

Development of a new indicator of surgical burden using person-time-adjusted surgical volume: a cross-sectional regional analysis in Japan

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ABSTRACT

Introduction Surgical volume is widely used as an indicator to assess surgical burden in many areas; however, it has a risk of neglecting the differences of individual operations. Moreover, the characteristics of operations differ between rural and urban areas. Fewer but more varied operations are performed in rural settings than in urban settings. A new indicator, the person-time-adjusted surgical volume, was developed by integrating surgical volume, operative time and the surgeon's workforce in each operation. This innovative measure expands the use of surgical volume in healthcare strategies, providing a promising tool for evaluating the surgical workforce on a timely basis.

Methods The new indicator of surgical volume, person-time-adjusted surgical volume, was developed using weighted standard operative time and the standard number of surgeons. All statistical data were derived from three published sources. Rural and local city area data were grouped together as regional areas, on the prefectural basis (n=47) and compared with the data from the urban areas of the secondary medical area (n=48) in Japan. The surgical volume of gastrointestinal surgeries and surgeon density in each area was collected and analysed. All analyses used the person-time-adjusted surgical volume per surgeon to account for differences between medical areas.

Results A negative association was found between the person-time-adjusted surgical volume and surgeon density. Regional areas had more person-time-adjusted surgical volume per surgeon than urban areas. A decrease in surgeon density resulted in an increased rate of person-time adjusted surgical volume in regional areas, which was a 10-fold increase in person-time-adjusted surgical volume per surgeon with decreasing surgeon density in regional areas. This suggests that surgeons in rural and local areas have a higher risk of overworking or burnout than those in urban areas.

Conclusion The person-time-adjusted surgical volume is useful for evaluating surgical burden and visualising the gap in underprivileged areas.

INTRODUCTION

Surgery is essential to people's health, and an adequate supply of surgical treatment is desired worldwide.¹ However, inequitable distribution of surgical treatment has

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Surgical volume was a feasible and collectible indicator in many areas and used to evaluate the effectiveness of surgical treatment in the area.
- ⇒ However, using raw surgical volume data raises concerns as it neglects the differences of 'individual operations'.

WHAT THIS STUDY ADDS

- ⇒ This study created a new indicator, 'person-time-adjusted surgical volume (tSV)', based on the combination of surgical volume, weighted operative time and surgeon workforce in 'individual operations' to expand the use of surgical volume in healthcare strategies.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ tSV could evaluate regional differences in surgical burden by incorporating time as a key parameter. In resource-limited settings, the use of standardised parameters may help identify treatment gaps. This approach may serve as a feasible tool to assess surgical burden and guide efforts to reduce disparities and promote equity in surgical care, particularly in underprivileged areas in the future.

been observed in many areas, particularly in low-income and middle-income countries (LMICs), as well as rural areas of high-income countries (HICs). The shortage of general surgeons is one of the issues associated with rural medicine, and research on rural surgery has increased globally.^{2–5} Interestingly, global surgery was launched in 2015 to address the inequities of surgical treatment on a population basis.⁶

Global surgery uses six indicators to evaluate the surgical burden for safe and affordable surgical care.⁶ The key factors in evaluating the surgical situation in each area include access to timely essential surgery, specialist surgical workforce density, surgical volume,

perioperative mortality rate, protection against impoverishing expenditure and protection against catastrophic expenditure.⁶

Surgical volume was identified as a feasible and collectible indicator in many areas and was used to evaluate the effectiveness of the surgical treatment in the area.⁷ It was also easy to compare the data with those of other areas. The Ministry of Health, Labour and Welfare in Japan used surgical volume as a key indicator for comparing surgical treatment across the country.⁸ Additionally, the public interprets the data to show the number of operations or the kind of operations performed in each area. A large number of operation cases is indicative of active or adequate surgical care. In the public's view, the discrepancy in surgical volumes among local areas indicates gaps in surgical treatment.

Surgical volume is a widely used indicator. However, using raw surgical volume data raises concerns, as it neglects the peculiarities of each operation. Operative time and the number of surgeons involved can differ in each operation; for example, a difference could exist between a simple operation, such as a 1-hour appendectomy for acute appendicitis, and one large operation, including approximately 8 hours of pancreaticoduodenectomy. Moreover, the characteristics of operations differ between rural and urban areas. In rural settings, fewer but more varied operations are performed than in urban settings.²⁹

Therefore, this study created a new indicator, 'person-time-adjusted surgical volume (tSV)', combining surgical volume, weighted operative time and surgeon workforce in 'each operation' to expand the use of surgical volume in healthcare strategies. It became comparable to surgical volume using the time parameter. This new indicator, tSV, could evaluate the surgical workforce on a time basis, as the time and human resources were limited. Additionally, it has the potential to become a tool for evaluating future workforce allocation.

MATERIALS AND METHODS

Creating a new indicator

The new indicator of surgical volume, tSV, was created using weighted standard operative time and the standard number of surgeons. The calculation of tSV is as follows:

Person-time-adjusted surgical volume (tSV) = $\sum \{ \text{number of operations (real data)} \times \text{standard operation time (fixed)} \times \text{standard number of operators (fixed)} \}$

The tSV can be practically applied to compare surgical volumes among different local areas. It is calculated by dividing the tSV by the actual number of qualified surgeons in each area, resulting in the tSV per surgeon ratio (tSV/s).

For example, if 15 appendectomies were in one area while one appendectomy usually needs two surgeons and 1 hour of standard operative time, the tSV in the area will be calculated as follows:

For example, 15 cases $\times$ 1 hour (fixed) $\times$ 2 surgeons (fixed) = 30 tSV.

then, if 3 surgeons were in the area, it will be 10-hour tSV per surgeon ($\frac{tSV}{s}$).

Database

This descriptive study was based on three data sources as follows: (a) the National Database of Health Insurance Claims and Specific Health Checkups of Japan (NDB) open data,⁸ (b) the Japan Medical Association Research Institute working paper¹⁰ with a national survey from the Ministry of Health, Labour and Welfare, Japan,¹¹ and (c) Gaihoren 2022 data from the Japanese Health Insurance Federation for Surgery.¹² For calculating tSV and tSV/s, surgical volume and operation type were collected from (a); the number of board-qualified surgeons, population density and high-age rate were collected from (b); and the standard operative time and standard number of surgeons for the operation were collected from (c). Data (a) represent the total surgical treatment from April 2021 to March 2022 in Japan. Statistical data (b) was used in the 2020 national survey. The national workforce survey is typically performed biennially, with almost a 2-year interval to publish. At the time of analysis, the latest survey was conducted in 2020. In data source (c), the Japanese Health Insurance Federation for Surgery publishes biennial standardised data from real-world data to seek the adjustment of government health insurance claim policies from a surgical perspective.

Area consideration

Japan has three levels of medical areas for health policy as follows: the primary medical area set municipally (the smallest), the secondary medical area and the tertiary medical area set by prefectures in 47 areas. The secondary medical area forms the basis of the Japanese healthcare plan, which encompasses 335 areas in 2020.¹³

The secondary medical areas are a key categorisation in Japan's healthcare system. Comparisons at the prefectural level often cover large areas, potentially obscuring local disparities. For example, Kyoto Prefecture is known as a region with a high number of physicians, but when examined at the level of secondary medical areas, only the Kyoto-Otokuni region has a surplus of physicians, while the other five regions have an average or below-average number. Therefore, to accurately assess regional disparities, it is appropriate to use smaller areas for analysis, making comparisons based on the secondary medical areas particularly valuable (figure 1).

Analysis

All 335 secondary medical areas in Japan were categorised into the following three groups: urban group (n=48), with over 1 million population or population density over 2000/km²; local city group (n=157), with 200 000 population or 100 000–200 000 population with a population density of ≥ 200 /km²; and rural group (n=130), which encompasses areas that do not meet the

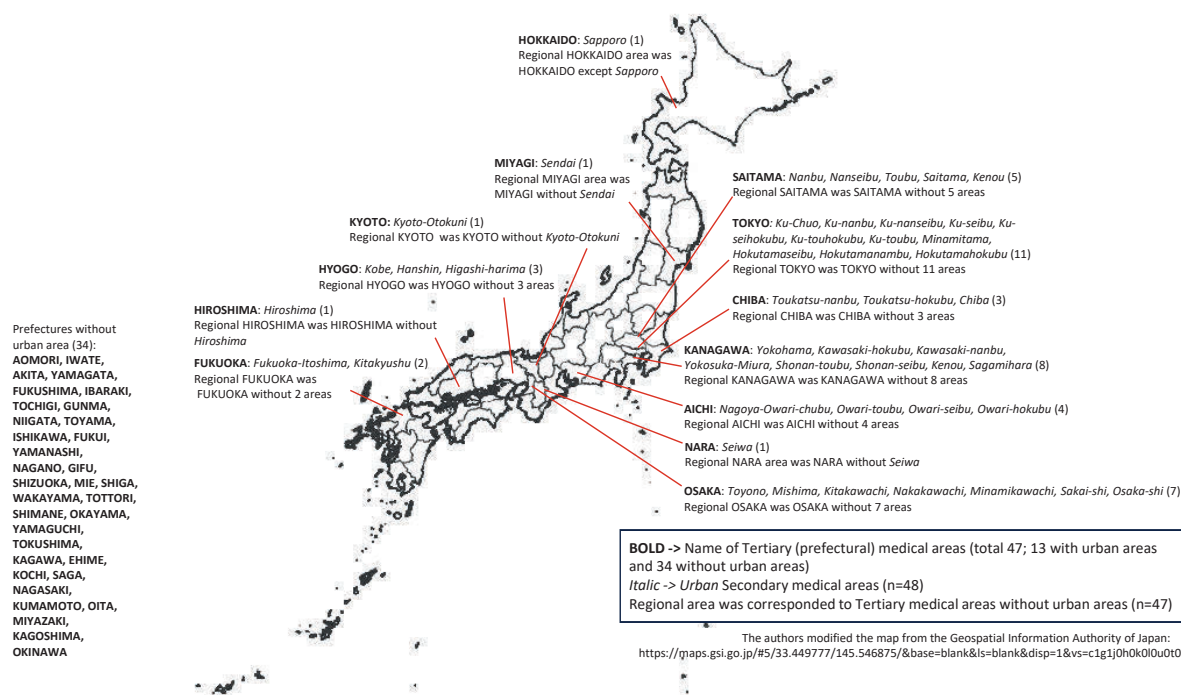


Figure 1 Geographical map of prefectural medical areas and secondary urban areas in Japan. Of 47 prefectural medical areas, 13 had secondary urban areas.

criteria for the other two groups.¹⁰ NDB open data of the secondary medical area intentionally excluded specific surgical volume in rural and local areas, which had <10 cases of each operation or <3 hospitals in each area; in contrast, large areas, such as those with vast populations, had little effect from this disadvantage. Therefore, rural and local city area data were calculated as one group, regional areas, on a prefectural basis, which was done by subtracting the urban group data from tertiary (prefectural) medical area data. In this study, these 47 prefectural regional areas were estimated and compared with the urban areas of the secondary medical area (n=48). All analyses used tSV/s to avoid this difference in the medical area (figure 1).

To demonstrate the shortage of surgeons in each area, the number of board-certified surgeons per 100 000 population was used¹¹ as surgeon density. The average surgeon density in Japan was 17.7 in 2021. Additionally, the distribution of surgeon density in each area with a high age rate was depicted as demographic information.

This study's outcome was the association between tSV/s and surgeon density between the urban and 'rural and local city area' groups, using the fractional polynomials method.

Target operations

General surgery covers a broad but essential surgical treatment at any place. In Japan, the term general surgery is usually used with gastrointestinal surgery¹⁴; therefore, this study focuses on abdominal operations, including

both benign and malignant operations of the stomach, small intestine, large intestine, anal area, liver, pancreas, biliary tract, spleen, abdominal wall and retroperitoneum. NDB open data were used to identify abdominal surgeries from the insurance claim list (K631–753), totaling 1 716 879 cases. Transplant and robotic surgeries were excluded because they typically require extensive medical resources and are predominantly conducted in urban areas. Although a large number (828 337 cases) of claims involved endoscopic procedures, these were also excluded because they are typically performed by gastroenterologists (non-surgeons) and cannot be clearly defined as surgeon-related procedures for the purposes of this analysis. After these exclusions, 888 409 cases were included in the final analyses. This analysis used only publicly open and published data rather than personal data; therefore, ethical consideration was not required for this study. All analyses were conducted using the R software (V.4.2.3); The R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was set at a p<0.05.

RESULTS

Figure 2 shows the distribution of surgeon density and high-age rate in 335 secondary medical areas in Japan. Many rural and local city areas had smaller surgeon densities and higher age rates than urban areas. This suggests that the shortage of surgeons was prominent in high-age-rate areas. Tokyo Ku-chuo area had an extremely

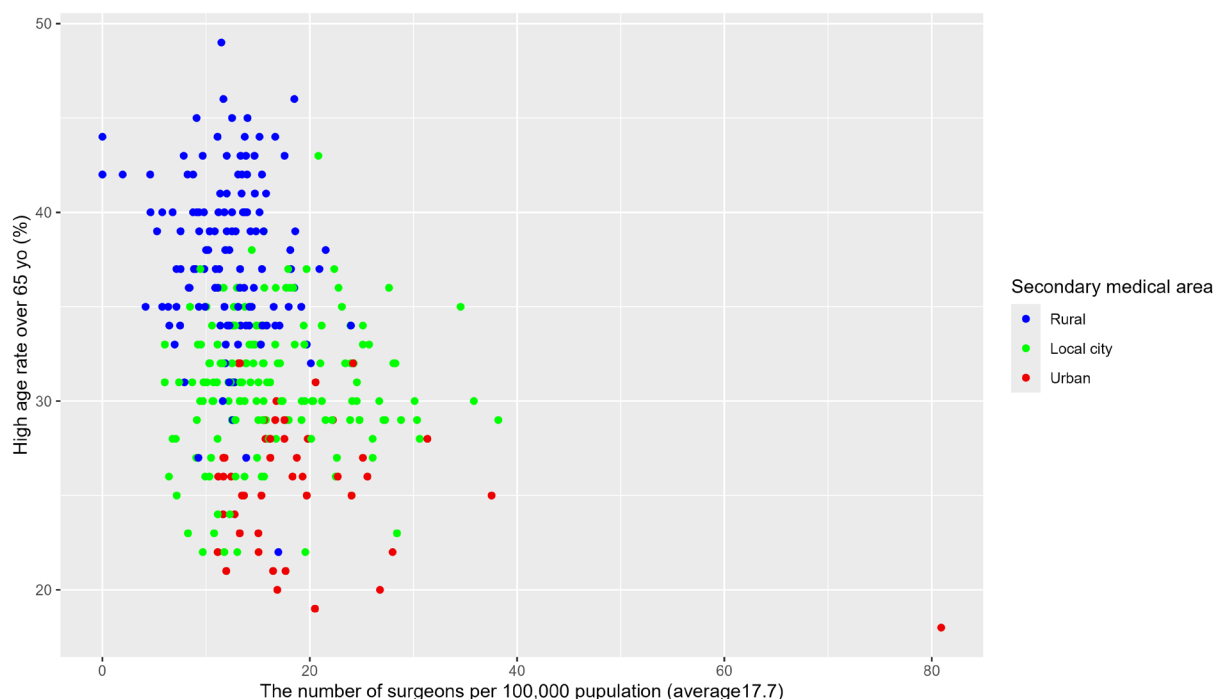


Figure 2 High age rate of >65 years and surgeon density in 335 secondary medical areas, 2021.

high surgeon density (80.9) (figure 2), and the area was excluded from the analysis as an outlier (leaving 47 urban areas).

Figure 3 shows the association between tSV/s and surgeon density. The tSV/s was relatively larger (225.2–582.5 hours, median: 303.2) in the regional areas than in urban areas (142.6–320.8 hours, median: 246.7).

Moreover, the slope of the tSV/s in the regional areas was steeper than that in the urban areas. Using fractional polynomials regression, data from both urban and regional areas were best fit with a linear model (power=1). Linear regression was used to compare these two groups, and a model with an interaction term between the number of surgeons and regional status provided a better fit than

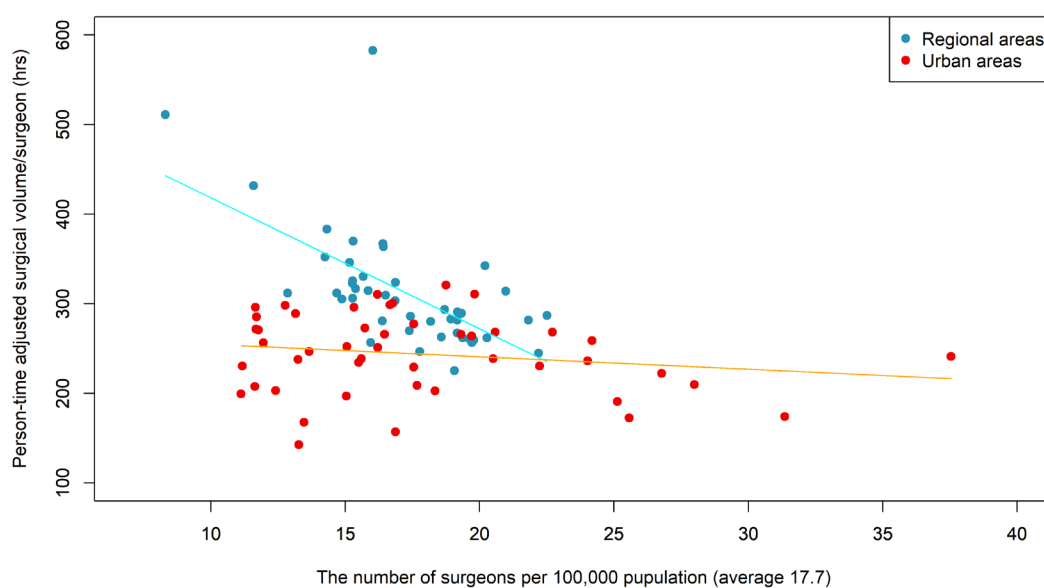


Figure 3 Person-time-adjusted surgical volume per surgeon and surgeon density between regional (prefectural, n=45) and urban (secondary medical areas, n=47) areas, 2021.

Table 1 The statistical results of linear regression with interaction comparing regional and urban areas

	Slope	95% CI	P value
Urban areas	-1.39	-3.83 1.05	0.26
Regional-urban difference	-13.24	-18.90 -7.58	<0.001

the one without interaction (Akaike's information criterion (AIC) 979.4 vs 997.6). This indicated very strong evidence that the effect of the number of surgeons on

tSV/s differs significantly between regional and urban areas ($p<0.001$). The tSV/s increased by 13.24 hours by decreasing one surgeon density in regional-urban difference (95% CI: -18.90 to -7.58), whereas it increased by 1.39 hours with the same decrease in surgeon density in urban areas (95% CI: -3.83 to 1.05) (table 1).

Figure 4 shows the tSV/s of 47 regional areas, in the order from northeast (regional Hokkaido, number 1) to southwest (Okinawa, number 47). Among the 47 regional areas in each prefecture, the tSV/s in regional Tokyo (1997.3 hours) and Kanagawa prefecture (1251.3 hours)

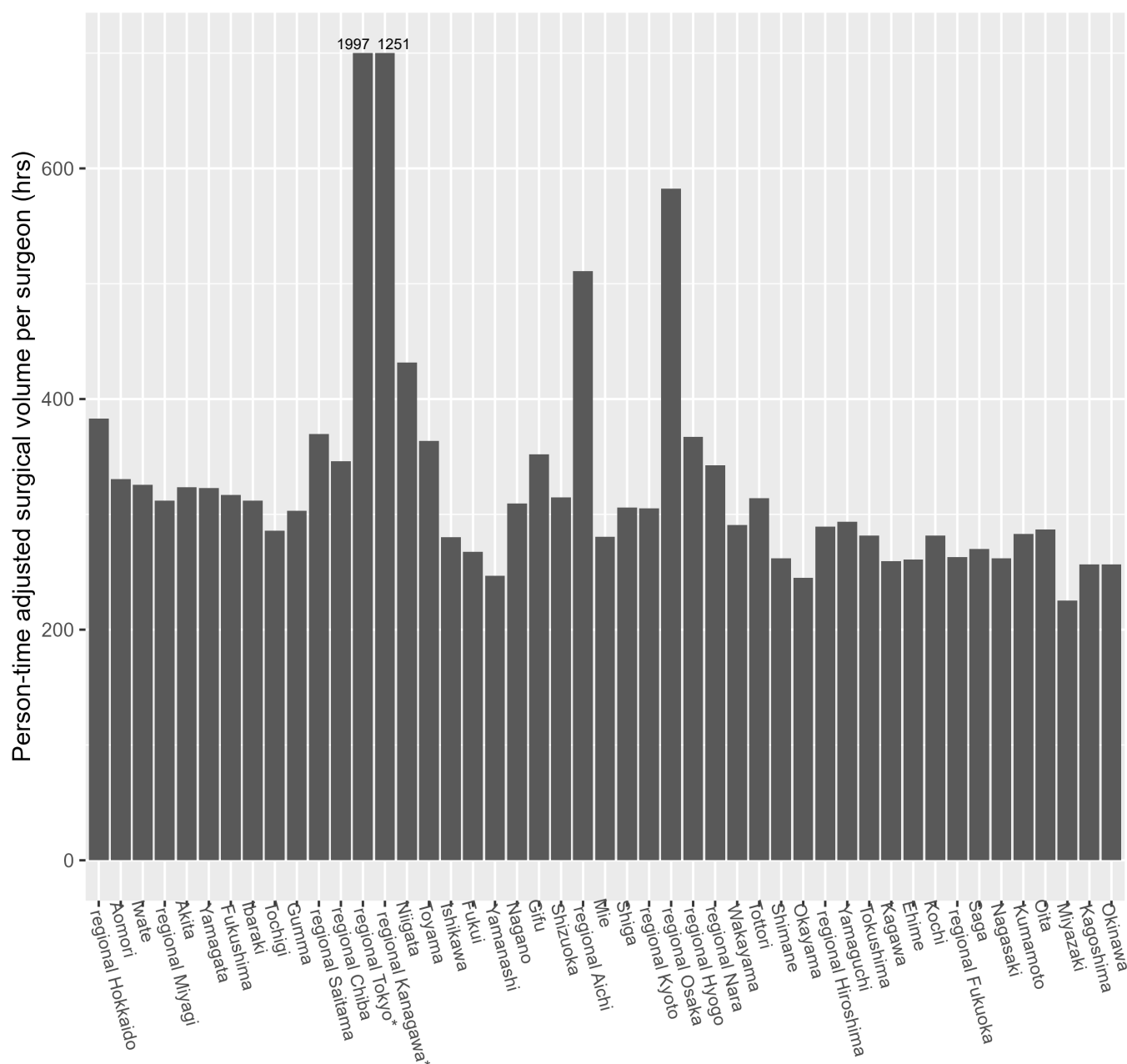


Figure 4 Person-time-adjusted surgical volume per surgeon in regional areas (prefectural, n=47), 2021. (*Included outliers; regional Tokyo and Kanagawa).

were extremely high. These two areas were excluded from this study as outliers with consideration because they included so many urban areas that the subtraction estimation of the small regional areas might affect the results differently.

Of the 45 regional areas, the largest tSV/s was 582.5 hours in the regional area of Osaka prefecture, whereas the smallest was 225.2 hours in Miyazaki prefecture. Regional Aichi and Niigata prefectures also had larger tSV/s of 510.8 and 431.6 hours, respectively. Okayama and Yamanashi prefectures had smaller tSV/s of 244.8 and 246.7 hours, respectively. A decreasing tendency was observed from left to right prefecture, which means from northeast to southwest in Japan.

DISCUSSION

The novel indicator of surgical volume, tSV, was created using weighted standard operative time and the standard number of surgeons for the operation. Our study compared regional and urban areas in Japan to expand the frequent use of tSV in healthcare tactics. Regional areas had more tSV/s than urban areas. Decreasing surgeon density resulted in an increasing rate of tSV/s in regional areas, which was a 10-fold increase in tSV/s with decreasing surgeon density in regional areas. Additionally, tSV could evaluate the difference in surgical burden among different areas over time parameter.

Surgical volume was a feasible and collectible indicator, and it was easy to compare surgical situations in different areas. It was used in LMICs as a metric of surgical burden, such as 5000 cases per 100 000 population.⁷ HICs use surgical volume to evaluate surgical quality and further debate the outcome.^{2 9} In both cases, considering the various operations and surgical workforce was necessary because the distribution of operations in rural areas differed from that in urban areas, regardless of whether the operations were conducted in HICs or LMICs.¹⁵ Estimating the number of surgeons' working hours needed to conduct one operation can help describe each area's operative burden. This can be calculated by adding time and the surgical workforce to the surgical volume.

tSV/s in regional areas was higher than in urban areas. In our study, rural and local cities of secondary medical areas had higher age rates and smaller surgeon densities than urban areas. A larger tSV/s was found in the area with a smaller surgeon density. Additionally, a negative association was found between tSV/s and surgeon density, and the slope of the increasing tSV/s in regional areas was steeper than in urban areas. If one surgeon's density decreased, the increased rate of tSV/s was almost 10 times larger in regional areas than in urban areas. It suggests that surgeons in regional areas (rural and local cities of secondary medical areas) have a higher risk of overworking or burnout than those in urban areas. Moreover, if surgeon density decreases in the rural and local city areas, the situation could be worse.

The new indicator of surgical volume can visualise differences between areas. In the 45-regional area analysis, a decreasing tendency was observed from northeast (Hokkaido) to southwest (Okinawa) (figure 4). This tendency is usually pointed out in many healthcare settings, using the Japanese word "*sei-ko-tou-tei*," which means "relatively sufficient medical resources (high) in the west and low in the east," originally derived from Japan's winter air pressure pattern – high air pressure to the west and low pressure to the east. Higher age rates, a shortage of medical workforce and lower medical costs have already been reported as prominent in the northeast area of Japan.¹⁶ This new indicator has great potential to become a tool to provide information about the actual surgical environment and visualise the actual surgical world situation more than current surgical volume metrics in rural and local areas in the future.

In this study, the data for regional areas was created by subtracting urban data from prefectural-level data. Since rural areas and local cities were grouped together and evaluated as "regional," further subdivisions within secondary medical areas, such as comparisons between rural areas and local cities, were not possible, which posed a limitation. Additionally, it is believed that in different countries or regions, smaller regional divisions for comparison are likely to reveal greater regional disparities. However, the primary aim of the tSV/s method adopted in this study is to enable the comparison of regional disparities, and slight differences in the target areas are not expected to significantly affect the results.

We used the number of board-certified surgeons in this study, which was fundamental in the Japanese surgical training system. In some clinical settings, operations were performed by non-qualified surgeons, such as residents. In this analysis, almost all operations required some skill levels, typically those of qualified surgeons or subspecialists¹² (online supplemental figure). Therefore, even if some non-qualified doctors conducted these operations, support from qualified surgeons was usually needed. It seemed rational to use the number of qualified surgeons in this study.

This study did not account for the number of part-time or rotation surgeons from different medical areas. These doctors could affect different numbers of board-certified surgeons in the area, resulting in variations in tSV/s in the area. This might be one reason for the substantial tSV/s in regional areas of big cities in figure 4, such as regional Tokyo or regional Kanagawa. Further investigation into the impact of part-time or rotation surgeons is needed.

Other unmeasured factors, such as hospital size and capacity, and patients' disease severity, may also influence the outcomes in tSV/s and surgeon density between regional and urban medical areas. Further investigation is warranted to account for these variables.

CONCLUSIONS

tSV was the novel indicator of surgical volume created using weighted standard operative time and the standard number of surgeons. This study compared regional and urban areas of Japan to evaluate the difference in surgical treatment among areas using this new indicator. In resource-poor situations, setting standardised parameters and evaluating the discrepancy with them is a potential tool for understanding the gap in surgical treatment. Therefore, using tSV could be a feasible way to evaluate surgical burden and decrease the gap, hoping for equity of surgical treatment in underprivileged areas in the future.

Correction notice This article has been corrected since it was first published. There were minor errors in the Methods section about the number of target operations. The numbers have now been updated for accuracy. 27 January 2026.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study used only publicly available, deidentified aggregate data and did not involve human participants or patient-level information. Therefore, ethical approval and informed consent were not required.

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