**Supplementary Methods: Gravity-Based Spatial Access Model**

Realizing the limitations of both travel impedance measures (eg. distance, time) 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), searches all population sites within each zone, and calculates the supply-demand ratio for *j* by

 $R\_{j}=\frac{S\_{j}}{\sum\_{j\in (d\_{kj}\in D\_{r})}^{}P\_{k}W\_{r}}$

$$=\frac{S\_{j}}{\sum\_{j\in (d\_{kj}\in D\_{1})}^{}P\_{k}W\_{1}+\sum\_{j\in (d\_{kj}\in D\_{2})}^{}P\_{k}W\_{2}+\sum\_{j\in (d\_{kj}\in D\_{3})}^{}P\_{k}W\_{3}+\sum\_{j\in (d\_{kj}\in D\_{4})}^{}P\_{k}W\_{4}}$$

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., $f\left(d\right)=e^{{-d^{2}}/{β}}$ where d represents a distance and $β$ 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:

$$A\_{i}=\sum\_{k\in (d\_{ik}\in D\_{r})}^{}R\_{k}W\_{r}$$

$$=\sum\_{k\in (d\_{ik}\in D\_{1})}^{}R\_{k}W\_{1}+\sum\_{k\in (d\_{ik}\in D\_{2})}^{}R\_{k}W\_{2}+\sum\_{k\in (d\_{ik}\in D\_{3})}^{}R\_{k}W\_{3}+\sum\_{k\in (d\_{ik}\in D\_{4})}^{}R\_{k}W\_{4}$$

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.

To minimize the influence of the infamous distance impedance problem (i.e., the selection of the impedance parameter $β$ 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 great 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 services1,9–11.

*Border Crossing:* For this study, for each CBG in the twelve states examined, we used SPAR values generated from our GIS platform of spatial access to EGS-capable hospitals for the entire United States. The SPAR for each CBG therefore accounts for access to neighboring states and the possibility of patient border crossing.

*Access to Advanced-Resource Hospitals:* For each patient, we calculated two values of SPAR: first to any EGS-capable hospital (SPAR1), and secondly to hospitals identified as having the advanced clinical resources defined above (SPAR2), as severe or complicated disease could require treatment at this subset of hospitals for which a patient’s spatial access could differ substantially compared to EGS-capable hospitals as a whole. For our primary analysis, our measure of spatial access was defined by the type of admitted hospital (i.e. SPAR2 if the patient was admitted to an advanced resource hospital). We subsequently performed several sensitivity analyses using a) SPAR1 for all patient encounters to measure spatial access to *any* surgical hospital, and b) SPAR 2 for all hospitals with “complex disease”, as these patients are likely to require resources found only at “advanced-resource” hospitals given severity of disease.

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