Who's at Risk in a Changing Climate? Mapping Electricity-Dependent Patient Populations in a Coastal City

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ABSTRACT

BACKGROUND: Climate change is causing increasingly frequent extreme weather events. This pilot study demonstrates a GIS-based approach for assessing risk to electricity-dependent patients of a coastal academic medical center during future hurricanes.

METHODS: A single-center retrospective chart review was conducted and the spatial distribution of patients with prescriptions for nebulized medications was mapped. Census blocks at risk of flooding in future hurricanes were identified; summary statistics describing proportion of patients at risk are reported.

RESULTS: Out of a local population of 2,101 patients with prescriptions for nebulized medications in the preceding year, 521 (24.8%) were found to live in a hurricane flood zone.

CONCLUSIONS: Healthcare systems can assess risk to climate-vulnerable patient populations using publicly available data in combination with hospital medical records. The approach described here could be applied to a variety of environmental hazards and can inform institutional and individual disaster preparedness efforts.

KEYWORDS: electricity-dependent, mapping, nebulizer, hurricane, climate change, power outage

INTRODUCTION

Climate change, an aging and medically complex population, increasing technological dependence, and fragile public infrastructure present mounting challenges to the health of patients and the operation of healthcare systems.[1-3] Health risks from heat waves, hurricanes, flooding, fires, and other hazards are already increasing as result of anthropogenic climate change.[4] This is of particular concern because an increasing number of patients are reliant on medical devices and a stable supply of electricity, which can be compromised by climate-related hazards and infrastructure failures.[5-7]

The use of Durable Medical Equipment (DME) has been rising in the United States with the growing prevalence of non-communicable diseases and an aging population.[8-10] As of 2016, over 2.5 million Medicare patients were dependent on electrically-powered DME (EDME) including ventilators, oxygen concentrators, and home hemodialysis machines.[11] During power outages, EDME-dependent patients (EDPs) may experience device failure or problems continuing their care in the community and may seek assistance at hospitals.[2,12-14] Many of the patients facing this situation are elderly, have multiple chronic comorbidities, are on multiple medications, or are physically disabled,[15,16] putting them at elevated risk of immediate or long-term health harm from EDME dysfunction.

Sea level rise, hurricanes, severe storms, wildfires, and heat waves are expected to intensify as a result of climate change and are a substantial threat to power grid stability and access to electricity.[17,18,19] The frequency of power outages in the US has risen in recent decades because of an increase in the incidence of weather-related outages; severe weather was responsible for 80% of major outages between 2003 and 2012.[3] Extreme weather can cause power grid disruptions in a variety of many ways, ranging from the flooding of low-lying electrical infrastructure that occurred during Hurricane Sandy[7] to increases in demand for electricity in combination with reduced power plant efficiency and production capacity, as seen during heat waves in Southern California.[5,6,20] Power companies also sometimes initiate Public Safety Power Shutoffs, preemptively turning off power in an effort to reduce risk of wildfire ignition during hot, dry, and windy conditions.[21]

As increasing numbers of patients become dependent on electricity for their healthcare, the value of proactive patient engagement and institutional preparedness for disaster-related threats to the electricity supply will increase, particularly in areas at high risk of outages and with high numbers of EDPs. Information on this population and the hazards it faces are crucial to these initiatives, and efforts to map EDPs at national, state, and municipal levels using insurance claims data, medical record searches, and geographic information systems (GIS) are ongoing.[1,11,22-24] The most comprehensive existing tool is the Department of Health and Human Services emPOWER system, which maps EDME users at the zip code level based on Medicare claims and can provide address-level information to EMS agencies seeking to reach specific patients during a disaster.[11] However, the tool does not provide information about where patients obtain healthcare, excludes patients covered under other insurance providers or who have no insurance, and does not allow for disaggregated analysis at the municipal or institutional level.[11,24]

In this article we present a complementary, locally actionable approach that utilizes retrospective medical records review in combination with publicly available hazard data to assess the vulnerability of institution-specific EDP populations to climate-related natural hazards. For purposes of this pilot study, we focused on home nebulizers as a representative EDME and hurricane-related coastal flooding as a representative climate-related hazard.

METHODS

This study consisted of a retrospective chart review followed by spatial aggregation, mapping, and analysis of presumed nebulizer users in relation to publicly available data describing hurricane inundation zones. Nebulizers were selected as the representative EDME because they are commonly used, use can be inferred from prescription information, and device failure can contribute to adverse clinical sequelae. Inundation zones were chosen because of the strong relationship between flooding and electrical outages which has been demonstrated in recent hurricane events.[3,6,7]

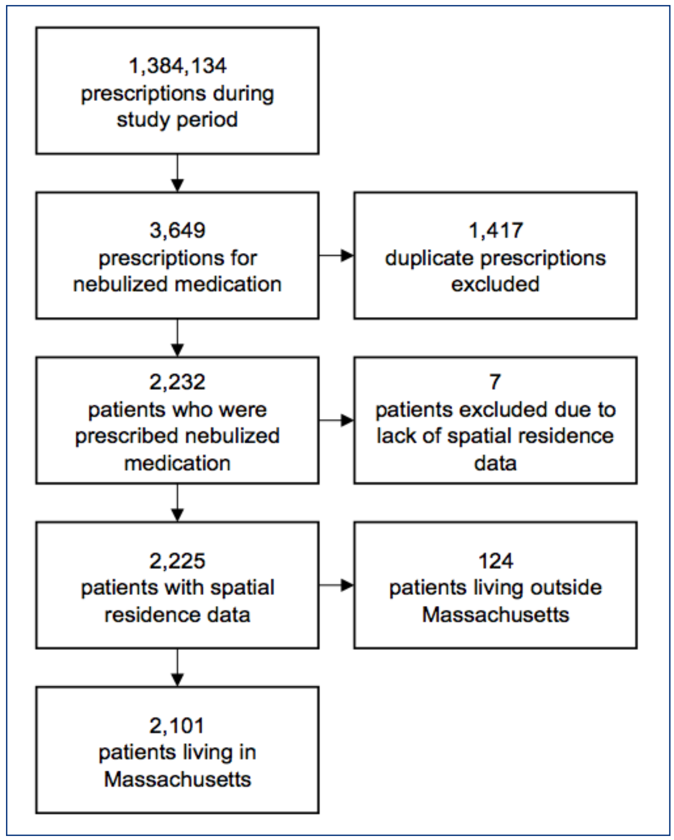
All medical records in the hospital online medical record (OMR) were queried for the presence of prescriptions for nebulized medications within the preceding year (10/25/2019 to 10/25/2020). Duplicate records from patients with multiple prescriptions within the time period were removed. Home addresses were converted to spatial coordinates via an application programming interface (API), and records were then aggregated to the level of census blocks to create the de-identified dataset used for this analysis. Hurricane Surge Inundation Zone data from the U.S. Army Corps of Engineers was obtained from MassGIS and overlaid with the frequency maps of nebulizer users.[25] A clip function was used to restrict the block-level nebulizer frequency maps to areas of overlap with hurricane inundation zones and quantify the population of patients with recent prescriptions for nebulized medication who would be exposed to storm surge inundation during a hurricane of a given Saffir-Simpson category. Attribute tables were exported and the sum and proportion of the total nebulizer population at risk and the increase in number and percent of patients expected with each increase in hurricane category were computed. Maps of nebulizer prescription frequency were created using 2010 US Census geographic data and are shown at the census tract level to protect patient anonymity.

Conversion of addresses to geo-coordinates was performed via the Google Maps API implemented in the ggmap package in R v3.6.1.[26,27] Spatial analysis and mapping was performed in ArcMap[28]; summary statistics were computed in MS Excel.[29] This study was reviewed and determined to be exempt by the BIDMC Institutional Review Board.

RESULTS

A total of 1,384,134 prescription entries for 185,906 patients were screened, from which a list of 3,649 nebulizer prescriptions was compiled. Of these, 1,417 duplicates (e.g. multiple prescriptions for the same patient during the study timeframe) were excluded, leaving 2,232 unique patient records. Seven records could not be successfully geocoded and were removed from the dataset, leaving 2,225 records representing presumed nebulizer users, from which the 2,101 patients residing in Massachusetts were included in the analysis of local vulnerability to hurricane inundation, as summarized in **Figure 1**.

Figure 1. Medical records screening and inclusion process. All records are from a single medical center during the period 10/25/2019 to 10/25/2020.



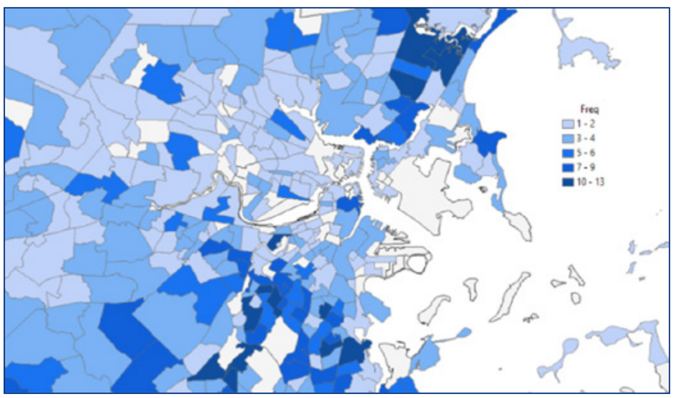
A total of 30 different medications were prescribed, including albuterol sulfate (1,237 patients), ipratropium-albuterol (372), budesonide (332), and other medications or combinations of medications (284). Most patients resided in Massachusetts (2,101), followed by New Hampshire (45), Maine (16), Rhode Island (14), and other states (49). Within Massachusetts, 730 lived in Suffolk County, 512 in Middlesex County, and 859 in other counties. See **Table 1**.

Within Massachusetts, 1,886 census blocks in 794 census tracts contained at least 1 presumed nebulizer user. All census tracts containing more than 10 patients were located in

Table 1. Study population characteristics, including locations of residence and nebulized prescriptions information.

	Number	Proportion (%)
Patients	2,225	100%
Prescription Type		
Albuterol	1,237	55.6 %
Ipratropium-Albuterol	372	16.7 %
Budesonide	332	14.5 %
Other / Combination	284	12.8 %
State of Residence		
Massachusetts	2,101	94.4 %
New Hampshire	45	2.0 %
Maine	16	0.7 %
Rhode Island	14	0.6 %
Other	49	2.2 %

Figure 2. Distribution of presumed nebulizer users in and around Boston, MA. Darker coloration corresponds to a larger number of presumed nebulizer users residing within the census tract.



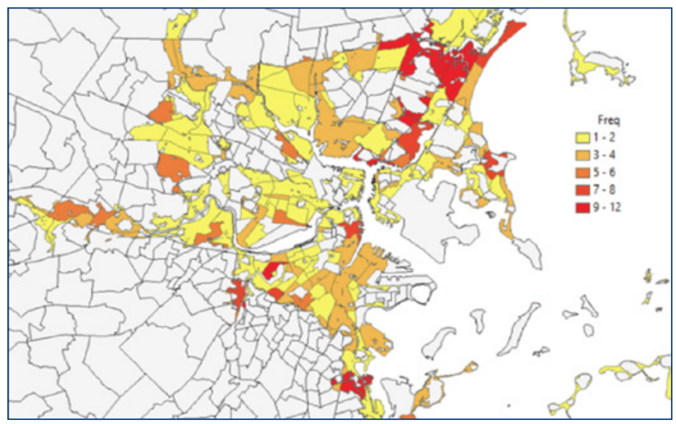
Dorchester, Saugus, and Revere. The spatial distribution of nebulizer users at the census tract level is shown in **Figure 2**.

At the block level, 521 presumed nebulizer users resided in census blocks that overlapped with hurricane flood zones. This population represents 24.8% of patients who received care at the study site during the study timeframe, were nebulizer users, and lived in Massachusetts. Subsets of this population living in each hurricane inundation zone were computed; stratified results are presented in **Table 2**. A total of 186 presumed nebulizer users (8.9%) reside in a zone that would flood in a Category 1 hurricane, and 372 (17.7%) reside in a zone that would flood in a Category 2 hurricane; the population of interest at risk of inundation in a Category 2 storm is approximately twice that at risk in a Category 1 storm. The spatial distribution of nebulizer users living in locations at risk of hurricane-related flooding is shown in **Figure 3**; data is presented at the census tract level to preserve anonymity.

Table 2. Population of presumed nebulizer users who received care at the study site during the study period and are at risk of inundation of their dwelling location in Category 1 through Category 4 hurricanes.

	Category 1 zone	Category 2 zone	Category 3 zone	Category 4 zone
Presumed nebulizer users at risk of flooding in this zone (n)	186	372	456	521
Proportion of Massachusetts nebulizer users (n=2,101) at risk of flooding in a storm of this category (%)	8.9	17.7	21.7	24.8
Additional patients at risk relative to next lowest category hurricane (n)	-	186	84	65
Proportional increase in number of patients at risk relative to next lowest category hurricane (%)	-	100%	22.6%	14.3%

Figure 3. Distribution of presumed nebulizer users residing in hurricane inundation zones. Darker red indicates a larger number of presumed nebulizers who may be at risk of inundation during a major hurricane.



DISCUSSION

This pilot study demonstrates a simple, reproducible methodology for mapping climate-related risk to electricity-dependent patients. Our approach, which uses publicly available hazard data in combination with internal medical records data, is not technologically complex and, thanks to the widespread use of electronic medical records, could be implemented by many healthcare institutions.

Our results show that nearly one-quarter of Massachusetts nebulizer users who received care at the study site are living in census blocks at risk of flooding during hurricanes, and that the number at risk approximately doubles in a Category 2 hurricane in comparison to a Category 1 hurricane. At the institutional level, this suggests there could be an increase in respiratory presentations in the hours or days following a hurricane; such information can help guide preparedness efforts. In addition, awareness of this risk may help primary care providers, pulmonologists, and patients make preparations so that alternative breathing treatments, sources of electricity, or temporary accommodations are available in the event of a major storm.

It was also noteworthy that the highest densities of presumed nebulizer users at risk of inundation in this study were in Dorchester, Saugus, and Revere – communities with substantial minority, historically marginalized, or financially constrained populations that may face substantial barriers to climate change adaptation. Such communities may benefit from hospital outreach efforts including collaboration with local governments or civil society organizations on community-based interventions to address these and other health risks.

This pilot study demonstrates that individual healthcare organizations already possess or can access the data needed to perform basic evaluations of the risk to their high-vulnerability patient populations posed by climate-related natural hazards. Practical information on the hazard exposure of vulnerable populations can be obtained using freely available datasets and analytical tools in combination with medical records data. Improving electronic medical records utilization, open-source statistical and geographic information systems, and availability of free training on their use mean that simple analyses should be within the reach of many institutions. While true real-time translational data readiness for disaster response remains an urgent and complex challenge,[30] static pre-disaster risk assessments such as the pilot results presented here can be performed at the level of individual institutions. Availability of such information may enhance engagement with community resilience and climate change adaptation efforts and could be expanded to a wide range of patient populations, hazards, and infrastructure issues.

At the organizational level, this information could contribute to forecasting patient surges and anticipating acute care needs. For example, Emergency Department (ED) demand forecasting is often done hour-to-hour[31-34]; the information and methods outlined here could be extended to allow organizations to predict which locations could receive a higher volume of EDME-related ED arrivals based on proximity to high-risk areas and vulnerable populations during disaster events. Community resilience efforts may also benefit from information on the hazard exposure of specific high-risk patient populations; such work may help avoid ED crowding related to DME problems and exacerbations of chronic conditions during disasters, which can lead to operational challenges, delays in care, and increased ED length of stay.[35-38]

Information on exposure to climate-related hazards can also inform care in the outpatient setting. Outpatient providers may find such information useful when counseling patients on issues such as respiratory health, heat wave safety, and disaster preparedness. Home Health Care (HHC) presents another intervention opportunity[39]; HHC organizations are uniquely positioned to assist EDME users with disaster preparedness at home – for example, using the National Association for Homecare and Hospice Emergency Preparedness Checklist.[40]

Analyses of climate change hazards in relation to vulnerable populations will be of growing importance in coming decades. There is a particularly urgent need to develop methods to proactively identify populations at high risk during disaster-related electrical outages in order to reduce suffering, avoid long-term health impacts associated with device failure, anticipate and reduce ED surges, and ease strain on hospital systems. Healthcare institutions have a responsibility to prepare for anticipated hazards that can affect their ability to provide care, including the risk of patient surges during extreme events. Healthcare providers are uniquely positioned to counsel patients on preparedness for natural hazards as a means of protecting their health and advocate for measures to adapt to climate change and protect health in the community. Information on local climate-related risk profiles can help inform such conversations.

LIMITATIONS

The population in this analysis is limited to nebulizer users and does not include persons dependent on other forms of EDME, which may have different spatial distributions. This medical records review was limited to a single medical center, and provides information specific to the hospital under assessment, rather than a portrait of the region as a whole. Our analysis infers that inundation from a hurricane is a predictor of electrical outage based on a variety of case studies and other evidence,[3,6,7] but lack of recent hurricanes means the degree of this correlation in the study region is not definitively known. In addition, quantifying the population at risk on the basis of residence within an inundation zone may underestimate the true number at risk, as damage to electrical infrastructure within flood zones may result in power outages affecting non-inundated areas, as occurred in large parts of Manhattan following a transformer failure during Hurricane Sandy.[6,7] Finally, a variety of factors may affect whether inundation actually harms electricity-dependent patients, including locations and fortifications of power stations and transmission lines, availability of public sites at which power is available, such as libraries or community centers, and whether or not a household is on a priority power restoration list or executes a pre-disaster evacuation plan.

CONCLUSION

Extreme weather related to climate change and the use of electricity-dependent medical devices are intersecting issues that combine to increase the risk of adverse health outcomes resulting from weather-related electrical outages. This pilot study uses publicly available hazard data and internal medical records data to show that a quarter of study-site patients who use nebulizers reside in locations that are expected to be inundated during a major hurricane and may experience electrical outages. Our findings suggest preparedness opportunities at both the population and institutional levels. The methodology necessary to conduct this type of assessment is not complex and could be reproduced in other settings to assess a variety of hazards and patient populations.

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Acknowledgment

This project was supported by the CrisisReady Initiative at Harvard and Direct Relief. Dr. Caleb Dresser's work was also supported by the Climate and Health Foundation.

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