Data Visualizations

New Method for Assessing the Effect of Driving Distance to Hospital Care

Using OpenStreetMap Routing in Cardiovascular Research

Daniel Lindholm, MD, PhD; Stefan James, MD, PhD; Bo Lagerqvist, MD, PhD; Mark A. Hlatky, MD; Christoph Varenhorst, MD, PhD

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Geography is a key determinant of access to health care. Patient outcomes cannot be improved if novel therapeutic and preventive strategies cannot be delivered to patients in a timely and equitable fashion.

We developed a new method to calculate driving distances to hospital care by integrating an open-source geographic database with a standard statistical software package to create a tool for outcomes research. We illustrate its application to cardiac care in Sweden; yet, the methodology is readily applicable to other geographical regions and other healthcare services.

Time to reperfusion in ST-segment–elevation myocardial infarction affects patient outcomes, and so guidelines recommend reperfusion be achieved within 120 minutes of symptom onset.[1] Delayed percutaneous coronary intervention (PCI) has been associated with worse outcomes also in patients with non–ST-segment–elevation myocardial infarction.[2] Furthermore, large distance to a center providing cardiac care could not only impede acute care but might also reduce access to other services, such as follow-up with a cardiac specialist, advanced cardiac testing, and cardiac rehabilitation.[3] Therefore, it would be of value to assess geographic barriers to cardiac care, and link this data to clinical and quality of care registries.

We obtained map data for Sweden from the OpenStreetMap project (http://www.openstreetmap.org), set up a local OpenStreetMap Routing Machine (http://project-osrm.org),[4] and programmed a custom R interface (code available in the Data Supplement) to obtain driving distance information from each zip code area centroid (n=10 007) to different levels of cardiac care. We then combined these data with information about residential locations of the Swedish population and plotted the shortest distance from each zip code to each of the hospital categories by layering distances over a background map freely available from Natural Earth (http://www.naturalearthdata.com/). We summarize distance to different levels of cardiac care with empirical cumulative distribution function plots. For additional details, see extended methods description in the Data Supplement.

We determined the driving routes from all 10 007 zip codes to all 73 hospitals in Sweden. Calculation of these 730 511 routes took about 53 minutes to complete or 4.3 ms per route. The software failed to find routes from 7 of the zip code areas (0.07%), all of which were small islands off the coast of Sweden that lack any road connections to the mainland. As of December 31, 2015, there were N=9 834 211 inhabitants in Sweden. The analysis population included 9 772 322 individuals, excluding 57 316 individuals (0.6%) living on the island of Gotland and 4573 individuals (0.05%) living in the 7 zip code areas from which routing failed.

We assessed driving distance to coronary revascularization (Figure [A]), categorizing the shortest distances from each zip code area to (1) any hospital providing acute cardiac care, (2) to any PCI-capable hospital, (3) to a PCI-capable hospital providing primary PCI 24 hours a day 7 days a week (24/7), and (4) to a hospital capable of both PCI and coronary artery bypass graft surgery. Driving distances for the population to different levels of cardiac care varied greatly (Figure [B]). The median (25th–75th percentiles) distance to any hospital was 10.6 (4.2–24.9) km, with mean 17.7 km, and a maximum distance of 292.1 km. For distance to any PCI-capable hospital, the median was 19.0 (6.2–45.0) km, mean 32.3 km, and maximum 464.6 km. The median distance to a PCI-capable hospital open 24/7 was 24.2 (8.6–59.6) km, mean 38.7 km, and maximum 464.6 km, whereas the median distance to a hospital capable of both PCI and coronary artery bypass graft was 49.6 (15.5–107.8) km, mean 76 km, and maximum 719.6 km. A total of 3 348 764 (34%) individuals had a non-PCI hospital as their nearest hospital, 1 983 264 (20%) lived closest to a PCI-capable hospital without 24/7 capability, 2 391 953 (24%) lived closest to a center capable of PCI 24/7, and 2 048 341 (21%) lived closest to a PCI/coronary artery bypass graft-capable hospital.

In summary, our new open-source tool to estimate the driving distance to hospital care seems useful in identifying geographic areas where timely access to health care is unlikely and in visualizing potential repercussions of policy changes. Although we used Swedish cardiac care in this study to illustrate the application of this tool, this method is generalizable to any geographic area in which coordinates of patients' neighborhoods (or proxies thereof) and of care facilities are available. Furthermore, because the software uses parallel computing to

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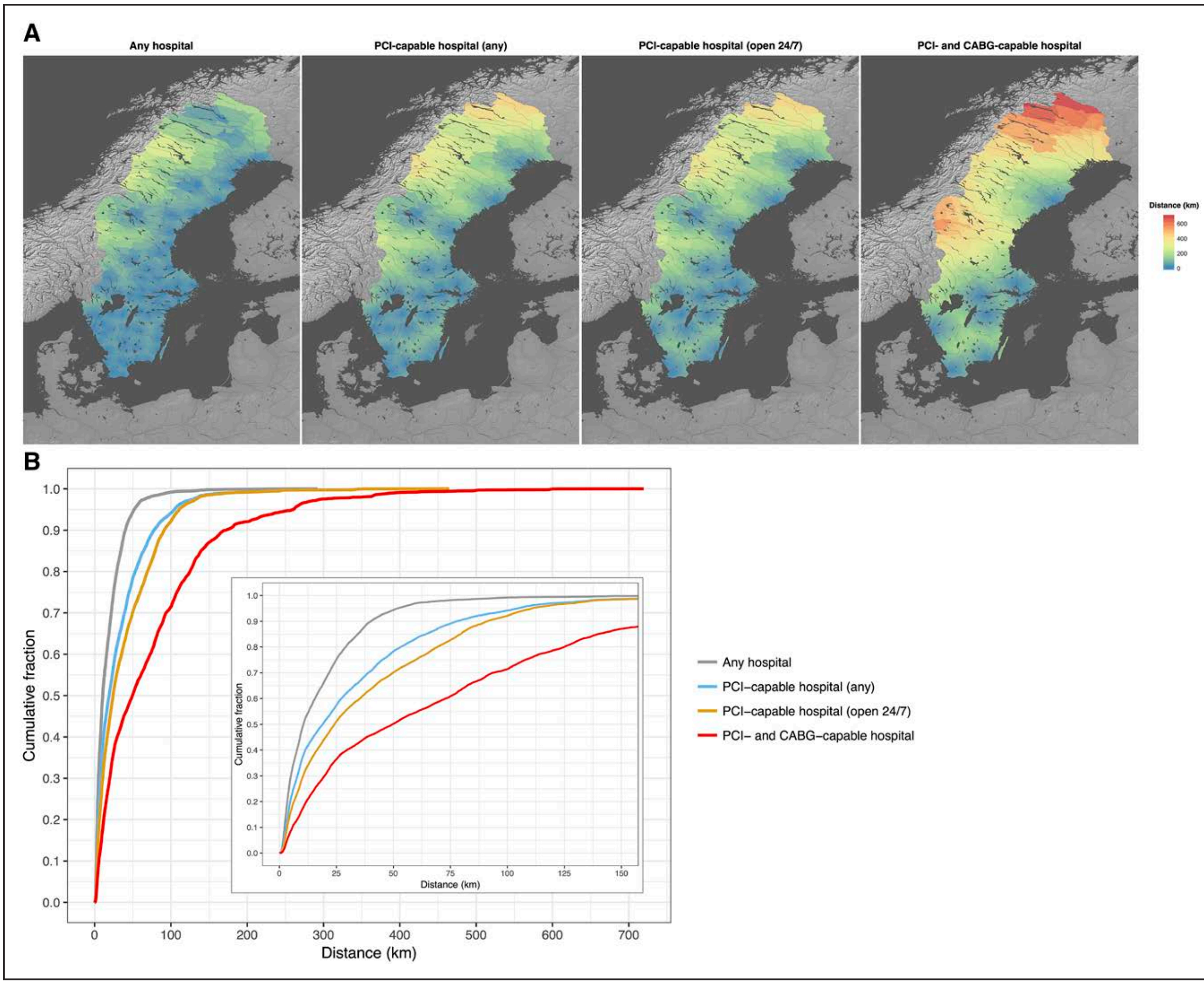

Figure. A, Distance to (1) any hospital providing acute cardiac care, (2) any percutaneous coronary intervention (PCI)–capable hospital, (3) a PCI-capable hospital with PCI capability 24/7, and (4) a hospital capable of providing both PCI and CABG, from all zip code areas in Sweden (except islands lacking road connection to the mainland). **B**, Empirical cumulative distribution functions of distance to (1) any hospital providing acute cardiac care, (2) any PCI-capable hospital, (3) a PCI hospital open 24/7, and (4) a hospital capable of providing both PCI and CABG, for the Swedish population (excluding people living on islands without road connection to the mainland). CABG indicates coronary artery bypass graft.

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determine distances, this method can be readily scaled-up in a high-performance computing environment and applied to larger territories and populations, such as the United States. Data on driving distances could be linked to data from clinical or quality of care registries, such as the nationwide SWEDEHEART registry (Swedish Web-System for Enhancement and Development of Evidence-Based Care in Heart Disease Evaluated According to Recommended Therapies) on coronary heart disease in Sweden, or the national cardiovascular data registries in the United States, which would provide the opportunity to assess the impact of driving distance on a wide array of cardiac services and outcomes, not just acute cardiac care and coronary revascularization. This method could just as easily be applied to other healthcare services in which geography could limit access to care, such as oncology, burn care, and infectious diseases.

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SUPPLEMENTAL MATERIAL

A New Method for Assessing the Effect of Driving Distance to Hospital Care – Using OpenStreetMap Routing in Cardiovascular Research

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Mark A. Hlatky, MD; Christoph Varenhorst, MD, PhD.

Extended methods

Routing software

OpenStreetMap (http://www.openstreetmap.org) is a map of the world freely available to use under an open license. Similar to other map services, such as Google Maps, there are several routing services that may be applied, one of which is the OpenStreetMap Routing Machine (OSRM, http://project-osrm.org/), a fast C++ based program(1). OSRM provides an application program interface (API) to perform routing and returns results in JavaScript Object Notation (JSON) format. We built OSRM version 5.3.0 following the instructions on the project homepage (http://github.com/Project-OSRM/osrm-backend), and deployed it locally using the OpenStreetMap database for Sweden (with timestamp 2016-09-11) obtained from Geofabrik (http://www.geofabrik.de/).

R interface for OSRM

To facilitate data analysis using distance data, we programmed a custom interface to query the OSRM API from within the R statistical software (http://www.r-project.org). This R function takes five arguments: latitude and longitude of the origin, latitude and longitude of the destination, and a server argument that points towards the network address where OSRM is running (by default, it selects the local machine). The R function submits a query to the OSRM, parses the results, and returns the driving distance from origin to destination in kilometers (km). The source code for the interface is found as an Appendix to this manuscript.

Distance to cardiac care in Sweden

To illustrate the potential uses of this framework for assessing driving distance to health care, we used access to cardiac care as a model. We calculated the driving distances to different types of cardiac care for each individual in the entire Swedish population. Sweden is divided into about 10,000 zip code areas. We obtained coordinates for the boundaries of each zip code area (from Postnummerservice AB [http://www.postnummerservice.se]), and calculated the coordinates for the centroid of each zip code area, by decomposition of the areas into triangles (allowing overlapping triangles) and calculating the weighted sum of the triangle centroids, as implemented in the *GEOS* software package, wrapped in the *rgeos* package for R. We identified the road closest to the centroid as the starting point for routing to health care facilities for all residents of that zip code. We then calculated the driving distance from each zip code centroid to each hospital in Sweden.

We classified hospitals in Sweden according to the highest level of coronary care:

1. Hospital with an emergency department, but without invasive treatments (percutaneous coronary intervention [PCI] or coronary artery bypass graft surgery [CABG]) available.
2. Hospital with an emergency department, with PCI available, but not on a 24 hour a day / seven day a week basis (24/7), and no CABG.
3. Hospital with an emergency department and PCI available 24/7, but with no CABG.
4. Hospital with an emergency department, PCI and CABG available. Typically, the university hospitals.

Using our routing framework, we calculated the distance from each zip code centroid to each hospital, and determined the shortest driving distance to any hospital, to any PCI-capable hospital, to a PCI-capable hospital with PCI available 24/7, and to a PCI/CABG hospital. We excluded the island Gotland (situated in the middle of the Baltic sea), since no road leads to a PCI- or CABG-capable center for the island.

We plotted the shortest distance from each zip code to each of the hospital categories, and displayed the results by layering distances over a background map freely available from Natural Earth (http://www.naturalearthdata.com/).

We then combined distance data with information regarding the number of inhabitants in each zip code area (data from Statistics Sweden, obtained from Postnummerservice AB). We present distances as empirical cumulative distribution functions, and by summary statistics (median, upper and lower quartile, mean and maximum). We also assessed, for each zip code area, which category hospital was the closest.

The analyses were conducted on a MacBook Pro (with a dual-core 3Ghz Intel Core i7 processor and 16GB of RAM) running macOS Sierra and the statistical software R version 3.3.2. All plots were created using the *ggplot2* package(2). No individual level data were used in this study.

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R interface for OSRM

(Supplement to Lindholm, James, Lagerqvist, Hlatky, Varenhorst)

This code provides an interface between OpenStreetMap Routing Machine (OSRM) and R. It takes five arguments:

- **fromLat** – latitude of the routing origin
- **fromLon** – longitude of the routing origin
- **toLat** – latitude of destination
- **toLon** – longitude of destination
- **server** – the address where OSRM is running. By default, this points to the demo routing server provided by the OSRM project. Note that usage restrictions may apply on that server. For the present project, we set up a server on our local machine.

```
library(rjson)

distance <- function(fromLat, fromLon, toLat, toLon, server = "router.project-osrm.org"){

  getDistance <- function(fromLat, fromLon, toLat, toLon, server){
    URL <- paste0("http://", server, "/route/v1/driving/",
                  fromLon, ",", fromLat, ";", toLon, ",", toLat,"?overview=false")

    dat <- tryCatch(fromJSON(tryCatch(readLines(URL, warn = FALSE),
                                      error = function(err){})),
                                      error = function(err){})

    #The status code "Ok" means that the routing engine found a route.
    #If it did not, NULL is returned.
    if (is.null(dat)) dat <- list(code = "error")
    if (dat$code == "Ok"){
      return(dat$routes[[1]]$distance/1000)} #Convert distance to kilometers
    else return(NA)
  }

  x <- mapply(getDistance, fromLat, fromLon, toLat, toLon, server)
  return(x)
}
```