JOURNAL OF THE AMERICAN COLLEGE OF CARDIOLOGY
VOL. 68, NO. 8, 2016

ISSN 0735-1097/$36.00
PUBLISHED BY ELSEVIER
http://dx.doi.org/10.1016/j.jacc.2016.03.609

Overcoming Spatial and Temporal Barriers to Public Access Defibrillators Via Optimization

Christopher L.F. Sun, BASc,[a] Derya Demirtas, PhD,[b] Steven C. Brooks, MD, MHSc,[c,d] Laurie J. Morrison, MD, MSc,[d,e] Timothy C.Y. Chan, PhD[a,d]

ABSTRACT

BACKGROUND Immediate access to an automated external defibrillator (AED) increases the chance of survival for out-of-hospital cardiac arrest (OHCA). Current deployment usually considers spatial AED access, assuming AEDs are available 24 h a day.

OBJECTIVES The goal of this study was to develop an optimization model for AED deployment, accounting for spatial and temporal accessibility, to evaluate if OHCA coverage would improve compared with deployment based on spatial accessibility alone.

METHODS This study was a retrospective population-based cohort trial using data from the Toronto Regional RescuNET Epistry cardiac arrest database. We identified all nontraumatic public location OHCAs in Toronto, Ontario, Canada (January 2006 through August 2014) and obtained a list of registered AEDs (March 2015) from Toronto Paramedic Services. Coverage loss due to limited temporal access was quantified by comparing the number of OHCAs that occurred within 100 meters of a registered AED (assumed coverage 24 h per day, 7 days per week) with the number that occurred both within 100 meters of a registered AED and when the AED was available (actual coverage). A spatiotemporal optimization model was then developed that determined AED locations to maximize OHCA actual coverage and overcome the reported coverage loss. The coverage gain between the spatiotemporal model and a spatial-only model was computed by using 10-fold cross-validation.

RESULTS A total of 2,440 nontraumatic public OHCAs and 737 registered AED locations were identified. A total of 451 OHCAs were covered by registered AEDs under assumed coverage 24 h per day, 7 days per week, and 354 OHCAs under actual coverage, representing a coverage loss of 21.5% ($p < 0.001$). Using the spatiotemporal model to optimize AED deployment, a 25.3% relative increase in actual coverage was achieved compared with the spatial-only approach ($p < 0.001$).

CONCLUSIONS One in 5 OHCAs occurred near an inaccessible AED at the time of the OHCA. Potential AED use was significantly improved with a spatiotemporal optimization model guiding deployment. (J Am Coll Cardiol 2016;68:836–45) © 2016 by the American College of Cardiology Foundation.

Listen to this manuscript's audio summary by *JACC* Editor-in-Chief Dr. Valentin Fuster.

From the [a]Department of Mechanical and Industrial Engineering, University of Toronto, Toronto, Ontario, Canada; [b]Department of Industrial Engineering and Business Information Systems, University of Twente, Enschede, the Netherlands; [c]Department of Emergency Medicine, Queen's University at Kingston, Kingston, Ontario, Canada; [d]Rescu, Li Ka Shing Knowledge Institute, St. Michael's Hospital, Toronto, Ontario, Canada; and the [e]Division of Emergency Medicine, Department of Medicine, University of Toronto, Toronto, Ontario, Canada. This study was funded by the ZOLL Foundation (ZOLL Foundation Research Grant). The Resuscitation Outcomes Consortium Epistry study is supported by a cooperative agreement (5U01 HL077863) with the National Heart, Lung, and Blood Institute in partnership with the National Institute of Neurological Disorders and Stroke, Canadian Institutes of Health Research-Institute of Circulatory and Respiratory Health, Defense Research and Development Canada, the Heart and Stroke Foundation of Canada, and the American Heart Association. Rescu Epistry is funded by a center grant from the Laerdal Foundation and knowledge translation collaborative grants from the Canadian Institutes of Health Research and the Heart and Stroke Foundation of Canada. Mr. Sun has received an Ontario Graduate Scholarship. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

Manuscript received January 6, 2016; revised manuscript received March 1, 2016, accepted March 29, 2016.

Out-of-hospital cardiac arrest (OHCA) represents a significant public health issue, associated with an estimated 400,000 deaths annually in North America and a <10% survival rate (1,2). Automated external defibrillator (AED) use, coupled with cardiopulmonary resuscitation (CPR), has been shown to increase survival from public location cardiac arrest (3–6).

Despite the substantial amount of financial resources committed to public access defibrillation programs, AED usage in public location OHCA cases remains low (7–9). There are many potential barriers to bystander AED use, including legal liability, awareness, training, technological limitations, and psychological factors (10–12). Another major barrier is the limited availability of AEDs due to building access (11,13–15).

SEE PAGE 846

The majority of the research in and guidelines for AED deployment focus on spatial factors with respect to cardiac arrest risk and AED availability. Studies have evaluated cardiac arrest risk according to location type (5,16–23) or optimized deployment of AEDs geographically (24,25), without considering temporal factors. In fact, the well-known American Heart Association guidelines for AED placement have suggested locating an AED where there has been a cardiac arrest every 2 years and, more recently, "in public locations where there is a relatively high likelihood of witnessed cardiac arrest" (26,27). The European Resuscitation Council guidelines are similar (28). AED deployment strategies that only consider spatial factors implicitly assume that AEDs and public locations that house AEDs are available and accessible 24 h a day.

Although cardiac arrest incidence and survival vary substantially according to time of day and day of week (29,30), temporal access has largely been ignored in the literature, with one notable exception (13). In the present article, we present the first mathematical optimization approach for AED deployment that considers both spatial and temporal accessibility. We hypothesized that: 1) OHCA coverage by existing AEDs is significantly overestimated when temporal accessibility is not considered; and 2) optimizing deployment of prospective AEDs, accounting for both spatial and temporal accessibility, can reverse coverage loss and generate a statistically significant increase in OHCA coverage over an approach that only considers spatial accessibility.

METHODS

Toronto has a population of approximately 2.8 million people in an area of about 630.18 km². A single emergency medical service (EMS) primarily serves the city; however, neighboring EMS respond to emergency events if they are close in proximity. Because Toronto has a tiered response system, multiple EMS units and the fire department often respond to a single emergency event.

ABBREVIATIONS AND ACRONYMS

AED = automated external defibrillator

CI = confidence interval

CPR = cardiopulmonary resuscitation

EMS = emergency medical service

OHCA = out-of-hospital cardiac arrest

STUDY DESIGN AND DATA SOURCES. This study was a retrospective population-based cohort trial using data from the Toronto Regional RescuNET cardiac arrest database. Rescu Epistry is compliant with the Resuscitation Outcomes Consortium Epistry-Cardiac Arrest and based on the Strategies for Post Arrest Resuscitation Care methodologies described elsewhere (31,32).

All public location, nontraumatic OHCA episodes in the city of Toronto from January 2006 to August 2014 were included in this study; information for each OHCA entry included demographic characteristics, circumstances of arrest, characteristics of care, and survival outcomes. Public locations included public buildings, places of recreation, industrial facilities, and outdoor public spaces; hospitals and nursing homes were excluded.

A list of registered AEDs was obtained from Toronto EMS as of March 2015. AED registration in Toronto is voluntary but strongly encouraged. The AED dataset contained 912 publicly and privately owned (included with owner consent) AEDs, located at 737 unique addresses. Each entry included the address and location type; most entries included the hours of operation. Missing information was completed by online search, telephone, or in-person visit (Online Appendix).

A dataset of candidate locations for AED placement was collected from June 2014 to January 2015, comprising 4,898 businesses and public points of interest. For each location, the address and hours of operation (if available) were obtained. Data collection was conducted online, by telephone, or by in-person visit.

STATISTICAL ANALYSIS. Two separate analyses were conducted.

Analysis 1: Coverage loss of registered AEDs factoring in temporal availability. We first calculated assumed coverage 24 h per day, 7 days per week. An OHCA is considered covered if it occurred within 100 m (25,26) of an AED regardless of the AED's availability. Second, we calculated actual coverage. An OHCA is considered covered if it occurred both within 100 m of an AED and when the AED was available, based on the location's hours of operation. Locations were considered temporally inaccessible