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REGIONAL VARIATION IN GENERAL SURGERY VOLUME AND ITS ASSOCIATION WITH HEALTHCARE SYSTEM CAPACITY: A NATIONAL STUDY FROM SAUDI ARABIA

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ABSTRACT
Background: Access to surgical care is a critical component of health system performance; however, disparities in surgical service delivery persist across regions. Such variation may be more closely related to differences in healthcare system capacity than to actual population need.
Objective: To analyze regional disparities in general surgery volume across Saudi Arabia and examine their association with healthcare system capacity indicators.
Methods: This national cross-sectional ecological study used publicly available data from the Saudi Open Data Platform and the Ministry of Health Statistical Yearbook (2024). General surgery volume was analyzed across 13 administrative regions and expressed per 100,000 population. Healthcare system capacity indicators included hospital density, hospital bed density, and primary healthcare center density. Pearson correlation and univariable linear regression analyses were performed.
Results: Substantial regional variation in general surgery volume was observed, ranging from 252.9 to 1,056.7 procedures per 100,000 population. Surgical volume was positively associated with hospital density ($r = 0.603$, $p = 0.029$), hospital bed density ($r = 0.590$, $p = 0.034$), and primary healthcare center density ($r = 0.657$, $p = 0.015$). Healthcare system capacity indicators explained approximately 34%–43% of the variation in surgical activity.
Conclusion: Regional differences in general surgery volume are closely associated with healthcare system capacity. Surgical service distribution may reflect where capacity exists, rather than where need is greatest. These findings highlight the importance of equitable, data-driven health system planning and underscore the need to move beyond infrastructure expansion toward capacity-aligned, need-informed strategies to ensure equitable surgical care delivery across regions.

KEYWORDS: General surgery; Surgical volume; Health disparities; Healthcare infrastructure; Healthcare access; Saudi Arabia.

INTRODUCTION
The provision of safe, timely, and affordable surgical care is considered a core indicator of effective health systems and an essential component of universal health coverage (1,2). Despite global efforts to strengthen surgical systems, disparities in access and utilization remain evident (3).
In Saudi Arabia, substantial progress has been made in expanding healthcare services over recent decades. However, national assessments continue to demonstrate regional variation in healthcare infrastructure, particularly in hospital bed capacity and primary healthcare center distribution (1,2). These structural differences may affect how patients access and utilize surgical services, potentially affecting service availability and utilization patterns (3).
Available evidence demonstrates notable heterogeneity in healthcare infrastructure across the Kingdom. Variations in hospital bed-to-population ratios and disparities in primary healthcare center distribution, particularly between urban and peripheral regions, suggest that access to care may not be uniformly distributed (1,2). Furthermore, institutional capacity has been associated with variation in healthcare system performance and outcomes across different settings (7).
General surgery constitutes a central element within overall surgical care delivery, encompassing both emergency and elective procedures. As such, surgical volume may serve as a pragmatic, though imperfect, proxy for service delivery and system capacity (8). While imperfect, it remains a practical indicator of service delivery and system capacity at the population level. Examining regional variation in general surgery volume provides an opportunity to explore whether differences in surgical activity align more closely with healthcare system capacity, while acknowledging that population need is not directly measured.
However, despite ongoing health system transformation efforts, there remains limited national-level evidence linking surgical activity to healthcare system capacity in Saudi Arabia. More importantly, it remains unclear whether observed regional differences in surgical volume represent appropriate variation or reflect potential imbalances in resource allocation and access to care. Addressing this gap is essential to inform data-driven, equity-focused health system planning.

Surgical activity is not solely a reflection of population need but may be shaped by the underlying capacity of the health system to deliver care. In this framework, healthcare infrastructure represents a measurable component of broader system capacity that influences access, utilization, and service distribution. The conceptual framework guiding this study is presented in **Figure 1.**

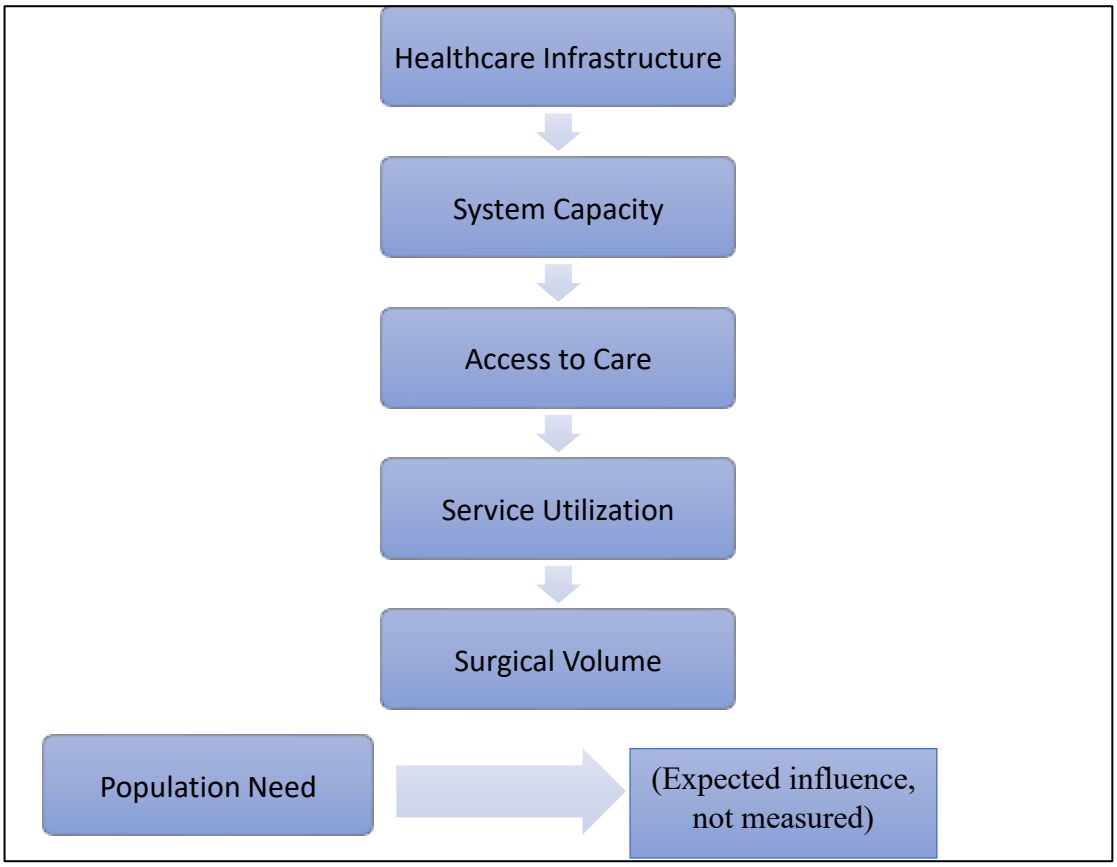


Figure 1. Conceptual framework illustrating the relationship between healthcare system capacity, access to care, and surgical volume, with population need as an unmeasured determinant.

Objectives

Primary Objective

To analyze regional disparities in general surgery volume across Saudi Arabia and examine their association with healthcare system capacity within a conceptual framework of system-driven surgical delivery.

Secondary Objectives

1. To quantify regional variation in general surgery volume using population-standardized rates.
2. To assess regional variation in healthcare system capacity using infrastructure-based indicators.
3. To evaluate the association between surgical activity and healthcare system capacity indicators.
4. To explore potential misalignment between surgical activity and healthcare system capacity across regions.
5. To examine whether observed patterns of surgical volume may reflect system capacity rather than underlying population need.

METHODS

Study Design

This study employed a national cross-sectional ecological design to examine regional variation in general surgery volume and its association with healthcare system capacity across Saudi Arabia.

Data Sources

Surgical activity data were obtained from the Saudi Open Data Platform using the dataset "Surgical Interventions at Ministry of Health (MoH) Hospitals (2024)," which provides aggregated counts of surgical procedures performed across specialties in MoH hospitals.

Healthcare infrastructure and population data were extracted from the Ministry of Health Statistical Yearbook 2024. Data on hospitals, hospital beds, and primary healthcare centers (PHCs) were collected at the administrative region level. Population estimates for 2022 were used as denominators to calculate population-standardized indicators.

All data used in this study were publicly available and aggregated at the regional level.

Study Variables

Outcome Variable

The primary outcome was general surgery volume, expressed as:

- Total number of procedures
- Procedures per 100,000 population

Independent Variables

Healthcare system capacity was operationalized using infrastructure-based indicators:

- Hospital density (hospitals per 100,000 population)
- Hospital bed density (beds per 100,000 population)
- Primary healthcare center density (PHCs per 100,000 population)

All variables were standardized per 100,000 population to ensure comparability across regions.

Derived Indices (System-Level Indicators)

To further characterize system-level performance, additional indices were constructed from population-standardized variables:

- Surgical Efficiency Index: Ratio of surgical volume to hospital bed density, reflecting surgical output relative to inpatient capacity.
- Hospital Utilization Index: Ratio of surgical volume to hospital density, reflecting the intensity of surgical activity per facility.
- Primary Care Leverage Index: Ratio of surgical volume to PHC density, reflecting the potential contribution of primary care to surgical utilization.

These indices were used to provide additional insights into system efficiency, resource utilization, and potential service pressure across regions.

Data Preparation

Datasets were merged at the administrative region level. Data preparation included standardizing region names, verifying data completeness, and ensuring consistency across data sources.

Statistical Analysis

Descriptive statistics were used to summarize surgical volume, healthcare infrastructure indicators, and derived indices across regions.

Pearson correlation coefficients were calculated to assess the relationship between surgical volume and healthcare system capacity indicators.

Univariable linear regression analyses were performed to evaluate the association between each infrastructure variable and surgical volume.

Due to the limited number of observations (n = 13), multivariable regression was not performed to avoid model instability, overfitting, and collinearity among predictors.

All statistical analyses were conducted using IBM SPSS Statistics (version 26). Statistical significance was defined as a two-tailed p-value < 0.05.

Ethical Considerations

This study was approved by the Institutional Review Board (IRB) of Umm Al-Qura University. The analysis utilized publicly available aggregated data and did not involve identifiable patient-level information.

RESULTS

Regional Variation in General Surgery Volume Across Regions

Descriptive statistics for general surgery volume and healthcare infrastructure indicators across all 13 administrative regions are presented in **Table 1**.

General surgery volume demonstrated substantial regional variation. After population standardization, rates ranged from 252.9 to 1,056.7 procedures per 100,000 population, indicating marked disparities in surgical service delivery across regions.

Overall, these findings highlight substantial heterogeneity in both surgical activity and healthcare system capacity across regions. Detailed regional data are presented in **Table 1.**

Table 1. Regional population, general surgery volume, and healthcare infrastructure indicators across the 13 administrative regions of Saudi Arabia

Region	Population	GS Procedures (n)	GS per 100,000 population	Hospitals per 100,000	Beds per 100,000	PHCs per 100,000
Riyadh	8,591,748	21,728	252.9	0.56	98.4	4.7
Makkah	8,021,463	29,428	366.9	0.56	115.0	3.89

Region	Population	GS Procedures (n)	GS per 100,000 population	Hospitals per 100,000	Beds per 100,000	PHCs per 100,000
Madinah	2,137,983	7,982	373.3	0.84	145.8	7.20
Qassim	1,336,179	14,119	1056.7	1.42	248.8	11.68
Eastern	5,125,254	16,323	318.5	0.74	127.0	4.47
Asir	2,024,285	12,871	635.8	1.38	168.0	13.88
Tabuk	886,036	3,294	371.8	1.35	216.7	9.59
Hail	746,406	2,611	349.8	1.88	259.9	14.74
Northern Borders	373,577	2,712	726.0	2.94	390.8	11.24
Jazan	1,404,997	12,116	862.4	1.57	207.5	12.38
Najran	592,300	5,975	1008.8	1.86	236.4	11.48
Al Baha	339,174	3,582	1056.1	2.95	381.8	27.42
Al Jouf	595,822	3,355	563.1	2.35	325.6	9.73

System-Level Performance Indicators

Beyond descriptive variation, system-level performance was further explored using derived indices **(Table 2).** Considerable variation was observed across all derived indices. The Surgical Efficiency Index varied notably between regions, indicating differences in surgical output relative to inpatient capacity. Some regions demonstrated high surgical output relative to available bed capacity, suggesting either increased system efficiency or elevated service pressure.

Similarly, the Hospital Utilization Index revealed substantial differences in the intensity of surgical activity per facility. Certain regions exhibited high utilization levels, indicating concentrated surgical activity within fewer facilities, whereas others showed lower utilization despite relatively higher infrastructure availability.

The Primary Care Leverage Index also varied across regions, suggesting differences in the role of primary healthcare systems in facilitating surgical care utilization. Regions with higher values may reflect stronger referral pathways and better integration between primary and secondary care services.

Table 2. Derived system-level performance indices across the 13 administrative regions of Saudi Arabia

Region	Surgical Efficiency Index	Hospital Utilization Index	Primary Care Leverage Index
Riyadh	2.57	451.6	53.8
Makkah	3.19	655.2	94.3
Madinah	2.56	444.5	51.8
Qassim	4.25	744.1	90.5
Eastern	2.51	430.3	71.2
Asir	3.78	460.7	45.8
Tabuk	1.72	275.4	38.8
Hail	1.35	186.1	23.7
Northern Borders	1.86	247.2	64.6
Jazan	4.15	549.8	69.5
Najran	4.27	542.6	87.0
Al Baha	2.77	358.0	38.5
Al Jouf	1.73	239.6	57.9

Abbreviations: GS = General Surgery; PHC = Primary Healthcare Center.

Derived indices:

Surgical Efficiency Index = General surgery procedures per 100,000 population ÷ hospital bed density per 100,000 population.

Hospital Utilization Index = General surgery procedures per 100,000 population ÷ hospital density per 100,000 population.

Primary Care Leverage Index = General surgery procedures per 100,000 population ÷ primary healthcare center density per 100,000 population.

Association Between Surgical Volume and Healthcare System Capacity

The association between general surgery volume and healthcare system capacity indicators was examined using Pearson correlation and univariable linear regression analyses.

Pearson correlation analysis demonstrated statistically significant positive associations between general surgery rates and all examined healthcare infrastructure indicators **(Table 3).** General surgery volume was positively correlated with hospital density ($r = 0.603$, $p = 0.029$), hospital bed density ($r = 0.590$, $p = 0.034$), and primary healthcare center density ($r = 0.657$, $p = 0.015$).

These associations were further examined using univariable linear regression models to estimate effect sizes and confidence intervals **(Table 5).** Healthcare system capacity indicators explained a substantial proportion of regional variation in surgical activity.

Hospital bed density explained 34.8% of the variation ($R^2 = 0.348$, $p = 0.034$), hospital density explained 36.4% of the variation ($R^2 = 0.364$, $p = 0.029$), while primary healthcare center density explained 43.2% of the variation ($R^2 = 0.432$, $p = 0.015$).

Collectively, these findings indicate that healthcare infrastructure is a significant determinant of surgical activity at the regional level.

Table 3. Pearson correlation between healthcare system capacity indicators and general surgery procedures per 100,000 population

Variable	Pearson r	p-value
Hospital density	0.603	0.029
Hospital bed density	0.590	0.034
Primary healthcare center density	0.657	0.015

Pearson correlation coefficients (r) were calculated using two-tailed tests.

A comprehensive summary of general surgery activity, healthcare infrastructure, and population-standardized indicators across regions is shown in **Table 4.**

Table 4. Comprehensive summary of general surgery activity, healthcare infrastructure, and population-standardized indicators across the 13 administrative regions of Saudi Arabia

Region	Population	GS Procedures (n)	GS procedures per 100,000 population	GS procedures (%)	Hospitals (n)	Hospitals per 100,000	Hospital Beds (n)	Hospital Beds per 100,000	PHC (n)	PHC per 100,000
Riyadh	8,591,748	21,728	252.9	17.3	48	0.6	8,457	98.4	404.0	4.7
Makkah	8,021,463	29,428	366.9	25.7	45	0.6	9,225	115.0	312.0	3.9
Madinah	2,137,983	7,982	373.3	21.6	18	0.8	3,118	145.8	154.0	7.2
Qassim	1,336,179	14,119	1,056.7	22.3	19	1.4	3,324	248.8	156.0	11.7
Eastern	5,125,254	16,323	318.5	19.2	38	0.7	6,511	127.0	229.0	4.5
Asir	2,024,285	12,871	635.8	18.9	28	1.4	3,400	168.0	281.0	13.9
Tabuk	886,036	3,294	371.8	24.3	12	1.4	1,920	216.7	85.0	9.6
Hail	746,406	2,611	349.8	12.9	14	1.9	1,940	259.9	110.0	14.7
Northern Borders	373,577	2,712	726.0	26.6	11	2.9	1,460	390.8	42.0	11.2

Region	Population	GS Procedures (n)	GS procedures per 100,000 population	GS procedures (%)	Hospitals (n)	Hospitals per 100,000	Hospital Beds (n)	Hospital Beds per 100,000	PHC (n)	PHC per 100,000
Jazan	1,404,997	12,116	862.4	26.3	22	1.6	2,915	207.5	174.0	12.4
Najran	592,300	5,975	1,008.8	24.0	11	1.9	1,400	236.4	68.0	11.5
Al Baha	339,174	3,582	1,056.1	20.0	10	3.0	1,295	381.8	93.0	27.4
Al Jouf	595,822	3,355	563.1	21.6	14	2.4	1,940	325.6	58.0	9.7
Mean ± SD	—	10,468.9 ± 8,367.1	610.9 ± 301.3	21.6 ± 3.9	22.3 ± 13.3	1.6 ± 0.8	3,608.1 ± 2,701.7	224.7 ± 96.5	166.6 ± 110.7	10.9 ± 6.1
Minimum–Maximum	—	2,611–29,428	252.9–1,056.7	12.9–26.6	10–48	0.6–3.0	1,295–9,225	98.4–390.8	42–404	3.9–27.4

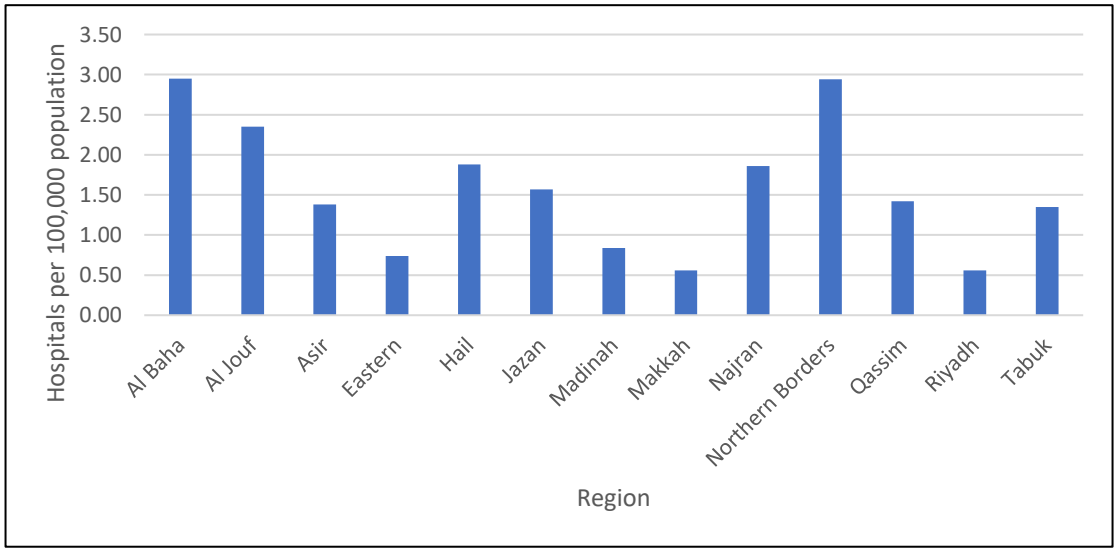
Data represent Ministry of Health hospitals across the 13 administrative regions of Saudi Arabia.
Abbreviations: GS = General Surgery; PHC = Primary Healthcare Center.
Rates are expressed per 100,000 population.
GS procedures (%) represent the proportion of general surgery procedures relative to the total number of surgical procedures performed within each region.

Table 5. Univariable linear regression analysis of healthcare system capacity indicators associated with general surgery procedures per 100,000 population

Predictor	Standardized β	Unstandardized B	95% CI for B	R^2	p-value
Hospital beds per 100,000 population	0.590	1.84	0.17 – 3.56	0.348	0.034
Hospitals per 100,000 population	0.603	223.50	27.4 – 419.6	0.364	0.029
Primary healthcare centers per 100,000 population	0.657	32.5	7.8 – 57.2	0.432	0.015
Univariable regression models were fitted separately due to collinearity among infrastructure indicators. Abbreviations: GS = General Surgery. Statistical significance was defined as $p < 0.05$.					

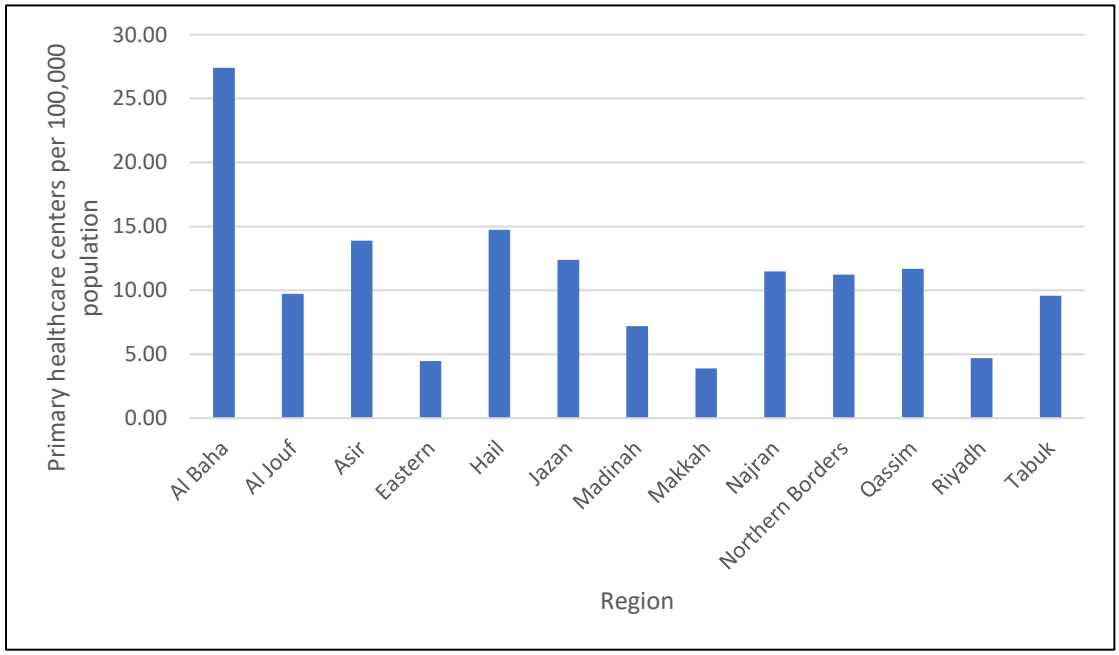
Regional variation in hospital density across administrative regions is illustrated in Figure 1

Figure 1. Distribution of hospital density (hospitals per 100,000 population) across the 13 administrative regions of Saudi Arabia



Regional variation in primary healthcare center density across administrative regions is illustrated in Figure 2

Figure 2. Distribution of primary healthcare center density (PHCs per 100,000 population) across the 13 administrative regions of Saudi Arabia.



The association between hospital bed density and general surgery procedures across regions is illustrated in Figure 3.

Figure 3. Association between hospital bed density (beds per 100,000 population) and general surgery procedures per 100,000 population across the 13 administrative regions of Saudi Arabia.

Together, these findings suggest that regional variation in surgical activity is closely aligned with differences in healthcare system capacity rather than solely reflecting underlying population need.

DISCUSSION

This national study provides robust evidence of marked regional variation in general surgery volume across Saudi Arabia and demonstrates a strong and consistent association between surgical activity and healthcare system capacity. While these findings offer important system-level insights, they should be interpreted as correlational rather than causal. However, the observed patterns extend beyond simple variation and point toward a deeper structural dynamic within the healthcare system.

The findings suggest that surgical activity may be influenced not only by population size or underlying need, but also by the distribution of healthcare resources. Within this framework, system capacity—particularly infrastructure components such as hospitals, inpatient beds, and primary healthcare centers—acts as a structural

driver of service delivery. This implies that the healthcare system may, in part, be configured to produce utilization patterns that reflect where capacity exists rather than where need is greatest.

This interpretation is further supported by the derived system-level ratios, which, while descriptive and not intended as validated performance measures, illustrate how surgical output relates to available infrastructure across regions. The observed variability in these ratios highlights differences in how regions translate available resources into delivered care, suggesting that both resource availability and system organization contribute to surgical activity.

These findings align with established health services research frameworks, particularly the concept of supply-induced demand, which posits that healthcare utilization may be influenced by the availability of services rather than solely by patient need. Similarly, Wennberg's theory of unwarranted variation emphasizes that differences in healthcare utilization across regions often reflect system-level factors rather than epidemiological variation alone. Within this context, the observed association between system capacity and surgical volume may reflect a pattern of system-driven utilization.

This relationship reveals a critical system-level implication with important equity consequences: if surgical activity is partially determined by healthcare system capacity, then regions with greater infrastructure may systematically generate higher procedural volumes independent of underlying demand, while lower-capacity regions may experience unmet surgical need. This dynamic introduces the possibility of structural inequities in access to care, where service delivery is unevenly distributed based on resource availability rather than population health requirements.

The strong association between hospital bed density and surgical volume underscores the operational importance of inpatient capacity. Bed availability likely constrains or enables surgical throughput by determining the system's ability to accommodate both elective and emergency procedures. While hospital density was also associated with surgical activity, its close relationship with bed capacity suggests that functional capacity—rather than the number of facilities alone—plays a more central role in determining service output.

The association between primary healthcare center density and surgical volume further highlights the importance of system integration. Primary care systems may influence surgical utilization through referral pathways, early detection, and coordination of care. In this sense, higher surgical volume may reflect more effective system connectivity rather than increased disease burden.

Notably, healthcare system capacity indicators explained approximately 34%–43% of the variation in surgical activity, indicating that a substantial proportion of variability remains unexplained. This suggests that additional factors—including workforce distribution, referral patterns, case complexity, and underlying disease burden—likely contribute to shaping surgical activity. The presence of unexplained variation reinforces the complexity of healthcare systems and highlights the limitations of infrastructure-based explanations alone.

Importantly, these findings should be interpreted at the system level and do not imply individual-level relationships. The ecological nature of the analysis limits causal inference and precludes conclusions regarding patient-level determinants of surgical care. However, the consistency of the observed patterns supports the interpretation that system-level factors play a significant role in shaping service delivery.

From a policy perspective, these results have important implications for health system planning. Expanding infrastructure alone may not be sufficient to achieve equitable access to surgical care if resource distribution is not aligned with population need. Instead, there is a need for data-driven approaches that integrate measures of system capacity with indicators of demand to ensure more balanced and equitable service delivery.

Ultimately, the findings suggest that surgical service distribution may reflect a system in which care follows capacity as much as, or even more than, need. Addressing this imbalance will require a shift from capacity-driven expansion toward need-informed, system-integrated planning to ensure equitable and efficient surgical care delivery across regions.

Limitations

Several limitations should be acknowledged. First, the ecological study design limits causal inference, and associations observed at the regional level may not reflect individual-level relationships. Second, the use of aggregated administrative data precluded adjustment for key confounders, including disease burden, workforce distribution, and case complexity. Third, the analysis was limited to Ministry of Health hospitals and did not include private or other governmental sectors, which may limit the generalizability of the findings. Finally, the relatively small number of regions (n = 13) may have limited statistical power and reduced the precision of the estimated associations.

CONCLUSION

Regional disparities in general surgery volume are closely associated with differences in healthcare system capacity across Saudi Arabia. These findings suggest that surgical service distribution may reflect underlying system resources as much as, or potentially more than, population need. While this study does not directly measure healthcare need, the observed patterns raise important questions about whether current service distribution aligns with underlying demand.

Addressing these disparities will require coordinated, equity-focused health system planning, including targeted investment in under-resourced regions, improved alignment between infrastructure and population needs, and strengthened integration between primary and secondary care services. Such efforts are essential to ensure equitable and efficient access to surgical care across all regions.

Ultimately, these findings underscore the importance of transitioning toward need-informed, data-driven health system planning to avoid reinforcing structural disparities in surgical care delivery.

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