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ORIGINAL RESEARCH

Trauma

Improving out-of-hospital notification in traumatic cardiac arrests with novel usage of smartphone application

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Abstract

Introduction: Timely out-of-hospital notifications in patients with traumatic cardiac arrest are associated improvements in mortality. Details surrounding these events are often limited, and decisions to perform advanced resuscitative procedures must be made based on limited data. This study evaluated the ability of a mobile application (app) called Citizen (sp0n Inc., New York, NY) to address these issues by providing a novel, secondary source of out-of-hospital information in traumatic cardiac arrest. Citizen sends notifications to mobile devices in response to nearby detected public safety events, and we sought to evaluate its utility in prenotification for traumatic cardiac arrest.

Methods: This was a retrospective observational study. Patients ≥ 15 years of age with traumatic cardiac arrest attributed to penetrating trauma were included. The 2 coprimary outcomes observed were the time difference between the app notification and emergency medical services notification, and the app's success rate in generating a notification for each patient in traumatic cardiac arrest.

Results: From February 2, 2019 to October 10, 2019, there were 43 patients who met the criteria for this study. On average, the Citizen app notification arrived 12.9 minutes before emergency medical services radio notification (95% confidence interval, 9.2–16.6; $P < 0.001$). Citizen generated a notification for 36 of 43 patients (84%).

Conclusion: The Citizen app generates earlier notifications in traumatic cardiac arrest compared with standard radio communications. It also provides a previously unavailable secondary source of information for making rapid resuscitative decisions upon the arrival of the arresting patient to the emergency department. Further research is needed to determine how to optimally integrate the app into existing trauma systems.

KEYWORDS
cardiac arrest, EMS, out-of-hospital, trauma

1 | INTRODUCTION

Time is a key predictor of clinical outcomes in the critically injured patient. Timely out-of-hospital notifications from emergency medical services (EMS) transporting trauma patients are associated with decreased mortality, more rapid interventions in the emergency department (ED), and a shortened hospital length of stay.[1-3] The importance of time is magnified in traumatic cardiac arrest,

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where the duration of out-of-hospital resuscitation predicts survival and is a critical factor in selecting appropriate patients for resuscitative procedures.[4-6] The care of patients with traumatic cardiac arrest requires substantial resource allocation and leads to disruptions to regular ED workflow resulting in delays in care to other ED patients and a temporarily reduced capacity to handle additional emergencies.

In our urban practice setting, most traumatic cardiac arrests are attributed to penetrating injury caused by gun violence. There are often unavoidable information limitations because of the nature of these events. EMS personnel typically arrive at unsecure scenes and often receive minimal collateral information regarding precise event timings. The EMS report is generally the sole source of prearrival information for injury timing and resuscitation duration available to the ED and trauma teams. Accurate reports of event timings in traumatic cardiac arrest are critical as time ambiguity can confound resuscitation decisions such as patient selection for aggressive interventions or determination of resuscitation futility. In addition, short out-of-hospital notification times limit the ability of the ED and trauma teams to prepare and mobilize resources. The purpose of this present study is to evaluate the ability of a smartphone application (app) called Citizen (version 0.986.0; sp0n Inc., New York, NY) to address these issues by providing a novel, secondary source of out-of-hospital information in traumatic cardiac arrest.

Citizen (https://citizen.com) is a free, multiplatform, mobile app that was designed with the stated purpose of improving public safety. It functions by sending real-time alerts to users about "incidents" occurring within a circumscribed radius. These include alleged crimes, fires, gas leaks, incidents involving firearms, and other public safety–adjacent topics. Data sources used by the app to generate incidents include 911 calls, reports from app users, police radio, and acoustic gunfire detection systems. Within an incident thread, updates are also provided in real time and users can submit supplementary comments, photos, or video streams. These notifications, in effect, function as aggregates of out-of-hospital information sources that typically have no cross-talk or would not otherwise be readily available to ED staff. As the window for intervention in traumatic cardiac arrest is extremely short, the availability of additional information could potentially improve trauma resuscitation care. We hypothesized that this app would generate earlier notifications compared with EMS in traumatic cardiac arrest.

2 | METHODS

This was a retrospective observational study at 2 urban trauma centers in Baltimore, Maryland. We studied patients with traumatic cardiac arrest, defined as absent signs of life according to the American College of Surgeons definition. A patient with absent signs of life is found to have no pupillary response, spontaneous ventilation, carotid pulse, measurable blood pressure, spontaneous extremity movement, or cardiac electrical activity.[7] The study occurred at 2 urban trauma centers in Baltimore, including a level 1 trauma center (65,000 ED visits/year,

The Bottom Line

As mobile app-based technology is evolving, there exists an opportunity to assess if the information gathered may be leveraged to improve out-of-hospital reporting of traumatic cardiac arrest to the emergency department. In this article, the authors evaluate the mobile app "Citizen" as an additional source of information with modestly promising results.

1162 beds) and a level 2 trauma center (60,000 ED visits/year, 463 beds) in the same hospital enterprise system. The institutional review board approved of this study at both sites with a waiver of informed consent.

Inclusion criteria were patients ≥15 years of age with traumatic cardiac arrest during the out-of-hospital or ED phases of care as a result of penetrating injury mechanisms. Exclusion criteria were blunt injury mechanisms, nontraumatic cardiac arrest, and patients who arrived via private vehicle without usage of EMS. All consecutive trauma arrest patients were considered eligible for this cohort beginning in February 5, 2019, coinciding with the start date of Citizen operations in Baltimore.

The 2 principal data sources used were electronic health record review and Citizen archival data. Patients were identified by running an electronic health record trauma census report. Narrative provider notes, procedure notes, nursing documentation, EMS out-of-hospital run sheets, and out-of-hospital radio consult forms were collected and analyzed. Individual chart reviews were performed using a structured data abstraction tool. Information collected included demographics (age, sex), clinical information (date of service, injury mechanism, presence/absence of signs of life [recorded as a binary], performance of resuscitative thoracotomy, ED disposition, survival), and event timings (911 call time, EMS scene arrival, radio consultation, ED arrival).

The second data source was archival data provided to our study team by Citizen. The following 2 variables were obtained from this database: the presence or absence of a Citizen incident for a corresponding traumatic cardiac arrest arriving in the ED (recorded as a binary) and the earliest timing of the app notification for the incident. The Citizen database does not record direct-identifying information such as names. Linkage of this unidentified dataset with our patient cohort was achieved via comparing temporal proximity of app notification time to ED arrival time, physical proximity of app notification address to the address of EMS response recorded in run sheets, and comparisons of the event description. An example of an archived incident involving a fatal shooting is shown in Figure 1; timestamps and locations that would make the patient potentially identifiable have been obscured. There were 309 fatal and 770 nonfatal shootings in Baltimore City in 2019, ≈3 events/day, which made the linkage between the 2 data sources trivial in nearly all cases.[8] The app notifications would have been available to any user during the study period, but were not used systematically in the institutions' trauma team notification or resuscitation decisions.
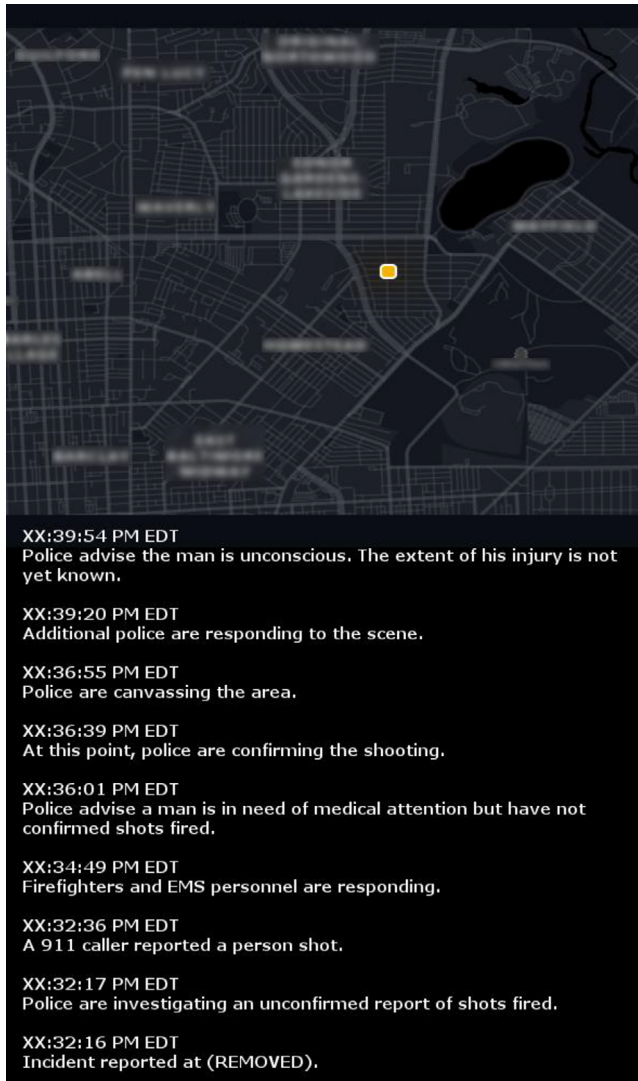
FIGURE 1 Example of a Citizen notification thread for a penetrating trauma arrest with identifying information removed. App users receive these notifications and subsequent updates in real time. EMS, emergency medical services

There were 2 coprimary outcomes studied. The first was the difference in notification time between the app and usual EMS notifications via radio. The difference between the app and EMS notification times would represent a potential advantage in notification time. The second was the app's success rate in generating a notification for each corresponding traumatic cardiac arrest that arrived in the ED. We also defined an exploratory objective of evaluating whether the app notification timings could be used as a supplementary source for determining the duration of cardiac arrest, particularly with reference to the commonly reported scenario of "patient with unknown downtime."

Pilot data from February 2019 showed a mean EMS notification time of 6.1 minutes (± 2.6) and mean app notification time of 13.2 minutes (± 8.4) prior to ED arrival. Pilot data were also included in the final data set. A difference of at least 5 minutes was judged to be the minimum clinically significant difference between notification times. This was chosen after discussions with both trauma and EM colleagues

**TABLE 1** Demographic and clinical characteristics

Age, y, median (IQR)	27 (20-35)
Male sex, n (%)	40 (93)
Injury mechanism, n (%)	
Gunshots	42 (98)
Stabbings	1 (2)
Signs of life present, n (%)	
Out-of-hospital	4 (9)
ED	5 (12)
Thoracotomy, n (%)	22 (51)
Outcome, n (%)	
Died in ED	36 (84)
Died in OR	5 (12)
Died during index hospitalization	1 (2)
Neurologically intact survival	1 (2)
Event timings, min, median (IQR)	
911 call	22 (20-27)
EMS dispatch	19 (17-24)
EMS scene arrival	14 (12-19)
EMS radio communication	5 (4-7)
Citizen notification, n (%)	36 (84)
Citizen notification timing, min, median (IQR)	17 (13-26)

ED, emergency department; EMS, emergency medical services IQR, interquartile range; OR, operating room.

as a balance between the benefit of earlier notification with potential harms, such as erroneous activations. Sample size was calculated to have 80% power to reject the null hypothesis at a 0.05 level of statistical significance, and 34 patients would be required for adequate power under these conditions. A paired t test was used for the primary outcome. A Pearson correlation coefficient was used for the exploratory outcome. Descriptive statistics, analyses, and data visualizations were done using SPSS 25.0 (IBM, Armonk, NY). In case of missing data, such as EMS run sheets or radio communication forms, the primary outcome was unable to be calculated, and these patients were excluded from the analysis. The authors aimed to adhere to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for reporting observational studies.[9]

3 | RESULTS

There were 71 traumatic cardiac arrests that occurred between February 5, 2019 and October 10, 2019 when the targeted sample size was reached. Of these, 17 were excluded for missing data (EMS run sheets or radio communication forms), 8 were excluded for blunt injury mechanisms, and 3 were excluded for arriving via private vehicle. The remaining 43 patients were included in the primary analysis. Patient demographics, clinical information, and event timings are summarized in Table 1.
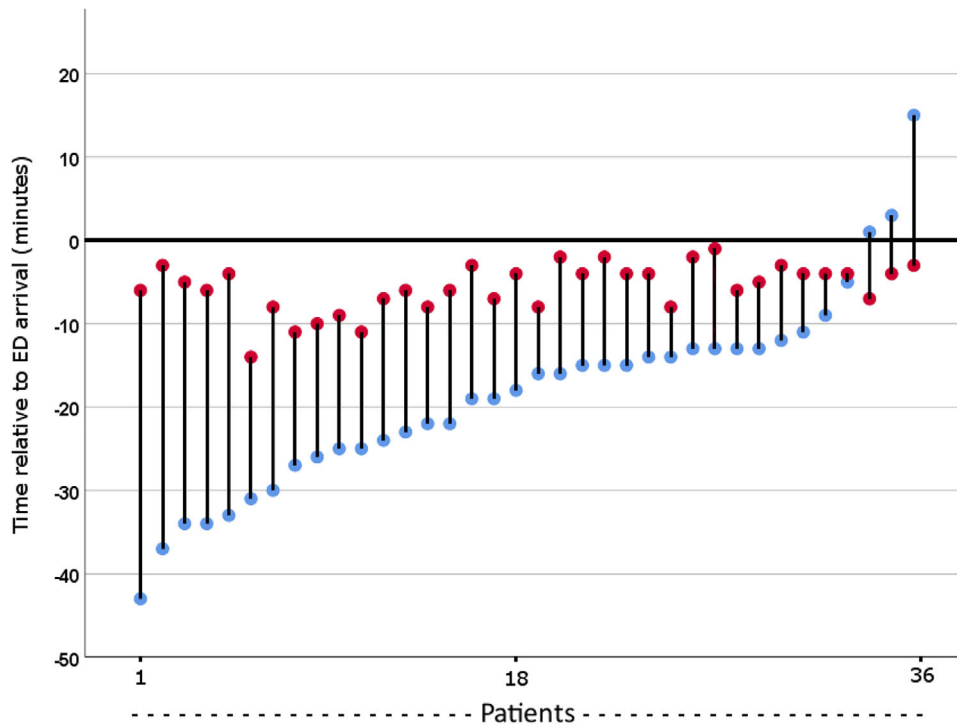
FIGURE 2 Comparison of emergency medical services notification times (red circles) and first notification generated by Citizen app (blue circles) relative to emergency department (ED) arrival (0 minutes). Black vertical lines between the 2 circles represent the differences in lead time notification between the 2 communication types

Citizen generated a notification for 36 of 43 patients (84%). The difference in means between the first Citizen notification and EMS communications was 12.9 minutes (95% confidence interval, 9.2–16.6; $P < 0.001$). In the 36 cases where Citizen generated a notification for a trauma arrest, the Citizen notification preceded EMS notification in 33 patients (92%). A graphical representation of the notification differences is shown in Figure 2. The initial data source used to generate the notifications was police radio (n = 22, 61%), acoustic gunfire detection (n = 8, 22%), 911 calls (n = 5, 16%), and app user (n = 1, 3%).

There was a moderately strong positive correlation (Pearson r = 0.64) between out-of-hospital time (difference of ED arrival and EMS scene arrival) and first Citizen notification (Figure 3). There were 22 ED thoracotomies performed in the cohort, with 19 (86%) being performed on patients with absent out-of-hospital signs of life at their initial EMS assessment. The minimum duration of cardiac arrest under these circumstances can be approximated by out-of-hospital time beginning at initial EMS assessment noting absent signs of life. ED thoracotomies were performed on 15 patients with ≥10 minutes arrest duration and 9 patients with ≥15 minutes arrest duration. There were no survivors among the patients with absent out-of-hospital signs of life on EMS arrival.

the Citizen notifications were not used in real time for trauma activations or resuscitation decisionmaking. The study was conducted in a state that ranks among the highest in the country in age-adjusted homicides.[10] The utility of the app may be attenuated in areas with fewer firearm fatalities, higher proportions of blunt traumatic cardiac arrests, or longer transport times. We were unable to obtain EMS run sheets on 18 patients. These patients were excluded from the analysis, which represents a potential source of bias. The app itself does not provide any information about patient status such as vital signs or a direct accounting of the duration of cardiac arrest. However, we feel that the app's communication of a timeline of the traumatic events provides key information that may have utility in real-time resuscitation decisionmaking, particularly in settings of reported "unknown downtime." Lastly, our data were intended to support an operational benefit for EDs and trauma systems using the Citizen app usage rather than an improvement in patient-oriented outcomes such as mortality. The survival in our cohort was very low (2%) and to demonstrate even a modest 4% survival, a sample size of 2282 patients would be needed. Public health safety measures and violence prevention programs are more likely to impact patient survivorship than the technology used for out-of-hospital notification.
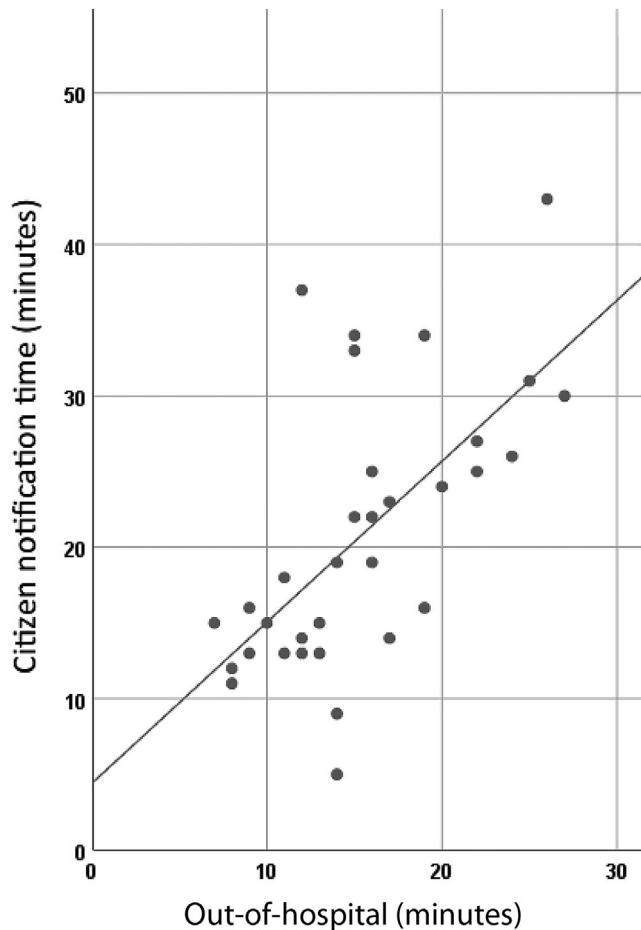
4 | LIMITATIONS

There are several limitations to our study. This was a retrospective study. The notification lead times presented are theoretical because

5 | DISCUSSION

The morbidity and mortality of traumatic cardiac arrest is incredibly high. Survivorship from gunshot wound patients undergoing ED

FIGURE 3 Scatterplot showing association between out-of-hospital time (difference between emergency department arrival and emergency medical services scene arrival time) and first Citizen notification (difference between emergency department arrival and app notification). A moderately strong positive correlation ($r = 0.64$) is present. A fit line approximated by the equation Citizen = 4.4 minutes + 1.1 × (out-of-hospital time)

elevation myocardial infarction, sepsis, cardiac arrest, and trauma. App-based out-of-hospital notification systems are not new, and implementations have demonstrated reductions in door-to-needle in stroke, door-to-balloon times in ST-segment–elevation myocardial infarction, and time to defibrillation in out-of-hospital cardiac arrest.[14-16] The novelty and utility of using the Citizen app for critical trauma care derives from several features. The app draws from multiple out-of-hospital information sources, which would normally have no cross-talk, and presents them directly to the end users in a unified format. The generation of an out-of-hospital event timeline may allow an emergency team to access injury timing, particularly in cases of violence and when signs of life were reported as absent on EMS scene arrival. Lastly, the feature of allowing user-submitted information to generate and update incidents represents a type of out-of-hospital information crowdsourcing.

A prospective implementation of this app in a trauma system would need to address several technical issues. During the study period, Citizen reported 23,094 incidents in Baltimore, or ≈70 alerts per day. Most of these incidents had no relevance to our study population of trauma arrest patients, including the majority of firearm-related notifications. The signal-to-noise ratio would thus be expected to be low if the app were implemented in its current iteration, which could lead to erroneous activation of trauma resources. In addition, the app sends signals to users within a geographic radius, by default 0.25 miles but increasing based on the nature and severity of the incident. In urban areas with overlapping catchment areas, there exists a potential for the app to generate correct notifications but have the patient divert to a different facility, which would lead to inappropriate trauma activations. These issues could be potentially addressed with a healthcare-specific implementation of the app, particularly with an interface that allows EMS or first-responder engagement. Further refinements such as filtering nonserious injuries and adjusting notification radii to align with hospitals' trauma catchment zones could also potentially improve the utility of the app to trauma teams.

The earliest iteration of what would become the Citizen app was accompanied by controversy. It was initially launched as "Vigilante" in 2016. Vigilante was subsequently removed from the Apple app store the same year for unspecified violations of Apple's app review guidelines. Contemporary news sources at the time documented concerns about the app potentially promoting vigilantism, implicit racial biases, and issues of privacy and consent to being recorded or photographed.[17] The rebranded Citizen was relaunched in 2017 with new emphases on safety, active discouragement of reckless user behavior, and content moderation. Although these concerns are not directly linked to our study hypothesis, they must be acknowledged as they could represent barriers to a future implementation of the app in a formalized trauma notification system.

thoracotomies is estimated at about 5%.[11] As mentioned previously, resuscitation of these patients requires a substantial reallocation of resources, which invariably distracts from the care of other ED patients. In addition, resuscitative thoracotomies convey a measurable risk to physician staff performing the procedure.[12] Previous work has been done on attempts to identify patients with higher chances of survival including point-of-care ultrasound; however, a persistent limitation in the care of these patients is the lack of reliable total downtime.[13] Our data suggest that the use of the novel app that is currently available can almost always provide further details surrounding a traumatic arrest. Our data also suggest that the app reliably provides advance notification when compared with EMS radio consults. This extra time can prove incredibly valuable in terms of resource allocation, equipment preparation, trauma team assembly, blood bank discussions, and other steps necessary to prepare for the acute resuscitation of a traumatic cardiac arrest.

Out-of-hospital notification has a clearly defined role in several time-sensitive emergency conditions, including stroke, ST-segment–

6 | CONCLUSION

The Citizen app generates earlier notifications in traumatic cardiac arrest compared with standard radio communications. It also provides

a previously unavailable secondary source of information for making rapid resuscitative decisions upon arrival of the arresting patient to the ED. Further research is needed to determine how to optimally integrate the app into existing trauma systems.

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AUTHOR CONTRIBUTIONS

GSK and DC conceived the study, methods, and performed data collection. Both authors drafted the article and are responsible for the quality and accuracy of the overall article.

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