Research Square

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Geographic inequalities in neurosurgical capacity and interprovincial hospitalization in Ecuador: a nationwide observational study

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Abstract

Background

Geographic inequalities in specialized healthcare capacity may influence where patients receive hospital care. We examined the distribution of neurosurgical resources and interprovincial hospitalization in Ecuador, assessing associations between provincial healthcare capacity and hospitalization outside the province of residence.

Methods

We conducted a nationwide observational study linking Ecuadorian hospital-discharge records from 2024 with provincial workforce, neuroimaging, critical-care, and hospital-bed indicators. The study included 15,604 hospitalizations for non-traumatic intracranial hemorrhage, central nervous system tumors, traumatic brain injury, and hydrocephalus. Out-of-province hospitalization was defined as hospitalization in a province other than the province of residence. Associations were examined using binomial generalized estimating equations clustered by province of residence, with bias-reduced covariance estimation.

Results

Among 3,545 hospitalizations for non-traumatic intracranial hemorrhage, 593 (16.7%) occurred outside the province of residence. Four destination provinces accounted for 84.3% of these interprovincial hospitalizations. Each 0.5-unit increase in recorded provincial neurosurgical workforce per 100,000 population was associated with lower adjusted odds of out-of-province hospitalization (adjusted odds ratio 0.55, 95% confidence interval 0.42–0.72). The inverse association was maintained across sensitivity analyses and was also observed in traumatic brain injury. Neurosurgical resources were geographically concentrated, with substantial differences across provinces.

Conclusions

Neurosurgical capacity and interprovincial hospital utilization were unevenly distributed across Ecuador. Higher provincial neurosurgical workforce density was associated with lower out-of-province hospitalization, highlighting geographic differences in reliance on specialized services. Linking healthcare capacity with observed hospitalization flows may inform geographically equitable health-system planning, although cross-provincial hospitalization alone does not establish inequitable access.

Background

Access to timely neurosurgical care depends not only on national workforce supply but also on the geographic distribution of specialists, imaging, critical-care capacity, and hospital resources. Large global disparities in neurosurgical workforce availability persist, with substantially lower specialist density in low-income than in high-income countries [1–3]. National averages may therefore obscure important subnational inequalities in access to specialized care.

From a health-equity perspective, geographic differences in specialist availability are important because populations living in resource-constrained provinces may depend disproportionately on healthcare services located elsewhere [4]. Such differences may reflect structural variation in the organization and distribution of healthcare resources [5, 6]. However, geographic differences in resource availability or hospital utilization should not automatically be interpreted as inequitable access without considering healthcare needs, referral arrangements, and patient outcomes [7] .

Subnational distribution is particularly relevant in Latin America, where marked variation in neurosurgical workforce and geographic access has been documented across countries and regions [8–11]. Recent analyses from the Caribbean and Peru illustrate substantial geographic concentration of neurosurgical services, emphasizing that spatial distribution may be as important as aggregate national supply.

Recent work in Ecuador demonstrated substantial geographic heterogeneity in surgical supply using a spatial accessibility model [12]. Such approaches characterize potential access, whereas administrative hospital-discharge data can measure realized utilization by identifying where residents are hospitalized relative to their place of residence [13, 14]. Linking hospitalization flows with regional capacity may therefore reveal dependence on services outside patients' home regions.

Using nationwide administrative data from the Instituto Nacional de Estadística y Censos [15], we therefore sought to characterize provincial neurosurgical capacity and observed interprovincial hospitalization flows in Ecuador. Non-traumatic intracranial hemorrhage was prespecified as the primary tracer condition because its management may require timely specialist assessment together with neuroimaging, critical-care, and neurosurgical resources [16]. Limited access to trained personnel, equipment, and geographically accessible services has been identified as an important barrier to neurosurgical care in low- and middle-income settings [17, 18]. We quantified residence-to-hospitalization flows between provinces and evaluated whether geographic variation in provincial neurosurgical workforce density was associated with out-of-province hospitalization, using observed hospital utilization as an indicator of geographic dependence on specialized healthcare services.

Methods

Study design and data sources

We conducted a nationwide observational study linking Ecuadorian hospital-discharge and health-system capacity data at the province level. Hospitalizations were obtained from the 2024 INEC Hospital Discharges Statistics (1,132,667 records) [15], workforce and imaging measures from the 2021

Resources and Health Activities Statistics (4,109 establishments) [19], and hospital beds from the 2024 Hospital Beds Statistics (626 establishments) [15]. Provincial population estimates were used to calculate resource densities.

Study population and diagnostic cohorts

A neurology/neurosurgery-oriented extract was created from the ECEH microdata using the principal ICD-10 diagnosis. The prespecified analytic cohorts were: non-traumatic intracranial hemorrhage (I60-I62), central nervous system (CNS) tumors (C70-C72, D32-D33, D42-D43), traumatic brain injury (S06), and hydrocephalus (G91, Q03). Non-traumatic intracranial hemorrhage was designated the primary tracer condition; CNS tumors, traumatic brain injury, and hydrocephalus were secondary or replication cohorts. Records with residence recorded as outside Ecuador were excluded from the province-based analytic models. The final analytic dataset comprised 15,604 hospitalizations: 3,545 for non-traumatic intracranial hemorrhage, 2,265 for CNS tumors, 8,813 for traumatic brain injury, and 981 for hydrocephalus.

Outcome definition

Outcome definition
The primary outcome was out-of-province hospitalization, defined by discordance between province of residence and province of hospitalization. Each discharge represented a hospitalization rather than a unique individual. Records with missing or non-Ecuadorian residence were excluded from province-based analyses. Origin–destination flows were aggregated to characterize interprovincial hospital use.

This outcome was interpreted as an indicator of realized geographic hospital utilization and dependence on services located outside the province of residence, rather than as a direct measure of unmet healthcare need or inequitable access. The available administrative data did not permit assessment of the clinical appropriateness, timeliness, or financial consequences of interprovincial hospitalization.

Primary exposure and secondary capacity measures

The primary exposure was provincial INEC-derived neurosurgical workforce density (“Neurocirujanos Uso INEC”, k191e), expressed per 100,000 population. The primary effect estimate was scaled per 0.5-unit increase. Secondary capacity indicators were neurosurgical beds, MRI units, CT units, and adult ICU beds per 100,000 population. Workforce, MRI, and CT measures used 2021 data and population denominators; bed measures used 2024 data and denominators. Because capacity indicators were correlated, they were modeled separately and secondary measures were standardized per one provincial standard deviation (Additional file 1: Table S1).

Covariates

Age was converted to years, restricted to 0–115 years, and modeled using a cubic B-spline with 4 degrees of freedom. Primary models additionally adjusted for sex, rural residence, and diagnostic subtype. Sensitivity analyses incorporated simplified insurance and ethnicity categories. No primary-model variables were missing after data cleaning. Hospital sector, length of stay, and in-hospital mortality were not included because they could occur downstream of the geographic care pathway.

Descriptive and geospatial analyses

Provincial boundaries were obtained from GADM version 4.1 and harmonized with INEC identifiers. Choropleth maps depicted capacity and out-of-province hospitalization. Origin–destination networks linked provincial centroids and therefore represent schematic interprovincial movements rather than individual travel trajectories. All observed routes were retained, and net flow was calculated as incoming minus outgoing hospitalizations.

Statistical analysis

The primary association was estimated using a hospitalization-level binomial generalized estimating equation (GEE) with logit link, exchangeable working correlation, and clustering by province of residence. Because the exposure was defined at the provincial level and only 24 geographic clusters were available, inference used the bias-reduced robust covariance estimator implemented in statsmodels (cov_type="bias_reduced"), corresponding to the small-sample covariance correction proposed by Mancl and DeRouen. Wald 95% confidence intervals were calculated from the bias-reduced standard errors [20]. Sensitivity analyses used an independence working correlation, additional insurance or ethnicity adjustment, any versus no recorded workforce, leave-one-province-out analyses, and a 2,000-resample province-cluster bootstrap. Secondary disease cohorts used the same framework, and alternative capacity measures were modeled separately. Secondary analyses were exploratory and were not adjusted for multiplicity.

Analyses were performed in Python 3.13 using statsmodels, GeoPandas, and related scientific Python packages.

Results

Study population and geographic capacity

The analysis included 15,604 hospitalizations across four tracer cohorts (Table 1): 3,545 for non-traumatic intracranial hemorrhage, 2,265 for CNS tumors, 8,813 for traumatic brain injury, and 981 for hydrocephalus. Out-of-province hospitalization occurred in 16.7%, 24.6%, 16.4%, and 23.0% of these cohorts, respectively.

[Table 1]

Neurosurgical capacity was geographically concentrated (Fig. 1A–B). Pichincha and Guayas accounted for 53.3% of the national INEC-derived neurosurgical workforce and 73.6% of neurosurgical beds. Six of 24 provinces had no recorded neurosurgical workforce and 11 had no neurosurgical beds.

[Figure 1]

Interprovincial hospitalization flows

Complete origin–destination networks revealed a highly centralized pattern of interprovincial care for both tracer conditions (Fig. 2). The geographic distribution of out-of-province hospitalization showed marked interprovincial heterogeneity for both non-traumatic intracranial hemorrhage and CNS tumors (Fig. 1C–D). For intracranial hemorrhage, 593 out-of-province hospitalizations occurred across 85 routes; Guayas, Pichincha, Santo Domingo de los Tsáchilas, and Azuay received 84.3% of these flows (Fig. 2A). For CNS tumors, 557 out-of-province hospitalizations occurred across 77 routes, with Pichincha, Guayas, and Azuay receiving 84.7% (Fig. 2B).

[Figure 2]

Primary adjusted analysis: non-traumatic intracranial hemorrhage

In the primary exchangeable GEE, higher provincial neurosurgical workforce density was associated with lower odds of out-of-province hospitalization. For each 0.5-unit increase in INEC-derived neurosurgical workforce per 100,000 population, the adjusted odds of out-of-province hospitalization were 45.1% lower (aOR 0.55, 95% CI 0.42-0.72; p<0.001) (Fig. 3A; Table 2). In the binary sensitivity analysis, residence in a province with any recorded neurosurgical workforce was associated with lower odds of out-of-province hospitalization than residence in a province with none (aOR 0.29, 95% CI 0.12-0.72; p=0.0076).

[Table 2]

[Figure 3]

Robustness analyses

The inverse association was preserved across all sensitivity analyses (Table 2). All 24 leave-one-province-out estimates remained below 1, and the 2,000-resample province-cluster bootstrap yielded a median OR of 0.54 (95% percentile interval 0.39–0.70).

Secondary disease cohorts

The association replicated in traumatic brain injury (aOR 0.38, 95% CI 0.27–0.53) and was directionally similar but imprecise for hydrocephalus (aOR 0.44, 95% CI 0.14–1.35). The CNS-tumor estimate was also imprecise and sensitive to the working-correlation specification (Additional file 1: Table S2; Fig. 3B).

Alternative regional capacity measures

In ICH, higher MRI and adult ICU capacity showed concordant inverse associations with out-of-province hospitalization, whereas estimates for neurosurgical beds and CT were imprecise (Additional file 1: Table S2; Fig. 3C).

Discussion

This nationwide study demonstrated marked geographic concentration of neurosurgical capacity and interprovincial hospital use in Ecuador. Greater provincial neurosurgical workforce density was consistently associated with lower odds of out-of-province hospitalization for intracranial hemorrhage, with a similar association in traumatic brain injury. These findings indicate that regional health-system capacity is closely related to realized patterns of specialized hospital use, although they do not establish that increasing workforce alone would causally reduce interprovincial care.

These findings extend previous evidence of pronounced geographic inequalities in neurosurgical workforce and access globally and within Latin America [1, 3, 8, 10, 11]. Recent work in Ecuador demonstrated substantial heterogeneity using modeled spatial accessibility [12]. Our analysis adds a complementary measure of realized utilization by examining where residents were actually hospitalized. Together, these approaches suggest that national resource totals can obscure subnational dependence on a limited number of regional centers and support the use of subnational indicators for health-system planning.

From a health-equity perspective, these findings highlight geographic differences in the availability and use of specialized healthcare services [21]. Provinces with limited recorded neurosurgical capacity may rely more heavily on services concentrated in a small number of regional centers [22]. This pattern identifies a potential dimension of territorial inequality that deserves attention in health-system planning [23]. Nevertheless, whether these geographic differences translate into inequitable access depends on factors not captured in the present study, including differences in healthcare needs, referral appropriateness, travel burden, and treatment outcomes [23, 24] .

Concordant associations for MRI and adult ICU capacity suggest that neurosurgical capacity reflects a broader tertiary-care ecosystem rather than specialist headcount alone [17, 25–28]. Because these indicators were correlated and modeled separately, their associations should not be interpreted as independent causal effects.

Disease-specific findings also indicate that interprovincial care should not automatically be interpreted as deficient local access. Although the workforce association replicated in traumatic brain injury, estimates for hydrocephalus and CNS tumors were less precise. Complex conditions may appropriately be regionalized to tertiary centers offering specialized multidisciplinary expertise [29, 30]. The policy question is therefore not whether interprovincial care should be eliminated, but whether referral pathways are timely, equitable, and adequately supported. Concentrated flows may identify effective regional hubs while simultaneously revealing dependence of surrounding provinces on external capacity [31–33].

Several limitations should be considered. The exposure was defined across only 24 provinces, leaving potential ecological and residual geographic confounding despite bias-reduced inference, leave-one-province-out analyses, and cluster bootstrap resampling [34]. Province was the finest common geographic unit, precluding assessment of within-province variation and residual spatial dependence. Hospital-discharge data identified patients' provinces of residence and hospitalization but did not provide information on formal referrals, clinical severity, symptom onset, travel time, patient preferences, or all insurance-related constraints. Moreover, the analysis was restricted to recorded hospitalizations and therefore could not identify individuals who required specialized care but were never hospitalized. Consequently, the study cannot quantify unmet neurosurgical need, determine whether interprovincial care was clinically appropriate, or establish whether the observed geographic differences constituted inequitable access. Workforce, MRI, and CT indicators were measured in 2021 whereas hospitalizations and bed capacity were measured in 2024, potentially introducing exposure misclassification. Finally, the INEC workforce measure represents recorded administrative workforce and should not be interpreted as an exact count of practicing neurosurgeons. Secondary capacity analyses were exploratory and unadjusted for multiplicity [35, 36].

Strengths include nationwide hospitalization data, linkage with independently measured capacity indicators, complete origin–destination networks, extensive sensitivity analyses, and replication in traumatic brain injury.

Conclusions

This nationwide study identified substantial geographic concentration of neurosurgical resources and interprovincial hospital utilization in Ecuador. Higher provincial neurosurgical workforce density was associated with lower odds of out-of-province hospitalization for non-traumatic intracranial hemorrhage, with a similar association observed in traumatic brain injury. These findings highlight geographic differences in the distribution and utilization of specialized healthcare services. Integrating provincial capacity indicators with observed hospitalization flows may help inform geographically equitable health-system planning. Further research incorporating travel burden, clinical need, referral pathways, and patient outcomes is needed to determine whether these geographic differences translate into inequitable access.

Abbreviations

aOR: Adjusted odds ratio.

CI: Confidence interval.

CNS: Central nervous system.

CT: Computed tomography.

ECEH: Estadística de Camas y Egresos Hospitalarios.

GEE: Generalized estimating equation.

ICH: Intracranial hemorrhage.

ICU: Intensive Care Unit.

INEC: Instituto Nacional de Estadística y Censos.

IQR: Interquartile range.

MRI: Magnetic resonance imaging.

OR: Odds ratio.

RAS: Recursos y Actividades de Salud.

SD: Standard deviation.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki, where applicable, and the Ecuadorian regulatory framework governing observational research. The study involved exclusively the secondary analysis of publicly available, de-identified administrative hospital-discharge and healthcare-resource data from the Instituto Nacional de Estadística y Censos (INEC). Under Article 8 of Ecuadorian Ministerial Agreement No. 00038-2021, which amended Ministerial Agreement No. 00015-2021, research conducted exclusively using open or public data does not require prior approval by a Human Research Ethics Committee (Comité de Ética de Investigación en Seres Humanos, CEISH). No direct participant contact occurred, and no directly identifying personal information was accessed or analysed. Accordingly, ethics committee approval and individual informed consent were not required.

Consent for publication

Not applicable. This manuscript does not contain identifiable individual participant information, images, or personal details.

Availability of data and materials

The hospital-discharge and healthcare resource datasets analysed in this study are publicly available from the Instituto Nacional de Estadística y Censos (INEC), Ecuador, through its Hospital Beds and Discharges Statistics (https://www.ecuadorencifras.gob.ec/camas-y-egresos-hospitalarios/) and Health

Resources and Activities Statistics (https://www.ecuadorencifras.gob.ec/actividades-y-recursos-de-salud/) portals. Provincial administrative boundaries were obtained from GADM version 4.1. The analytic code and non-restricted derived data supporting the findings are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

APMG contributed to conceptualization, methodology, investigation, data curation, formal analysis, software development, project administration, writing of the original draft, and reviewed and edited the manuscript. GGMG contributed to conceptualization, supervision, and manuscript review and editing. All authors read and approved the final manuscript.

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Tables

Tables 1 to 2 are available in the Supplementary Files section.

Figures

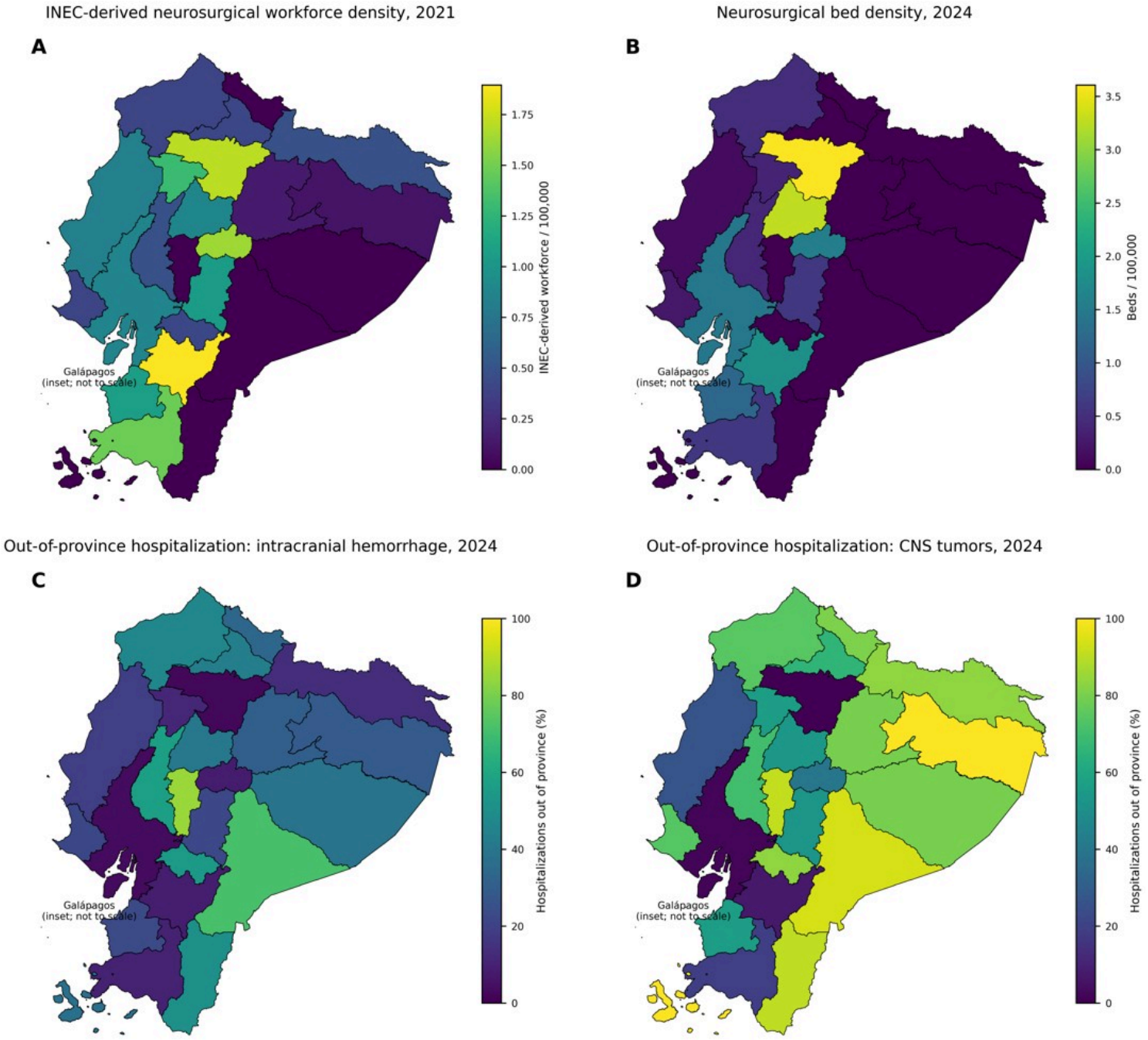


Figure 1

Spatial distribution of neurosurgical capacity and out-of-province hospitalization in Ecuador.

(A) Provincial density of INEC-derived neurosurgical workforce per 100,000 population in 2021. **(B)** Provincial neurosurgical bed density per 100,000 population in 2024. **(C)** Proportion of hospitalizations for non-traumatic intracranial hemorrhage occurring outside the province of residence in 2024. **(D)**Proportion of hospitalizations for central nervous system tumors occurring outside the province of residence in 2024. Workforce density was calculated using the RAS 2021 INEC-derived neurosurgical workforce measure and 2021 provincial population denominators; neurosurgical-bed density was calculated using 2024 hospital-bed data and 2024 population denominators. Out-of-province

hospitalization represents the percentage of hospitalization records in which the province of hospitalization differed from the province of residence. Galápagos is displayed as an inset and is not shown at its true geographic distance from mainland Ecuador. **CNS**, central nervous system; **INEC**, Instituto Nacional de Estadística y Censos; **RAS**, Recursos y Actividades de Salud.

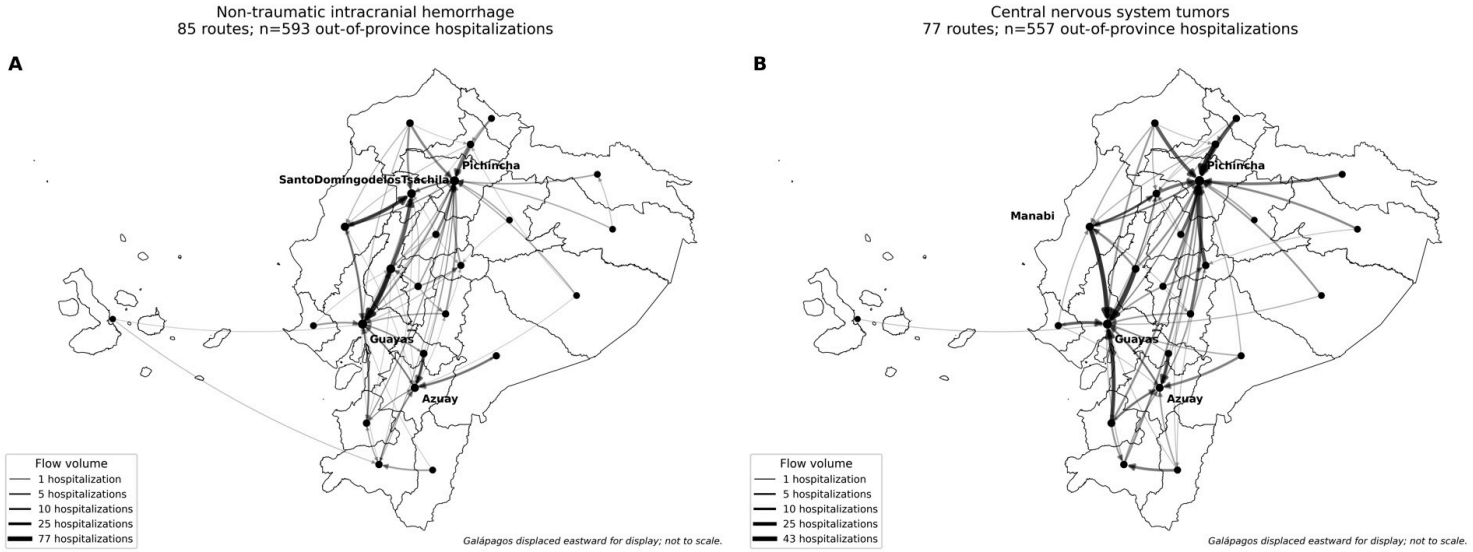


Figure 2

Interprovincial hospitalization flows for intracranial hemorrhage and central nervous system tumors in Ecuador, 2024.

(A) Interprovincial flows among patients hospitalized for non-traumatic intracranial hemorrhage. A total of 593 out-of-province hospitalizations were distributed across 85 observed origin–destination routes. **(B)**Interprovincial flows among patients hospitalized for central nervous system tumors. A total of 557 out-of-province hospitalizations were distributed across 77 observed routes. Each arrow represents an observed origin–destination flow of hospitalization records from the province of residence to the province of hospitalization. Arrow width is proportional to the number of hospitalizations represented by each route. All observed interprovincial routes, including routes involving a single hospitalization, are displayed. Labels identify major receiving provinces. **CNS**, central nervous system.

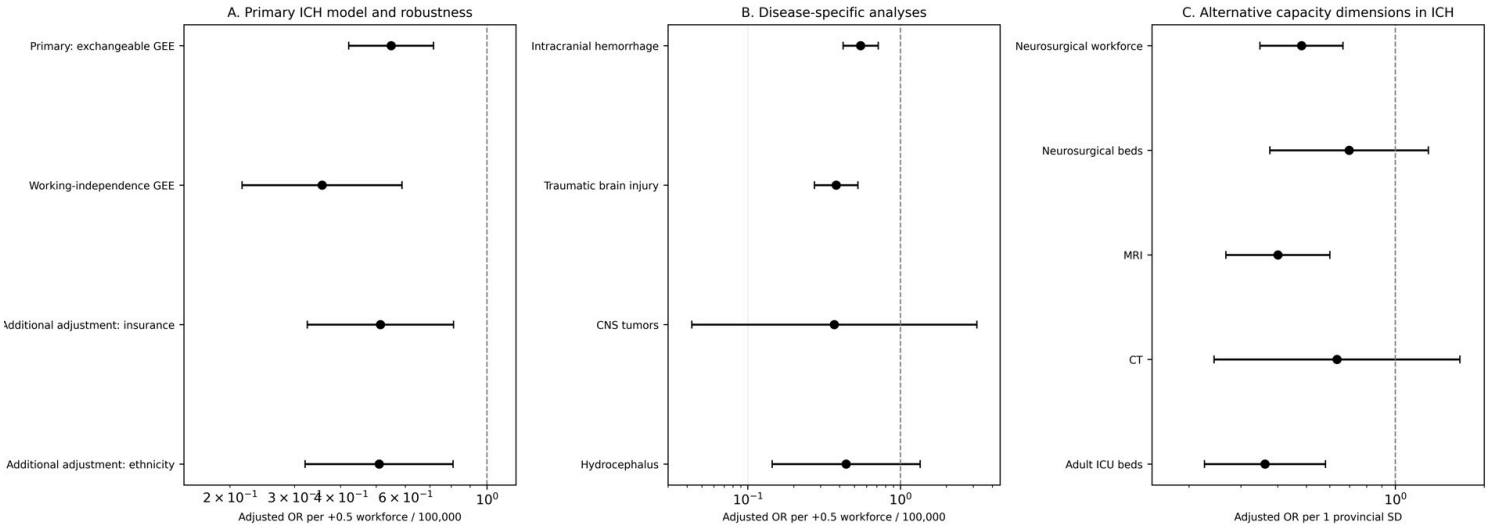


Figure 3

Adjusted associations between regional neurosurgical capacity and out-of-province hospitalization.

Points represent adjusted odds ratios (aORs) and horizontal bars indicate 95% confidence intervals. The vertical dashed line denotes the null value (OR=1). The x-axes are displayed on logarithmic scales. **(A)**Primary and sensitivity analyses for non-traumatic intracranial hemorrhage. The primary model used a binomial generalized estimating equation (GEE) with exchangeable working correlation and bias-reduced covariance, clustered by province of residence and adjusted for age using a cubic B-spline basis, sex, rural residence, and hemorrhage subtype. Additional models used an independence working correlation or further adjustment for insurance or ethnicity. Estimates are expressed per 0.5-unit increase in INEC-derived neurosurgical workforce per 100,000 population. **(B)** Disease-specific analyses using the primary exchangeable GEE specification for non-traumatic intracranial hemorrhage, traumatic brain injury, CNS tumors, and hydrocephalus. Estimates are expressed per 0.5-unit increase in workforce density. **(C)** Separate models of alternative regional capacity measures among patients with non-traumatic intracranial hemorrhage. Each estimate represents a one-standard-deviation increase in the provincial distribution of the corresponding resource measure. Capacity dimensions were modeled separately because several resource measures were correlated at the provincial level. **aOR**, adjusted odds ratio; **CI**, confidence interval; **CNS**, central nervous system; **CT**, computed tomography; **GEE**, generalized estimating equation; **ICU**, intensive care unit; **INEC**, Instituto Nacional de Estadística y Censos; **MRI**, magnetic resonance imaging; **OR**, odds ratio; **SD**, standard deviation.

Supplementary Files

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