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Towards defining the surgical workforce for children: a geospatial analysis in Brazil

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ABSTRACT

Objectives The optimal size of the health workforce for children's surgical care around the world remains poorly defined. The goal of this study was to characterise the surgical workforce for children across Brazil, and to identify associations between the surgical workforce and measures of childhood health.

Design This study is an ecological, cross-sectional analysis using data from the Brazil public health system (*Sistema Único de Saúde*).

Settings and participants We collected data on the surgical workforce (paediatric surgeons, general surgeons, anaesthesiologists and nursing staff), perioperative mortality rate (POMR) and under-5 mortality rate (U5MR) across Brazil for 2015.

Primary and secondary outcome measures We performed descriptive analyses, and identified associations between the workforce and U5MR using geospatial analysis (Getis-Ord-Gi analysis, spatial cluster analysis and linear regression models).

Findings There were 39 926 general surgeons, 856 paediatric surgeons, 13 243 anaesthesiologists and 103 793 nurses across Brazil in 2015. The U5MR ranged from 11 to 26 deaths/1000 live births and the POMR ranged from 0.11–0.17 deaths/100 000 children across the country. The surgical workforce is inequitably distributed across the country, with the wealthier South and Southeast regions having a higher workforce density as well as lower U5MR than the poorer North and Northeast regions. Using linear regression, we found an inverse relationship between the surgical workforce density and U5MR. An U5MR of 15 deaths/1000 births across Brazil is associated with a workforce level of 5 paediatric surgeons, 200 surgeons, 100 anaesthesiologists or 700 nurses/100 000 children.

Conclusions We found wide disparities in the surgical workforce and childhood mortality across Brazil, with both directly related to socioeconomic status. Areas of increased surgical workforce are associated with lower U5MR. Strategic investment in the surgical workforce may be required to attain optimal health outcomes for children in Brazil, particularly in rural regions.

Strengths and limitations of this study

- Use of geospatial analysis allows precise definition of associations between the surgical workforce and under-5 mortality rate (U5MR) across Brazil.
- Analysis can demonstrate an inverse relationship between the surgical workforce and U5MR, allowing for location of areas of increased workforce which are associated with lower U5MR levels.
- Geospatial tools can confirm disparities in the surgical workforce as well as U5MR across Brazil, and support modelling to define the relationship between the surgical workforce and U5MR.
- Our findings of an association between surgical workforce and U5MR does not demonstrate causation, as many confounding factors and modifiers other than surgical disease impact the U5MR
- Although our findings of an association between surgical workforce and U5MR does not demonstrate causation.

INTRODUCTION

Healthcare is workforce intensive, and an adequate level of human resources is essential to maintain strong health systems. Discrepancies between local health needs and the health workforce leads to clinical errors, wastage of resources and increased patient mortality and morbidity.[1] For surgical care, the workforce is grossly inadequate and inequitably distributed in many low-income and middle-income countries (LMICs), with rural areas disproportionately affected.[2 3]

Studies from the Lancet Commission on Global Surgery (LCoGS) have proposed a density of 20–40 specialist physicians (surgeons, anaesthesiologists or obstetricians, SAO) per 100 000 general population to attain desired health outcomes, such as perioperative mortality rate (POMR).[2–4] However, surgical care for children is fundamentally different from adult care, with surgical resources provided through multiple tiers in a national health system in proportion to population needs and surgical complexity required.[5] In these complex health systems,

the optimal surgical workforce for children remains poorly defined.

Brazil offers a rich environment to closely examine the health workforce, as it has extremely heterogeneous geography, health infrastructure and socioeconomic status across the country (GINI index 53.3 in 2017).[6 7] Brazil has a large public health system (*Sistema Único de Saúde, SUS*) and maintains several publicly available datasets (DATASUS).[6 8] Efforts to reduce health disparities across the five Brazil regions (North, Northeast, Midwest, Southeast and South) have made great strides in recent years, particularly through workforce expansion in primary care.[9]

Previous geospatial analysis by ourselves and others have identified wide disparities in surgical care across Brazil.[10 11] Facilities providing surgical care for children are inequitably distributed across the country, with higher density of infrastructure and surgical access per population unit associated with areas of higher socioeconomic status.[10] Spatial cluster analysis demonstrated a higher under-5 mortality rate (U5MR) in the poorer North, Northeast and Midwest regions compared to the wealthier Southeast and South regions, although the POMR for a proxy set of children's conditions does not vary across the country.[10] Increased access to surgical care is associated with a lower U5MR, and access to surgical care differs by geographic region independent of socioeconomic status.

The goals of this study are to characterise the surgical workforce for children in the public health system in Brazil using geospatial analysis and to identify associations between the surgical workforce and childhood mortality rates. Through this analysis, we hope to provide an assessment of Brazil's surgical workforce, identify disparities in workforce distribution and estimate the required surgical workforce to obtain desired health outcomes for children.

METHODS

This study is an ecological, cross-sectional, geospatial analysis using data from the Brazil public health system. Brazil is composed of 5570 municipalities across the union of the Federal District and 26 states, which are distributed across five regions (Midwest, North, Northeast, South and Southeast). We collected data on all children <15 years of age undergoing a surgical procedure from 2010 to 2015 across Brazil using datasets from DATASUS (see table 1 for all datasets and study timeframes). Auxiliary data were collected from databases from the World Bank and the Brazilian Institute of Geography and Statistic (IBGE).[8] We used several tools of geospatial analysis to explore relationships between surgical workforce, POMR and U5MR. All health estimates were summarised in line with the Guidelines for accurate and transparent health estimates reporting (GATHER) statement.[12]

We extracted demographic and socioeconomic indicators from IBGE.[13] We used this data along with the Brazilian gross domestic product to classify municipalities according to income groups as high-income, upper-middle income or lower-middle income as defined by the 2017 World Bank criteria of gross national income (GNI) per capita adjusted to US dollars (low income: GNI per capita $1005 or less; lower middle income: GNI per capita between $1006 and $3955; upper middle income: GNI per capita between $3956 and $12 235; high income >$12 235) (figure 1).[14]

Surgical workforce density

We summarised data on the surgical workforce at the municipality, state and regional levels. We summarised several workforce roles, including general surgeons, paediatric surgeons, anaesthesiologists, obstetricians and nurses, using professional role definitions from the CNES. The CNES keeps a record of the appointment of all health providers at public health facilities. The density of each profession was weighted per 100 000 children. For comparison to common surgical workforce metrics used in the LCoGS,[2–4] we also summarised the density of SAO.

U5MR and POMR

We summarised annual all-cause U5MR at the regional and municipality level using data from the Brazilian Mortality Information System database (SIM), which collects data on all deaths by age, sex, cause and residence.[8] The U5MR was calculated using methods of the Inter Agency Group for Mortality Estimation, and was expressed as deaths per 1000 live births.[15]

We collected procedure-based POMR from the DATASUS Hospitalization Information System database (SIH) using the procedure codes for a proxy set of general surgical procedures. This set was based on the Optimal Resources for Children's Surgery document of the Global Initiative for Children's Surgery which specifies representative surgical procedures to assess the delivery of surgical care within a national health system.[5] These five procedures included appendectomy, colostomy, hernia repair, laparotomy and abdominal wall reconstruction for gastroschisis, omphalocele or other indication. The SIH defines perioperative mortality as any death occurring during any surgical procedure. We summarised procedure-specific POMR at the regional level across the country.

Note that due to differences in the data quality,[10] we limited analysis of the surgical workforce to use of U5MR as the outcome metric. We chose not to use POMR, as the SIH dataset only records deaths occurring during operative procedures and thus likely far underestimates the true POMR which is generally accepted as within 30 days of surgery.[16] We recognise that U5MR measures both surgical and non-surgical causes of child mortality, although we chose to use it for analysis of associations between the surgical workforce and childhood health as it is a widely used measure of health system strength for children.

Data analysis

All analyses were performed using the municipality as the main observation unit. We summarised descriptive

Table 1 Primary datasets used for analysis derived from the Brazilian public health system (*Sistema Único de Saúde, SUS*) which maintains several publicly available datasets (DATASUS)

Source	Variables	Date range	Data entries	Scope
DATASUS: Hospitalisation information system (SIH)	► Hospitalisation procedures performed ► ICD code ► Age of patient ► Location of residence ► Costs associate to the procedure ► Hospital	2008–2015	267 248 procedures	Appendectomy (ICD 10 0DTJ4ZZ, 0DTJ0ZZ) Laparotomy (ICD 10 0WJP0ZZ) Hernia (ICD 10 0YQ54ZZ, 0YQ64ZZ, 0YQ50ZZ, 0YQ60ZZ, 0WQF4ZZ, 0WUF07Z, 0WUF0KZ, 0BQR4ZZ,0BQS4ZZ, 0BQR0ZZ, 0BQS0ZZ) Colostomy (ICD 10 0WQFXZ2) Abdominal wall reconstruction (ICD 10 0WQF0ZZ)
DATASUS: Mortality information system (SIM)	► Deaths of patients under 14 years old ► The municipality of residence and of death ► Mortality rate by municipality	2010–2015	326 459 deaths	All deaths between 2010 and 2015
CNES: National registration of health establishments	► Geolocation ► Type of care provided ► Accreditation	2014	6498 hospitals	District and referral level hospitals
World Bank	► Gross national income (GNI) ► Atlas index ► GNI per capita ► Income level classification	2010–2013	5565 municipalities	–
IBGE: Brazilian Institute of Geography and Statistics	► · Paediatric population by municipality ► · Gross domestic product (GDP) ► · GDP per capita	2008–2014	5565 municipalities	–

Auxiliary data collected from the World Bank and IBGE.

ICD, International Statistical Classification of Diseases and Related Health Problems.

outcomes at the municipality, state and regional levels. Descriptive statistics were used to report the mean and SD of workforce variables. The density of the surgical workforce and U5MR were displayed using geospatial choropleth maps. Geographic mapping was used to identify the distribution of each indicator within a spatial area.[17] We used a Getis-Ord Gi analysis to depict the spatial autocorrelation within each indicator (workforce density and U5MR). We identified hot spots (red areas) depicting clusters of municipalities with adjacent municipalities with high values for a given indicator (workforce density or U5MR), and cold spots (blue areas) depicting areas of adjacent clusters with low values for each indicator. Yellow areas mark locations where no clustering was observed. Geographic mapping was used to identify the distribution of each indicator within a spatial area.

To identify potential associations between the surgical workforce and U5MR, we used linear regression on the aggregated data on the state level, adjusting for regional distribution. Scatter plots were built to graphically depict the association between workforce and U5MR. Each point in the graphic was proportional to the average U5MR (per 1000 live births), with display by state as well as by region level. We also performed quadratic and splines regression analysis, but the linear models showed better fit to the data, assessed in comparison using analysis of variance and residual evaluation.

Further analysis evaluated the association between workforce and U5MR accounting for the spatial heterogeneity, using Moran's I bivariate spatial autocorrelation between each indicator. For our study, we identified high-high spots (red areas) depicting clusters of municipalities with high workforce adjacent municipalities with high values for a U5MR, and low-low spots (blue areas) depicting areas of adjacent clusters with low values for each indicator. High-low (light red areas) and low-high

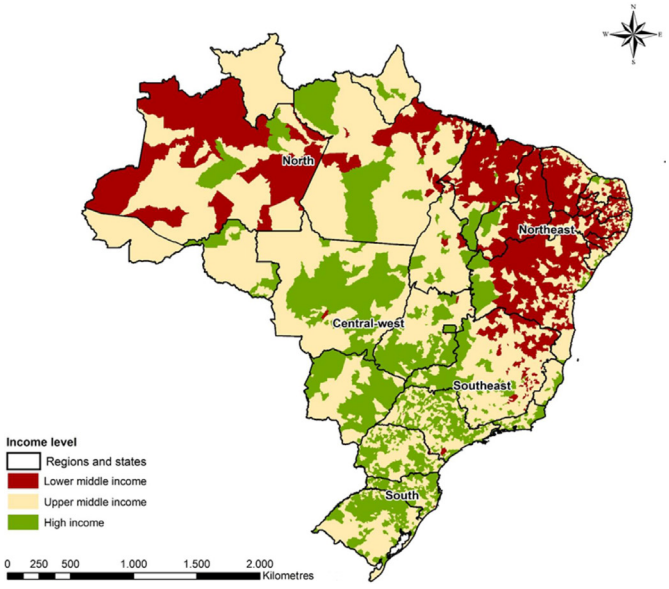

Figure 1 Income group distribution of Brazilian municipalities. socioeconomic data were extracted from Brazilian Institute of Geography and Statistic, and used with the Brazilian gross domestic product to classify municipalities according to income groups as defined by the world bank as high income, upper-middle income or lower-middle income. The map of Brazil was freely obtained in shapefile format through online access to the website of the Brazilian Institute of Geography and Statistics (https://mapas.ibge.gov.br/bases-e-referenciais/bases-cartograficas/malhas-digitais.html). Reprinted from Vissoci *et al*.[10]

(light blue areas) marked locations cluster of high in one indicator was adjacent to a low in the other.

Patient and public involvement

As an ecological study, there was no direct patient involvement with this research. However, there is public interest in addressing challenges with the surgical care of children in Brazil. We used anonymised publicly available datasets to address these research questions. All research findings will be disseminated to the public and health community in Brazil through publication, academic meetings and social media.

RESULTS

We found that there were 39 926 general surgeons, 856 paediatric surgeons, 13 243 anaesthesiologists, 103 793 nurses and 9674 obstetricians across Brazil in 2015. During the same year, there were 43 045 reported deaths in children under 5 years of age in Brazil, with the U5MR ranging between 11 and 26 deaths/1000 live births across states. The POMR for the proxy set of surgical procedures ranged from 0.11–0.17 deaths/100 000 children across regions.

By use of scatter plots, we developed a set of linear regression models to define the association between the density of surgical workforce at the state level and U5MR (figure 2A–F). Using linear regression, we e found all professional roles had a direct relationship between workforce density and U5MR (table 2). However, when adjusting the models by the interaction of workforce density and region of the country, we noticed that some of the associations had lower coefficients and were not significant, suggesting that the association between workforce and U5MR is dependent on the geographic and social context.

Disparities in the surgical workforce and U5MR across Brazil

The surgical workforce for children in Brazil is unequally distributed across the country, with the South and Southeast regions having a higher density of all professional roles, while the North and Northeast regions have a lower density of each role (figure 3). We found an inverse pattern of disparities in U5MR across the country,. The South and Southeast regions had the lowest U5MR. In contrast, the North and Northeast regions had higher U5MR (figure 4).

At a municipality level, we found wide disparities in the workforce density as well as U5MR across Brazil, with inequities even within states (figure 5). Several municipalities did not have even one general surgeon, paediatric surgeon, obstetrician or anaesthesiologist. Some wealthier parts of the North and Northeast regions showed high inequities in workforce distribution, with the workforce preferentially localised in areas around the state capitals. The high areas of workforce distribution was similar to the patterns of low U5MR seen at the municipality level.

Relationship between surgical workforce density and U5MR

We found a direct association between the surgical workforce and U5MR across Brazil, with higher density of each professional role associated with lower U5MR across regions (figure 6, table 2). This pattern is consistent across workforce roles (surgeon, anaesthesiologist, nursing, etc), although there are some variations in the distribution patterns across the country. For example, in the South and Southeast, we found the highest density of paediatric surgeons as well as the lowest levels of U5MR, although this pattern was not seen in the Federal District, where there was a high density of all workforce roles as well as higher levels of U5MR compared to surrounding regions. The Federal district is where the Brazilian government is located, and the density of the surgical workforce in this state-city was higher than in all other states.

DISCUSSION

As surgical care is an essential component of functioning healthcare systems, there is a need to improve our understanding of the surgical workforce for children. Brazil has wide disparities in socioeconomic status and healthcare delivery.[18 19] Our previous work has shown disparities in the density of delivery and infrastructure for surgical care for children per population unit across Brazil, with areas of higher socioeconomic status associated with increased delivery of surgical care.[10] Although Brazil

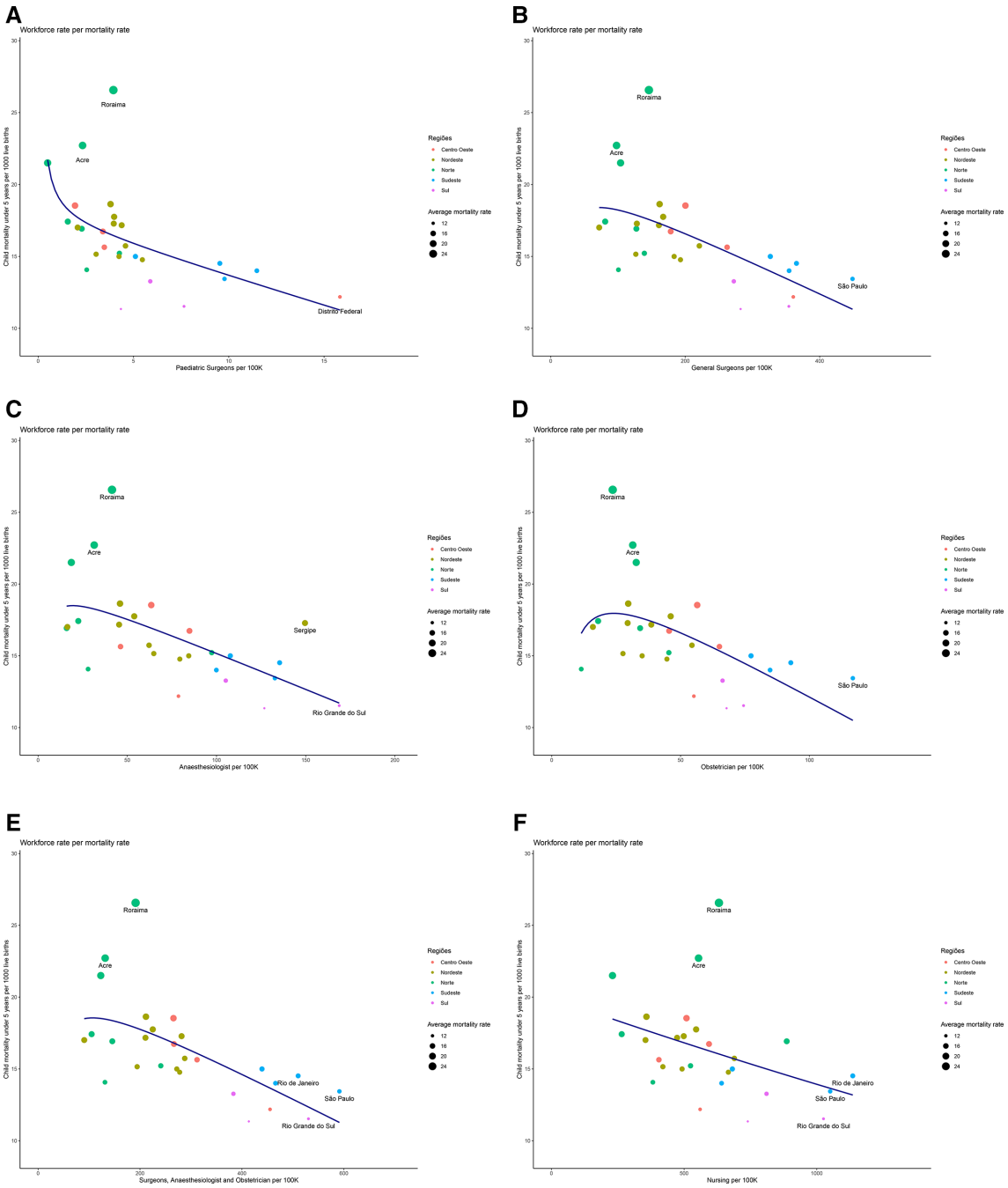

Figure 2 (A–F): Association between the density of the surgical workforce (weighted per 100 000 children) and under-5 mortality rate (U5MR, per 1000 live births) in each state across Brazil. Linear regression models were used to define associations between the workforce density and U5MR. The line resulting from each regression model was plotted using bivariate scatter plots. The size of each point in the graphic is proportional to the average U5MR for each state, with different colours used to summarise data by region.

does have widely variable geography, these disparities are corrected for population density, and therefore reflect underlying disparities in health access. Our current study demonstrates disparities in the surgical workforce across the country, with a higher workforce density per population unit found in areas of higher socioeconomic status. In addition, increased surgical workforce density is associated with areas of lower U5MR, suggesting that an adequate and equitable surgical workforce is essential for support of high-quality healthcare for children.

Disparities in surgical care for adults have been previously noted in Brazil as well as other countries, although disparities in the surgical care for children remain poorly understood. Reports from the LCoGS have shown an association between the density of SAO and the rate of surgical procedures or POMRs.[2–4] Our data align with recent analyses of surgical care for adults in Brazil which showed wide disparities in manpower and surgical care.[11 20] The Brazilian government has long recognised challenges with healthcare delivery across the country,

Table 2 Linear regression coefficients for the association between workforce and under-5 mortality rate in Brazil, unadjusted and adjusted by region of the country

	Mean (SD)	Unadjusted coefficient (SE)	Adjusted coefficient (SE)
General surgeon rate	208.01 (103.93)	−0.02 (0.01)*	−0.01 (0.01)
Paediatric surgeon rate	4.86 (3.38)	−0.53 (0.17)*	−0.32 (0.20)
Obstetrician rate	48.95 (25.37)	−0.07 (0.02)*	−0.02 (0.05)
Anaesthesiologist rate	74.34 (43.32)	−0.05 (0.01)*	−0.02 (0.02)
Surgeons, anaesthesiologists and obstetrician rate	287.22 (140.70)	−0.02 (0.00)*	−0.01 (0.01)

*P<0.01.

and have implemented several programs to increase primary care access in rural areas.[6 9 21]

The POMR is often used to gauge the quality of a surgical system,[16] although we suggest that metrics of overall childhood health such as U5MR may offer an alternative, and potentially even more valuable metric to guide manpower planning. First, given the increasing emphasis on surgical care as an integral part of a comprehensive health system, associations between each aspect of the health workforce and overall measures of population health may be the most appropriate measure of manpower across an entire health system, including the surgical workforce.[16] For example, neonates or children with cancer often require surgical care, and an adequate surgical workforce is essential to ensure high-quality outcomes for these children. Second, despite interest around the world for collection of POMRs, data quality for POMR continues to be challenging in many settings.[22] Our previous work in Brazil suggests that data quality for POMR is too poor to allow for analysis of the surgical workforce.[10 16] Third, the United Nations and the WHO have identified several indicators to evaluate health interventions in children, including the U5MR, rate of growth stunting, immunisation coverage and prevalence of common childhood diseases.[23] These metrics are routinely collected around the world, and our analysis suggests that strategic expansion of the surgical workforce can be guided by these widely collected metrics. Finally, we confirmed an association between the nursing workforce and U5MR, as few analyses have examined the nursing workforce requirements for surgical care.

To assist with policy development, geospatial analysis can identify priority regions of workforce needs. The sequence of steps in our analysis may be generalisable to other countries to guide scale-up of the surgical workforce to desired levels of health outcomes. For example, we found that U5MR of 15 deaths/1000 births across Brazil is associated with an approximate workforce level of 5 paediatric surgeons, 200 surgeons, 100 anaesthesiologists or 700 nurses/100 000 children. Geospatial analyses has help guide health workforce expansion in Thailand,[24] as well as in some countries in sub-Saharan Africa.[25] However, we caution that the workforce associations in Brazil may not be applicable to other countries. In addition, geospatial analysis requires access to high-quality national datasets which remains problematic in many countries around the world.

The areas of Brazil with lower socioeconomic status remain challenging environments for healthcare, where there is a long history of difficulties with retention of healthcare professionals.[18 19] Our findings align with studies of adult surgical workforce in Brazil which have shown inequities in the density of SAO professionals across the country, with rural regions disproportionately affected.[26] Similar to many counties around the world,

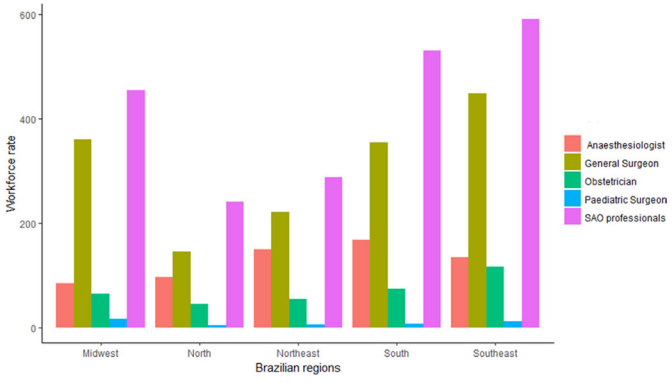

Figure 3 The density (rate) of the surgical workforce for each professional role across Brazil as summarised by region. The density of each professional role is weighted per 100 000 children. SAO, surgeons, anaesthesiologists or obstetricians.

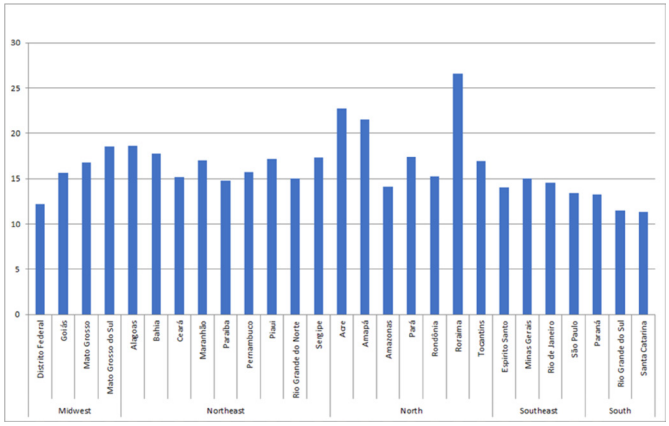

Figure 4 Under-5 mortality rates (per 1000 live births) across Brazil summarised by state as well as by region levels.

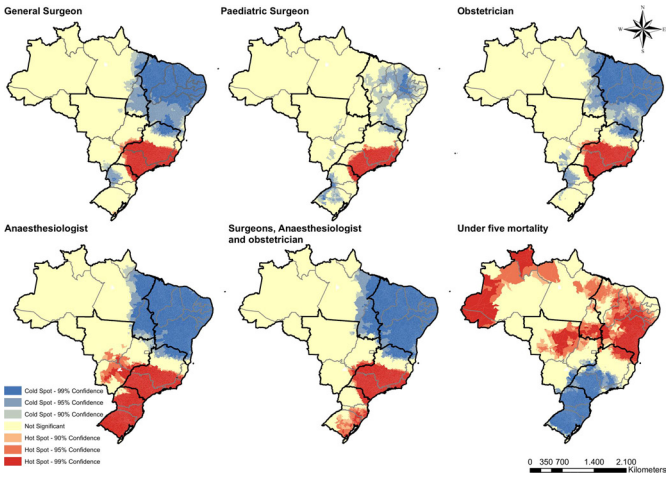

Figure 5 Spatial distribution of the surgical workforce density (weighted per 100 000 children) and under-5 mortality rate (U5MR, per 1000 live births) at the municipality level. hot spot cluster analysis of association between the surgical workforce density (weighted per 100 000 children) and U5MR (per 1000 live births) across Brazil using Getis-Ord-Gi analysis.17 hot spots (red areas) depict clusters of municipalities with adjacent municipalities with high values for a given indicator (workforce density or U5MR), and cold spots (blue areas) depict clusters with an adjacent low values regarding each indicator. Yellow areas mark locations where no clustering was observed. Note that the scatter plots are not adjusted for spatial autocorrelation.

the rural areas in Brazil have high levels of poverty and a scarcity of health infrastructure.[27 28] Brazil has successfully increased access to the primary care workforce in rural areas through the *Mais Médicos* programme,[29] and our findings suggest that similar expansion of the surgical workforce may improve the health of children.

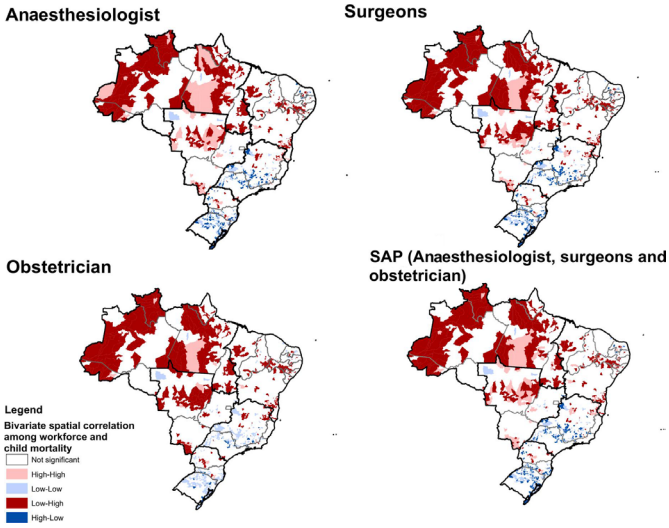

Figure 6 Association between the surgical workforce density (weighted per 100 000 children) and under-5 mortality rate (U5MR, per 1000 live births) across Brazil using spatial correlation analysis. High-high areas (red areas) depict clusters of municipalities with high values for workforce adjacent municipalities with high values for a U5MR, and low-low areas (blue areas) depict clusters with an adjacent low values regarding each indicator.

As with any population-based study, our work has several limitations. First, our findings of an association between surgical workforce and U5MR do not demonstrate causation. We recognise that many confounders other than surgical workforce impacts the U5MR (such as non-surgical disease, non-surgical workforce, etc). However, we view surgical care as a core component of a functional health system, and therefore association between the surgical workforce and U5MR can help guide workforce planning. Although our analysis did not account for detailed study of the confounding and modifying variables which impact the U5MR, further discernment of which components of a health workforce are most important for childhood health is a critical question that merits further analysis. Second, there is a lack of consensus in geospatial analysis about how the density of professionals should be weighted regarding different populations (ie, overall population, child population, etc), although we chose to weigh by child population. Finally, we recognise that the surgical workforce includes many type of subspecialists that were not included in our analysis.

In conclusion, we found that the surgical workforce for children is inadequate and inequitably distributed across Brazil, suggesting that strategic investment in the surgical workforce is required to support high-quality and equitable healthcare for children. There is a direct relation between the surgical workforce and U5MR across Brazil, with higher levels of the surgical workforce associated with improved U5MR. These findings have several policy implications to improve the health of children in Brazil:

- Increased investment in the surgical workforce is required to support the health of children in Brazil, particularly in rural regions
- Identification of associations between the workforce and measures of population health (such as U5MR) may be a valuable tool to define surgical workforce levels in LMICs.
- Definition of workforce indicators is particularly challenging for children's surgical care given the complexity of care across different levels of national health systems.
- Geospatial analysis can help define the required surgical workforce to attain desired population health goals, and may be generalisable across other LMICs.

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