Initiatives for Improving Out-of-Hospital Cardiac Arrest Outcomes

Running title: Myerburg; Tracking Cardiac Arrest and Responses

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Out-of-hospital cardiac arrest (OHCA), leading to sudden cardiac death (SCD), remains a huge public health burden, accounting for more than 350,000 deaths in the United States each year\textsuperscript{1} and an equivalent number in Europe. The societal impact is evident from the fact that as many as 50\% of all cardiac deaths are SCDs\textsuperscript{1}, with many of the affected individuals in their productive years. One cost estimate places the financial burden on society at $33 billion per year in the U.S.\textsuperscript{2}, based on the cost of response systems, post-cardiac arrest hospitalizations, and long-term care of survivors. The latter includes rehabilitation, disability expenses, and medical costs specific to survivors such as ICDs.

**Prediction, Prevention, Intervention**

Attempts to address the OHCA/SCD challenge encompass 3 basic strategies -- prediction, prevention, and intervention. Prediction remains a daunting challenge, since 50\% of SCDs are first cardiac events without specific forewarnings of unrecognized disease\textsuperscript{1,3,4}. Data on familial clustering of SCD as first cardiac events\textsuperscript{4} suggest the possibility of genetic profiling of individual risk. However, other than the rare inherited arrhythmia syndromes, identification of genetic SCD risk markers with a large effect size remains a hope for the future. The numerically large problem associated with the common cardiac disorders dominates the public health burden. Atherosclerosis risk scoring methods do provide some profiling capability for this most common cause, but the latter are largely not specific for cardiac arrest itself, and have limitations for individual risk prediction\textsuperscript{3}.

Prevention is equally challenging. It depends on unrealized strategies for developing individual risk prediction models having small denominators and proportionally large numerators, and cost-effective preventive therapies that provide high levels of efficiency. The latter is defined as high absolute risk reduction in an identified population subset that
encompasses a substantial proportion of the event burden. Only a small part of the prevention strategy is addressed by use of ICD’s and other therapies in the identified high risk subgroups, such as primary prevention of SCD in patients with low EFs and/or heart failure, and the rare inherited arrhythmogenic syndromes. However, the majority of OHCA’s and SCD’s occur among 3 lower risk groups: the apparently normal general population, plus those with risk factors for atherosclerosis in the absence of recognized disease, and those with known disease that is profiled to be at low risk. Risk factor modification and treatment have had impact on expression of disease prevalence, but less so for SCD than other expressions of atherosclerosis.

The third leg of this tripod – intervention – has provided benefits, but also requires additional attention to achieve better outcomes. The evolution of hospital- and community-based responses to cardiac arrest is a fascinating piece of medical history, but outcomes from responses to OHCA, measured as survival free of significant neurological deficits, remain disappointingly low. Overall survival is in the range of 10% or less, with some exceptions based on locations and response times. Private homes are the most common sites of OHCA and have the worst outcomes; public locations have better outcomes, with airports, airliners, casinos, and a few other public locations among the best reported. The optimist in me believes that over time society will come forth with resources for research leading to greater progress in prediction and prevention; but while we wait, we need to seek new strategies that will improve intervention outcomes.

Emerging Strategies in Community Response Designs – The Copenhagen Initiative

A great deal of effort has been expended in attempts to improve outcomes from responses to OHCA, with various levels of success. The 2 major areas of focus have included response times and intra- and post-arrest management strategies. In this issue of the Circulation, Hansen and co-
workers\textsuperscript{8} report on a network of voluntarily deployed AEDs in the city of Copenhagen, Denmark, along with its methodology and observations of coverage of cardiac arrests in the city. The foundation for this program resides in a publically accessible grid system that permits geocoding of precise location coordinates for various public benefit purposes\textsuperscript{9}. The basis for this is a standardized European Grid System. The specific feature of interest for this project was the development of an integrated, internet-accessible actively managed network providing information on locations of all registered AEDs in the community, analogous to initiatives such as crowdsourcing strategies\textsuperscript{10}, and for other initiatives with similar goals\textsuperscript{11-14}. Features of the Copenhagen model include the capability to update the data on a continuous basis and the ability of both Emergency Medical Services (EMS) and lay responders to access the information online in order to identify the closest AED during a response. The result is coordination between victim location, first responder, AED location, and EMS call center.

With the network in place, it was feasible to collect data tracking and linking the locations of OHCAs and AEDs, with changes in patterns over time from 2007 through 2011, and also create a map of the distributions of OHCAs in the community from 1994-2011. The investigators defined the term "accessible AEDs" as those devices within 100 meters of an event and analyzed for “coverage” of cardiac arrest on that basis. This is the recommended distance based on a reasonable estimate to achieve a 1½ minute AED-to-victim access time. They further separated their community into high-risk areas, defined as $\geq$1 cardiac arrests every 2 years in a 100 meter area, low risk areas based on fewer numbers of events, and those areas with no cardiac arrests for the duration of the observation. High risk areas accounted for only 1% of the city area, but contained 18% of the cardiac arrests. During the study period, AED coverage of cardiac arrest, as defined above, increased from 2.7% to 32.6% overall, and from 5.7% to 51.3% in the
high-risk areas. Although the match between AED deployment sites and high-risk areas was not optimal during this observation period, with only 55 cardiac arrests occurring within 100 meters of an AED, the change in coverage over time in the high-risk areas, plus the ability to identify changes in risk patterns for specific areas over time, suggest a methodology that offers an opportunity to continuously improve this pattern as the network matures.

There are 2 major points of interest associated with the network development and the analysis of related data reported in this manuscript. The most obvious is the practical concept of an active, coordinated, frequently updated system of information from which both lay responders and emergency medical personnel can draw while responding to emergency calls. This offers hope for improving coverage and reducing time to defibrillation as more data are collected and the system becomes more sophisticated. As an example, the most pessimistic outcomes data derives from the fact that approximately 80% of out-of-hospital cardiac arrest occur in private homes and survival rates in the U.S. are no better than 6%. While this may relate in part to medical circumstances in that population subset, delays in activation and response times may also be important factors. The potential for benefit of a neighborhood-based (rather than home-based) AED deployment system was suggested on a hypothetical basis by Zipes in 2001\textsuperscript{15}, but never gained attention or testing because of feasibility questions, in addition to data suggesting that a home-AED strategy was not effective\textsuperscript{16}. With the development of accessible integrated, high resolution mapping of locations of victims, AED’s, and lay responders, perhaps this is a notion worth revisiting, given the magnitude of the problem.

**From Copenhagen to Chicago**

The second point of interest, much broader in nature, is the potential for mapping historical locations of cardiac arrest and AED locations as part of a generalizable methodology for
response planning in other communities of various sizes and generation of other data of strategic value. By extrapolating from the design of the Copenhagen study, one can envision the development of registries of information on cardiac arrest, including its frequency and related distributions of response resources. This might provide unique response assistance in many different geographic patterns, and at the same time provide a continuous source of information on the evolution of those response patterns that are most effective for increasing survival. In order for this to occur beyond the limits of a single moderate-sized city such as Copenhagen (population ~600,000; area 97 Km² or 60 mi²), methods and strategies suited to data collection and analysis for specific locations and circumstances will be necessary.

In the United States, we are in desperate need of uniform access to OHCA data across a country that is heterogeneous in respect to local population numbers and densities, population origins, and basic geography. One of the major limitations in dealing with the geographic epidemiology of OHCA and SCD is the lack of uniform reporting systems for planning purposes. Geographic epidemiology of OHCA can be analyzed in terms of population density and geographic dispersion. Approximately one-half of the U.S. population is located within the 13% of all metropolitan statistical areas (MSAs) with populations of 1 million or more and approximately 10% of the population is distributed in the 50% of MSA’s with populations <250,000. There is a general relationship between population size and population density, with a tendency for areas of smaller populations to be distributed over larger geographic areas. For both extremely dense populations in major cities such as Chicago and New York and in sparsely populated regions, the relationship between population density and population size impacts on response times. In fact, data from very densely populated areas that include vertical development such as high rise living and working sites, and from areas that are very sparsely populated,
demonstrate worse outcomes for survival, based in part on impaired ability to respond timely. If we can gain greater specific insight into the geographic distribution of cardiac arrests and design systems that are best suited to specific population density patterns, response times to sites of OHCA may improve.

**From Integrating AED Access to Integrating Hospital Transport**

An additional potential benefit of a grid-based tracking and linking method is extension to strategies for transport from sites of OHCA to receiving hospitals. The standard principal of transport to the nearest facility appropriately equipped for handling cardiac arrest victims is being challenged by the concept of EMS bypass, based on the notion that cardiac arrest victims with major post-cardiac arrest complications will have better outcomes in regional centers capable of advanced support. While still debated, some recent data supports this concept\(^\text{17}\); but the question remains when and how to make the decision to bypass to a regional advance care facility. Admission to the nearest facility, with subsequent transport to an advanced facility, is one approach; but another might be to use geocoded grids, as suggested in Figure 1, to integrate hospitals capable of various levels of care with on-site post arrest status of the victim.

The Copenhagen model provides a foundation for this additional level of coordination. By adding information on the capabilities and locations of local and regional hospitals on a Copenhagen-style grid, a mathematical integral of OHCA location, initial post-arrest status, level of care required, distance, and transport time (even including instantaneous traffic conditions), could be generated. The 4-tiered model of post-arrest status and level of care required (Figure 1) reflects such a priority-based bypass system. Based upon the updating component of the Copenhagen model, this can include prospective measures of outcomes and subsequent remodeling, when indicated.
Geocoding for Data Sourcing

Addressing the problem of SCD in its broadest perspectives will require greater insights into numbers, regions, specific locations, circumstances, disease prevalence, population characteristics, and response systems than are currently available. The Copenhagen model provides a foundation for providing a database on OHCA that can ultimately expand to include data for addressing these broader epidemiological issues. Uniform identification and logging of most, if not all, OHCA/SCDs is the first step in the creation of a comprehensive database that can lead to such analyses. In fact, the Copenhagen methodology did become national in Denmark in 2010, suggesting feasibility of developing national reporting systems. It would be naive to think that the application of a method that appears to have been relatively easily developed in a small country could be as easily developed in United States. Nonetheless, there is great potential value to the accumulation of data on cardiac arrest on a nationwide basis. In order to achieve this, the first step is identification of OHCAs in centrally accessible databases, allowing the user to evaluate local, regional, or national questions patterns of events and outcomes. Beyond that, however, is the even greater value of a national database on cardiac arrest, which might ultimately provide access to data on causes, outcomes, and even potentially genetic characterization of regional populations, given the heterogeneity of the U.S. population. To achieve this, OHCA/SCD would have to be declared a reportable event. This differs from the voluntary Copenhagen program for AED tracking.

Conclusion

The Copenhagen report provides a description and analysis of a practical and important system for tracking cardiac arrests and improving AED access to lay responders. It also integrates EMS calls with responders and AED locations. However, the components provide a foundation that
with potential to extend far beyond the initial intent and design. Extrapolation and development of the methodology for broader uses offers an opportunity for advances in the intervention approaches to OHCA, and perhaps contribute new knowledge about SCD prediction and prevention, as well.

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**References:**


Figure Legend:

**Figure 1.** Targeted Urgency Scale. A 4-tiered model aligning immediate post-cardiac arrest status and level of required care is illustrated to reflect a priority-based hospital bypass system. The Copenhagen model provides a foundation for this additional level of coordination. Patients can be transported to the closest facility appropriate to the optimal or minimal care requirements. [PCI = percutaneous coronary intervention; ED = Emergency Department; ICU/CCU/NICU = intensive, coronary, and neurological intensive care units; circles are color-coded symbols for linking level of patient urgency to recommended hospital resources on community grid maps]
<table>
<thead>
<tr>
<th>Level</th>
<th>Patient Status</th>
<th>Hospital Resource Minimums</th>
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<tbody>
<tr>
<td>Level 1</td>
<td>- Failure to restore circulation;</td>
<td>Local or regional facility capable of providing highest level of neurological, cardiovascular, and intensive care support 24/7 (ICU/CCU/NICU)</td>
</tr>
<tr>
<td></td>
<td>- ROSC without regaining consciousness ± hemodynamic instability ± acute coronary syndrome; ± recurrent arrhythmias</td>
<td></td>
</tr>
<tr>
<td>Level 2</td>
<td>- ROSC with restoration of consciousness;</td>
<td>Nearest facility capable of providing high level cardiovascular and intensive care support 24/7; cardiac catheterization laboratory capable of providing PCI within 90 minutes</td>
</tr>
<tr>
<td></td>
<td>- Persistent hemodynamic instability ± acute coronary syndrome; ± recurrent arrhythmias</td>
<td></td>
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<tr>
<td>Level 3</td>
<td>- ROSC with restoration of consciousness;</td>
<td>Nearest facility with cardiac catheterization laboratory capable of providing PCI within 90 minutes - 24/7</td>
</tr>
<tr>
<td></td>
<td>- hemodynamically stable</td>
<td></td>
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<tr>
<td></td>
<td>- Evidence of acute coronary syndrome; ± recurrent arrhythmias</td>
<td></td>
</tr>
<tr>
<td>Level 4</td>
<td>- ROSC with restoration of consciousness;</td>
<td>Nearest facility capable of providing standard ED, ICU/CCU; cardiac catheterization desirable with PCI capability within 24 hours</td>
</tr>
<tr>
<td></td>
<td>- hemodynamically stable; no evidence of acute coronary syndrome</td>
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