaline), bicarbonate and shocks given during the arrest; total arrest duration in minutes; most advanced airway used intra-arrest (none; bag-valve-mask; supraglottic airway; endotracheal intubation; advanced airway placed prior to arrest (for ED arrests or IHCA); other; or, unknown); number of rearrests; early post-arrest illness severity modeled as Pittsburgh Cardiac Arrest Category (PCAC);[7,8] and survival to hospital discharge. PCAC is a validated 4-level ordinal scale summarizing illness severity after cardiac arrest as follows: awake (PCAC I), moderate coma without cardiorespiratory failure (PCAC II), moderate coma with cardiorespiratory failure (PCAC III), and severe coma (PCAC IV).[7,8] In cases of unwitnessed OHCA, we defined arrest duration as time from 911 call to ROSC.

Statistical analysis

We used descriptive statistics to summarize baseline population characteristics and clinical features by arrest location (OHCA; ED arrest; or IHCA) and in the overall cohort. We reported normally distributed continuous variables using means with standard deviations (SD), reported medians with interquartile ranges [IQR] for non-normal continuous variables and raw numbers with corresponding percentages for categorical variables.

We used unsupervised learning, a data-driven analytical approach to identify patterns within complex data without consideration of outcome labels. We used the "clustMixType" package in R to perform k-prototypes clustering, one of the methods used in unsupervised learning.[9] We selected k-prototypes because of its efficiency in dealing with large data sets with mixed continuous and categorical variables.[10] In our main analysis, we first identified clusters among OHCA cases, then repeated the procedure for IHCA cases. We determined the optimal number of clusters in each group using scree plots.[11] We calculated Gower distances from each individual ED arrest case to every OHCA and IHCA cluster center, then assigned each ED arrest case to the nearest cluster. Gower distance ranges from 0 to 1, where a distance of 0 between two clusters indicates that the clusters are identical, and a maximum distance of 1 indicates that the clusters are maximally dissimilar.[12]

We used several alternative approaches to explore our data. We identified clusters within the ED arrest population, and calculated pairwise Gower distances between each ED arrest, IHCA and OHCA cluster center. We also calculated mean Gower distances from the centers of all ED clusters to all OHCA centers, ED to IHCA and OHCA

Table 1 – Clinical characteristics of the study cohort, stratified by arrest location.

Variable	OHCA (n = 1709)	ED arrest (n = 372)	IHCA (n = 642)	Overall (n = 2723)
Age, years	58 (16.9)	61 (16.4)	62 (15.5)	60 (17)
Female sex	693 (41)	173 (47)	244 (38)	1110 (41)
Initial arrest rhythm				
VT/VF	543 (32)	125 (34)	149 (23)	817 (30)
PEA	471 (28)	166 (45)	336 (53)	973 (36)
Asystole	541 (32)	54 (14)	120 (19)	715 (26)
Unknown	144 (8)	27 (7)	34 (5)	205 (8)
Epinephrine intra-arrest	3 [1–5]	2 [1–3]	2 [1–3]	2 [1–4]
Bicarbonate intra-arrest	0 [0–1]	0 [0–1]	0 [0–1]	0 [0–1]
Shocks	0 [0–2]	0 [0–1]	0 [0–1]	0 [0–2]
Duration of arrest, minutes	21 [12–33]	9 [4–16]	10 [4–16]	16 [7–27]
Most advanced airway intra-arrest				
None	190 (11)	31 (8)	20 (3)	241 (9)
Bag valve mask	198 (12)	35 (9)	91 (14)	324 (12)
New supraglottic	312 (18)	0 (0)	9 (2)	321 (12)
New ET	898 (53)	189 (51)	320 (50)	1407 (52)
Pre-existing airway	39 (2)	77 (21)	159 (25)	275 (10)
Rearrests	0 [0–0]	0 [0–1]	0 [0–1]	0 [0–0]
PCAC				
I	225 (13)	149 (40)	240 (37)	614 (23)
II	291 (17)	53 (14)	72 (11)	416 (15)
III	114 (7)	31 (8)	63 (10)	208 (8)
IV	947 (55)	98 (26)	152 (24)	1197 (44)
Survival to hospital discharge	518 (30)	195 (52)	280 (44)	993 (37)

Data are presented using means with standard deviations (SD) for normally distributed continuous variables, median [interquartile range] for non-normal continuous variables, and raw number with corresponding percentages for categorical variables.

Abbreviations: OHCA— out-of-hospital cardiac arrest; IHCA—in-hospital cardiac arrest; ED—emergency department; VT/VF—ventricular tachycardia or fibrillation; PEA—pulseless electrical activity; ET—endotracheal tube; PCAC: Pittsburgh Cardiac Arrest Category.

to IHCA. In order to visualize the pairwise distances between cluster centers, we used a Fruchterman–Reingold algorithm to create a force directed plot using the "qgraph" package in R.[13,14] We assumed ED arrest cases, OHCA cases and IHCA cases each formed a single uniform cluster. We identified the center of each of these three clusters and calculated Gower distances between each pair. Finally, we explored potential heterogeneity within the OHCA cohort by separately clustering EMS-witnessed OHCA cases and OHCA cases not witnessed by EMS, hypothesizing that ED arrests might be substantively similar to cases of EMS-witnessed OHCA. We repeated our analyses treating these subgroups of OHCA as separate groups. To evaluate the quality of our k-prototype clustering, we calculated silhouette indices to compare within-cluster variability to between-cluster variability.[15] We used Stata version 15.1 (StataCorp, College Station, TX, USA) for the descriptive section of the analysis, and R version 3.6.1 for the remaining analysis and data visualization.

Results

We included 2723 patients: 372 (14%) ED arrests, 1709 (63%) OHCA, and 642 (23%) IHCA. ED arrests occurred in one of 65 hospitals' EDs; OHCA cases were resuscitated by one of 175 EMS services and transported to one of 80 hospitals prior to referral to our center; and, IHCA cases were resuscitated at one of 51 hospitals. Overall, most patients were male (1613, 59%), mean (SD) age was 60 (17) years (Table 1) and 1633 (61%) arrived to our facility via interfacility transfer.

We identified 3 clusters of OHCA patients, and 4 clusters of IHCA patients. Of ED arrest cases, 292 (78%) most closely resembled an IHCA cluster and 80 (22%) most closely resembled an OHCA cluster. The large majority (64%) of ED arrests that were closest to an IHCA survived to hospital discharge; 50% of this subset were awake post-arrest (PCAC I), and 16% were deeply comatose (PCAC IV). In contrast, only 13% of ED arrests that were closest to an OHCA cluster survived to hospital discharge; 65% of this subset were deeply comatose (PCAC IV) and only 5% were awake post arrest (PCAC I) (Table 2).

In our secondary analyses, we identified three clusters within OHCA, four clusters within IHCA, and four clusters within ED arrests (Fig. 1). Mean (SD) Gower distances between ED arrest and OHCA centers was 0.41 (0.11), between ED arrest and IHCA centers was 0.33 (0.20), and between IHCA and OHCA centers was 0.41 (0.11). Two ED arrest clusters closely resembled IHCA clusters, with Gower distances of 0.02 and 0.03. This was not the case between any of the ED and OHCA subgroup centers, where the shortest Gower distance was 0.28. Considering ED arrest, IHCA and OHCA to reflect three distinct and homogeneous clusters, ED arrests also most closely resembled IHCA. When we considered EMS-witnessed and non-EMS witnessed OHCA as separate populations, our results did not substantively change. Specifically, individual ED arrest cases most often were closest to an IHCA cluster center, and after clustering ED arrest centers were on average closest to IHCA centers.

Discussion

We used unsupervised learning to examine clinical features of patients resuscitated from ED arrests in relationship to both IHCA and

Table 2 – Clinical characteristics of ED arrests closest to the IHCA cohort and ED arrests closest to the OHCA cohort.

Variable	ED arrests closest to an IHCA center (n = 292)	ED arrests closest to an OHCA center (n = 80)
Age, years	61.1 (16.4)	60.8 (16.3)
Female sex	143 (49)	30 (38)
Initial arrest rhythm		
VT/VF	93 (32)	32 (40)
PEA	152 (52)	14 (18)
Asystole	30 (10)	24 (30)
Unknown	17 (6)	10 (12)
Epinephrine intra-arrest	2 [1–3]	2.5 [2–4]
Bicarbonate intra-arrest	0 [0–1]	0 [0–2]
Shocks	0 [0–1]	1 [0–2]
Duration of arrest, minutes	8 [4–15]	11.5 [7.75–20.25]
Most advanced airway intra-arrest		
None	27 (9)	4 (5)
Bag valve mask	31 (11)	4 (5)
New supraglottic	0 (0)	0 (0)
New ET	144 (49)	45 (56)
Pre-existing airway	58 (20)	19 (24)
Rearrests	0 [0–1]	0 [0–1]
PCAC		
I	145 (50)	4 (5)
II	43 (15)	10 (13)
III	26 (9)	5 (6)
IV	46 (16)	52 (65)
Survival to hospital discharge	185 (64)	10 (13)

Data are presented using means with standard deviations (SD) for normally distributed continuous variables, median [interquartile range] for non-normal continuous variables, and raw number with corresponding percentages for categorical variables.

Abbreviations: OHCA—out-of-hospital cardiac arrest; IHCA—in-hospital cardiac arrest; ED—emergency department; VT/VF—ventricular tachycardia or fibrillation; PEA—pulseless electrical activity; ET—endotracheal tube; PCAC—Pittsburgh Cardiac Arrest Category.

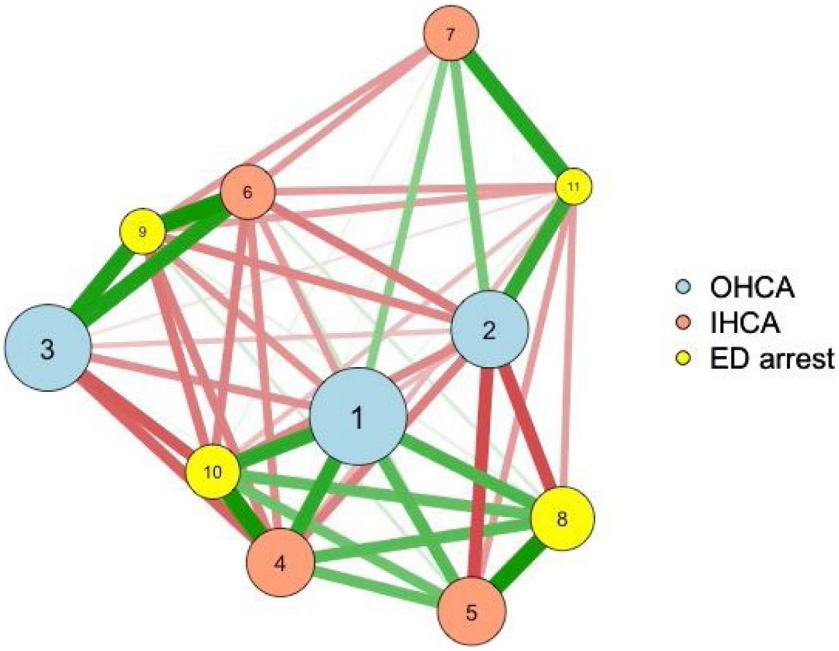

Fig. 1 – Force directed plot showing pairwise distances between the 11 cluster centers. Clusters are colored by arrest location, and their size is proportional to the size of the cluster. Edges (connections between clusters) are weighted as the inverse of the Gower distance.

OHCA. We found that ED arrests most closely resemble cases of IHCA. Both ED arrests and IHCA occur in well-resourced healthcare settings where resuscitation can be started promptly and efficiently, so this finding has good face validity. Past research and consensus statements have been quite inconsistent in how ED arrests were handled, variably considering them to be IHCA, OHCA or a distinct clinical entity.[16–20] At least with regard to post-arrest research, our findings support the first approach and good homogeneity of the ED arrest and IHCA populations.

Our study has several limitations. First, as a single center study the generalizability of our findings is limited. Although OHCA cases were resuscitated by a large number of EMS services, and although ED arrest and IHCA cases were referred from a large number of hospitals, inclusion in this cohort required survival to tertiary care. Our findings may thus be biased by non-random referral to our center and differential survival, and are limited to the post-arrest population, which may or may not resemble patients who suffer cardiac arrest. Detailed characteristics of referring hospitals and their EDs were not available for inclusion in this analysis, and in many cases varied over time during the study period. It is likely that capabilities varied, for example between tertiary care centers and small rural hospitals, and we were unable to explore this source of potential heterogeneity in this study.

Conclusion

Taken together, our work suggests that clinical features of patients resuscitated from ED arrest closely resemble cases of IHCA occurring after hospital admission. This work can guide further epidemiologic classifications of cardiac arrest populations.

Conflict of interest

The authors have no disclosures or potential conflicts of interest to report.

CRediT authorship contribution statement

Nancy Mikati: Conceptualization, Methodology, Formal analysis. **Clifton W. Callaway:** Conceptualization, Methodology, Resources. **Patrick J. Coppler:** Resources, Data curation. **Jonathan Elmer:** Conceptualization, Methodology, Resources, Data curation, Supervision.

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