Supplemental Online Content

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This supplemental material has been provided by the authors to give readers additional information about their work.
eFigure 1. Hospital selection flowchart

6,025 General medical hospitals

4,468 Non-federal hospitals

679 Hospital Excluded
136 Limited service hospitals
511 Hospitals with <10 inpatient surgeries annually
32 Hospitals without emergency

3,789 Hospitals with emergency and surgical services

64 Hospitals verified by American College of Surgeons Committee on Trauma, not present in AHA Annual Survey

3,853 Hospitals with emergency surgery capabilities
**eTable 1. Hospital resources**

| Resources Considered in Definition of Advanced Resources | Non-Advanced resource hospitals N=2787 | Advanced resource hospitals N=1066 |
|---------------------------------------------------------|----------------------------------------|-----------------------------------|
| **CT Scanner †**                                        | 1,920 (98%)                            | 1066 (100%)                       |
| **Ultrasound †**                                        | 1,881 (96%)                            | 1066 (100%)                       |
| **ERCP †**                                              | 105 (11%)                              | 1066 (100%)                       |
| **Medical/Surgical Intensive Care Unit Beds >5 †**      | 382 (19.5%)                            | 1066 (100%)                       |
| **Medical/Surgical ICU Beds**                           | 3 [0-6]                                | 17 [11-28]                        |
| **Trauma Level**                                        |                                        |                                   |
| 1 or 2                                                  | 0                                      | 570 (53%)                         |
| 3 or 4                                                  | 498 (18%)                              | 301 (28%)                         |
| Non-trauma                                              | 2289 (82%)                             | 195 (18%)                         |
| **Number of annual inpatient surgeries**                | 360 [137-1002]                         | 2800 [1460-5311]                  |
| **Additional Resources**                                |                                        |                                   |
| **Total bed number**                                    | 53 [25-120]                            | 388 [146-388]                     |
| **Medical School Affiliation**                          | 724 (16%)                              | 765 (48%) (43.0%)                 |

*All values shown are N (%) unless otherwise noted
† N= 3,026
ERCP = Endoscopic Retrograde Cholangiopancreatography; ICU=Intensive Care Unit
eMethods: Gravity-based spatial access model

Realizing the limitations of both travel impedance (cost) measures and provider-population ratios in modeling spatial access to healthcare, researchers have adopted gravity models to account for the complicated interactions among healthcare supply, population demand for healthcare, and travel impedance between population locations and healthcare sites.1–4 Gravity-based spatial access models estimate spatial access to medical services based on the law of gravitation.5 Specifically, gravity models assume a population site’s spatial access to a medical site decreases with the increase of travel distance to that medical site. A distance impedance function, $f(d)$, is generally used to model the influence of travel distance $d$ on the spatial access.

One of the most commonly used and widely validated gravity models is the enhanced 2-step floating catchment area (E2SFCA) method.2,3,6–8 Given $m$ population sites (e.g., CBG centroids) and $n$ medical sites (e.g., hospitals) in a study area, E2SFCA works in two steps. The first step calculates the supply-demand ratio of each medical site, $j$. Specifically, it generates a 60-minute driving zone (also called a catchment area) around $j$, divides the catchment into four contiguous zones based on predefined driving time intervals (e.g., 0-10 min, 10-20 min, 20-30 min, 30-60 min), searches all population sites within each zone, and calculates the supply-demand ratio for $j$ by

$$R_j = \frac{S_j}{\sum_{k \in (d_{kj} \in D_r)} P_k W_r}$$

where $S_j$ is the medical capacity (estimated by number of inpatient beds) of medical site $j$, $P_k$ is the population size of the $k$th population site within the catchment, $d_{kj}$ is the travel cost between $j$ and $k$, $D_r$ is the $r$th sub-zone, and $W_r$ is a distance-based weight for $D_r$. Following previous studies1,3,4, we used the Gaussian function (i.e., $f(d) = e^{-d^2/\beta}$ where $d$ represents a distance and $\beta$ represents an impedance parameter) to calculate $W_r$. More details on the Gaussian function and the calculation of $W_r$ can be found in Wan et al. 20124.

The second step of E2SFCA is to calculate a Spatial Access Index (SPAI) for each population site $i$. Specifically, a 60-min catchment and four driving zones (i.e., 0-10 min, 10-20 min, 20-30 min, 30-60 min) are generated for $i$, following the same procedures in the first step. Then it summarizes the supply-demand ratios of all medical sites within the catchment using the following formula:

$$A_i = \sum_{k \in (d_{ik} \in D_r)} R_k W_r$$

where $A_i$ is the SPAI for $i$, $R_k$ is the supply-to-demand ratio (calculated in step 1) of medical site $k$ that falls inside the catchment of $i$, and $d_{ik}$ is the travel time between $k$ and $i$. $W_r$ is the same distance-based weight calculated in step 1.

The E2SFCA implements the idea of gravity assumption, as a shorter distance denotes a higher population demand for a hospital (realized by function $f(d)$ in step 1) and better spatial access for a population site (realized by function $f(d)$ in the second demand). Therefore, a higher $A_i$ denotes a better spatial access, and vice versa.

The above mentioned E2SFCA method will be used to examine spatial access to emergency surgical services (for both all hospitals with emergency surgical capabilities and advanced-resource centers) in the United States in this study. Specifically, the population size of each CBG is used to approximate demand and number of inpatient beds at each hospital is used to represent the relative capacity of each hospital. CBG population size is the most direct
measure of population demand, as CBG-level estimates of EGS disease are not available. Hospital bed number is commonly used as a marker of facility size and capacity and is frequently used in health care research and planning. Both CBG population size and number of hospital beds are standard measures used in other studies of spatial access to hospital care using E2SCA models.9–11

To minimize the influence of the infamous distance impedance problem (i.e., the selection of the impedance parameter $\beta$ could influence the spatial access results), we used a weighted spatial access index, Spatial Access Ratio (SPAR)$^4$, to represent the eventual result. SPAR for a population site is calculated as the ratio between that population site’s SPAI and the average of SPAI among all population sites in the study area. The higher the SPAR, the better the spatial access. And SPAR values greater than one means better-than-state-average spatial access, and vice versa. SPAR has been proved effective in overcoming the distance impedance problem in multiple studies and has been used to explore spatial access to a variety of healthcare services$^1,12$–14.
**eTable 2: Regional variation in proportion of population living in CBGs with low access to any EGS-capable hospital**

| Region  | Total Population | Population in Low-Access CBG (N, %) |  |
|---------|------------------|------------------------------------|--|
|         |                  | Any EGS-Capable Hospital | Advanced-Resource Hospital |  |
| Northeast | 54,742,785      | 2,498,809 (4.61%)           | 8,711,221 (15.9%)       |  |
| Midwest  | 66,885,126       | 6,992,348 (10.5%)            | 21,847,527 (32.7%)     |  |
| South    | 118,770,525      | 13,259,211 (11.2%)           | 34,076,915 (28.7%)     |  |
| West     | 74,678,812       | 7,583,587 (10.2%)            | 16,705,812 (22.4%)     |  |

CBG=Census Block Group; EGS=Emergency General Surgery
### eTable 3. Univariable models of factors associated with low-access CBGs

#### a. Metropolitan

|                      | All EGS Hospitals |                      | Advanced Clinical Resource Hospitals |                      |
|----------------------|-------------------|----------------------|--------------------------------------|----------------------|
|                      | Low Access RR (95% CI) | Medium Access RR (95% CI) | Low Access RR (95% CI) | Medium Access RR (95% CI) |
| **Median Age**       | 1.05 (1.05-1.05)*  | 1.00 (1.00 – 1.00)    | 1.01 (1.01-1.02)*                | 1.00 (1.00-1.01)*     |
| **High-share Minority** |                  |                      |                                      |                      |
| Black                | 0.27 (0.25-0.28)*  | 0.36 (0.35-0.37)*     | 0.38 (0.37-0.39)*                | 0.37 (0.36-0.38)*     |
| Hispanic             | 0.53 (0.51-0.56)*  | 1.28* (1.25-1.30)     | 0.58 (0.56-0.60)*                | 1.20 (1.17-1.23)*     |
| Other Racial and Ethnic Minority Groups | 0.30 (0.28-0.32)* | 1.29 (1.26-1.32)* | 0.40 (0.39-0.42)* | 1.42 (1.40-1.46)* |
| **Median Income**    |                  |                      |                                      |                      |
| Non-poor (>200% FPL) | 0.73 (0.69-0.77)*  | 0.44 (0.43-0.45)*     | 1.03 (0.99-1.07)                | 0.45 (0.44-0.46)*     |
| Near-poor (100-200% FPL) | (0.19-0.27)* | (0.20-0.22)* | (0.54-0.63)* | (0.21-0.24)* |
| Poor: Below FPL      |                  |                      |                                      |                      |
| Public Insurance     | 1.07 (1.01-1.14)^  | 0.55 (0.53-0.56)*    | 1.17 (1.12-1.22)*                | 0.58 (0.57-0.60)*     |
| Uninsured            | 1.41 (1.33-1.49)*  | 0.64 (0.63-0.66)*    | 1.12 (1.07-1.16)*                | 0.61 (0.60-0.63)*     |

CBG=Census Block Group; EGS= Emergency General Surgery; RR= rate ratio; FPL=Federal Poverty Limit

^p<0.05; *p<0.001
b. Micropolitan

|                        | All EGS Hospitals | Advanced Clinical Resource Hospitals |
|------------------------|-------------------|--------------------------------------|
|                        | Low Access RR (95% CI) | Medium Access RR (95% CI) | Low Access RR (95% CI) | Medium Access RR (95% CI) |
| **Median Age**         | 1.03 (1.03-1.04)* | 1.01 (1.01-1.01)* | 1.01 (1.00-1.02)* | 1.00 (0.99-1.00)* |
| **High-share Minority**|                   |                       |                        |                          |
| Black                  | 0.42 (0.47-0.52)* | 0.46 (0.42-0.49)* | 0.47 (0.42-0.53)* | 0.48 (0.40-0.57)* |
| Hispanic               | 1.21 (1.08-1.37)* | 1.34 (1.23-1.46)* | 3.02 (2.45-3.72)* | 2.95 (2.31-3.78)* |
| Other Racial and Ethnic Minority Groups | 1.06 (0.94-1.20) | 0.81 (0.74-0.89)* | 1.77 (1.47-2.13)* | 1.17 (0.90-1.50) |
| **Median Income**      |                   |                       |                        |                          |
| Non-poor (>200% FPL)   | 1 [Reference] | 1 [Reference] | 1.09 (0.99-1.22) | 0.92 (0.79-1.06) |
| Near-poor (100-200% FPL) | 0.71 (0.65-0.77)* | 0.74 (0.70-0.79)* | 0.73 (0.60-0.86)* | 0.72 (0.63-1.78) |
| Poor: Below FPL        | 0.33 (0.27-0.39)* | 0.42 (0.37-0.47)* | 0.72 (0.60-0.86) | 1.06 (0.63-1.78) |
| **High-share Insurance**|                   |                       |                        |                          |
| Public Insurance       | 10.97 (10.89-1.06) | 0.77 (0.72-0.82)* | 1.25 (1.11-1.39)* | 1.09 (0.94-1.27) |
| Uninsured              | 1.02 (0.93-1.12) | 1.00 (0.92-1.08) | 1.17 (1.04-1.31)* | 1.10 (0.94-1.29) |

CBG=Census Block Group; EGS= Emergency General Surgery; RR= rate ratio; FPL=Federal Poverty Limit

^p<0.05; *p<0.001
| c. Rural |
|-----------------|-----------------|-----------------|-----------------|
| | All EGS Hospitals | Advanced Clinical Resource Hospitals |
| | Low Access RR (95% CI) | Medium Access RR (95% CI) | Low Access RR (95% CI) | Medium Access RR (95% CI) |
| **Median Age** | 1.02 (1.02-1.03)* | 1.01 (1.00-1.01)^ | 1.03 (1.02-1.04)* | 1.00 (0.99-1.01) |
| **High-share Minority** | | | | |
| Black | 0.61 (0.55-0.67)* | 0.83 (0.75-0.92)* | 0.54 (0.41-0.69)* | 0.83 (0.60-1.13) |
| Hispanic | 1.73 (1.52-1.98)* | 1.21 (1.05-1.38)^ | 1.74 (1.12-2.71)^ | 1.52 (0.91-2.53) |
| Other Racial and Ethnic Minority Groups | 1.29 (1.15-1.45)* | 0.87 (0.76-0.98)^ | 11.73 (1.13-2.65)^ | 1.22 (0.74-2.01) |
| **Median Income** | | | | |
| Non-poor (>200% FPL) | 1 [Reference] | 1 [Reference] | | |
| Near-poor (100-200% FPL) | 0.88 (0.82-0.95)* | 0.98 (0.79-1.22) | 0.93 (0.72-1.22) | |
| Poor: Below FPL | 0.69 (0.59-0.81)* | 0.60 (0.51-0.70)* | 0.73 (0.47-1.13) | 1.06 (0.63-1.78) |
| **High-share Insurance** | | | | |
| Public Insurance | 0.91 (0.84-0.98)^ | 0.88 (0.81-0.95)* | 0.75 (0.61-0.94)^ | 1.12 (0.87-1.46) |
| Uninsured | 1.40 (1.29-1.52)* | 1.00 (0.92-1.08) | 1.70 (1.30-2.22)* | 1.22 (0.89-1.68) |

CBG=Census Block Group; EGS= Emergency General Surgery; RR= rate ratio; FPL=Federal Poverty Limit

^p<0.05; *p<0.001
eTable 4. Multinomial model of spatial access for all census block groups

a) All EGS Hospitals

|                                | Low Access          | Medium Access        |
|--------------------------------|---------------------|----------------------|
|                                | aRR (95% CI)        | aRR (95% CI)         |
| **Median Age**                 | 1.03 (1.03-1.03)*   | 1.01 (1.00-1.01)*    |
| **High-share Minority**        |                     |                      |
| Black                          | 0.27 (0.26-0.28)*   | 0.46 (0.45-0.47)*    |
| Hispanic                       | 0.57 (0.55-0.60)*   | 1.42 (1.38-1.45)*    |
| Other Racial and Ethnic Minority Groups | 0.42 (0.40-0.44)* | 1.06 (1.03-1.08)*   |
| **Median Income**              |                     |                      |
| Non-poor (>200% FPL)           | 1 [Reference]       | 1 [Reference]        |
| Poor: Below FPL                | 0.52 (0.48-0.57)*   | 0.39 (0.37-0.40)*    |
| Near-poor (100-200% FPL)       | 1.04 (1.00-1.08)    | 0.64 (0.63-0.66)*    |
| **High-share Insurance**       |                     |                      |
| Public Insurance               | 1.21 (1.16-1.25)*   | 0.95 (0.93-0.98)*    |
| Uninsured                      | 1.58 (1.52-1.64)*   | 0.90 (0.87-0.92)*    |

^p<0.05; *p<0.001
b) Advanced Resource Hospitals

|                                | Low Access | Medium Access |
|--------------------------------|------------|---------------|
|                                | aRR (95% CI) | aRR (95% CI)  |
| **Median Age**                 | 1.02 (1.02-1.02)* | 1.00 (1.00-1.01)* |
| **High-share Minority**        |            |               |
| Black                          | 0.28 (0.27-0.28)* | 0.47 (0.46-0.49)* |
| Hispanic                       | 0.42 (0.41-0.43)* | 1.42 (1.39-1.46)* |
| Other Racial and Ethnic Minority Groups | 0.39 (0.38-0.41)* | 1.26 (1.23-1.29)* |
| **Median Income**              |            |               |
| Non-poor (>200% FPL)           | 1 [Reference] | 1 [Reference] |
| Poor: Below FPL                | 1.18 (1.12-1.24)* | 0.38 (0.35-0.40)* |
| Near-poor (100-200% FPL)       | 1.76 (1.71-1.80)* | 0.59 (0.57-0.60)* |
| **High-share Insurance**       |            |               |
| Public Insurance               | 1.25 (1.21-1.28)* | 0.98 (0.95-1.01) |
| Uninsured                      | 1.29 (1.25-1.32)* | 0.81 (0.79-0.84)* |

*p<0.05; *p<0.001
**Table 5.** Interaction of race and ethnicity and poverty in predictors of census block group with low-access to any emergency general surgery capable hospital*

|                          | aRR  | 95% CI      | p-value |
|--------------------------|------|-------------|---------|
| **Metropolitan**         |      |             |         |
| Black Q4: Below FPL      | 0.39 | 0.30 - 0.55 | < 0.001 |
| Black Q4: Near-poor (>200% FPL) | 0.82 | 0.73 - 0.93 | 0.001   |
| Hispanic Q4: Below FPL   | 0.64 | 0.44 - 0.91 | 0.01    |
| Hispanic Q4: Near-poor (>200% FPL) | 0.52 | 0.47 - 0.59 | < 0.001 |
| Other Minority Q4: Below FPL | 2.42 | 1.61 - 3.63 | < 0.001 |
| Other Minority Q4: Near-poor (>200% FPL) | 1.30 | 1.12 - 1.52 | 0.001   |
| **Micropolitan**         |      |             |         |
| Black Q4: Below FPL      | 1.47 | 0.93 - 2.30 | 0.10    |
| Black Q4: Near-poor (>200% FPL) | 0.96 | 0.71 – 1.28 | 0.76    |
| Hispanic Q4: Below FPL   | 1.83 | 1.12 – 2.98 | 0.02    |
| Hispanic Q4: Near-poor (>200% FPL) | 1.12 | 0.94 – 1.57 | 0.13    |
| Other Minority Q4: Below FPL | 0.70 | 0.39 – 1.26 | 0.24    |
| Other Minority Q4: Near-poor (>200% FPL) | 0.91 | 0.71 – 1.18 | 0.47    |
| **Rural**                |      |             |         |
| Black Q4: Below FPL      | 1.06 | 0.71 – 1.59 | 0.80    |
| Black Q4: Near-poor (>200% FPL) | 1.05 | 0.79 – 1.40 | 0.73    |
| Hispanic Q4: Below FPL   | 1.11 | 0.62 – 1.97 | 0.73    |
| Hispanic Q4: Near-poor (>200% FPL) | 0.79 | 0.59 – 1.05 | 0.10    |
| Other Minority Q4: Below FPL | 3.71 | 2.21 – 6.37 | < 0.001 |
| Other Minority Q4: Near-poor (>200% FPL) | 1.57 | 1.22 – 2.03 | 0.001   |

*All models adjusted for Age, High-Share Race/Ethnicity groups, Median Income, High-share Insurance groups

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**eTable 6.** Comparison of logistic regression model adjusting for spatial autocorrelation with multinomial model risk of low vs. high spatial access±

|                      | Metropolitan |          | Micropolitan |          | Rural |          |
|----------------------|--------------|----------|--------------|----------|-------|----------|
|                      | Logistic Regression Model aOR (95% CI) | Multinomial Model aRR (95% CI) | Logistic Regression Model aOR (95% CI) | Multinomial Model aRR (95% CI) | Logistic Regression Model aOR (95% CI) | Multinomial Model aRR (95% CI) |
| **Median Age**       | 1.03 (1.03-1.03)* | 1.03 (1.03-1.03)* | 1.03 (1.03-1.03)* | 1.03 (1.03-1.03)* | 1.03 (1.02-1.03)* | 1.03 (1.03-1.03)* |
| **High-share Minority** |              |          |              |          |       |          |
| Black                | 0.31 (0.30-0.33)* | 0.33 (0.31-0.35)* | 0.51 (0.45-0.57)* | 0.51 (0.44-0.57)* | 0.66 (0.59-0.74)* | 0.64 (0.58-0.72)* |
| Hispanic             | 0.58 (0.54-0.62)* | 0.63 (0.60-0.68)* | 1.34 (1.18-1.53)* | 1.35 (1.19-1.54)* | 1.80 (1.57-2.07)* | 1.80 (1.57-2.01)* |
| Other Racial and Ethnic Minority Groups | 0.29 (0.27-0.31)* | 0.30 (0.28-0.32)* | 1.10 (0.97-1.25)  | 1.12 (0.99-1.28)  | 1.33 (1.17-1.50)* | 1.31 (1.16-1.48)* |
| **Median Income**    |              |          |              |          |       |          |
| Non-poor (≥200% FPL) | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] |
| Near-poor (100-200% FPL) | 0.74 (0.70-0.78)* | 0.73 (0.69-0.77)* | 0.68 (0.61-0.75)* | 0.70 (0.63-0.77)* | 0.84 (0.77-0.91)* | 0.84 (0.78-0.92)* |
| Poor: Below FPL      | 0.23 (0.20-0.28)* | 0.23 (0.19-0.27)* | 0.36 (0.29-0.45)* | 0.38 (0.31-0.47)* | 0.73 (0.61-0.88)* | 0.73 (0.61-0.88)* |
| **High-share Insurance** |          |          |              |          |       |          |
| Public Insurance     | 1.09 (1.03-1.16)* | 1.07 (1.01-1.14)* | 1.36 (1.23-1.51)* | 1.34 (1.22-1.48)* | 1.03 (0.94-1.12) | 1.03 (0.94-1.12) |
| Uninsured            | 1.40 (1.33-1.49)* | 1.41 (1.33-1.49)* | 1.45 (1.31-1.61)* | 1.40 (1.26-1.55)* | 1.53 (1.40-1.68)* | 1.55 (1.41-1.69)* |

±Logistic regression model adjusts for spatial autocorrelation using an exponential spatial covariance structure, where covariance between observations is based on Euclidian distance between centroids

^p<0.05; *p<0.001

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