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Distribution and determinants of hospital efficiency and relative productivity in county-level hospitals in rural China: an observational study

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ABSTRACT

Background Cataract surgery is very important to prevent blindness, but its productivity and efficiency in China are unknown. Our study aimed to evaluate the geographical distribution of cataract surgeons and prospectively identify the factors associated with the increased productivity in cataract surgery and efficiency in outpatient ophthalmic services in rural Chinese hospitals.

Methods Data were prospectively collated from various hospital datasets and the census registered by the geographical unit county. Prior to mapping, the geographical location data of counties were cross-linked with the equivalent ophthalmologist and service output data to create categories and map multiple data attributes. Descriptive statistical analyses were performed to characterise the data stratified by county. Linear regression analyses were used to explore the factors associated with the increased productivity/efficiency.

Results The ophthalmologists, surgical productivity of ophthalmologists and outpatient efficacy of ophthalmologists significantly varied across counties. During the period between 2016 and 2018, the median (IQR) change in surgical productivity of and outpatient efficacy of ophthalmologists were 31.627 (−3.33 to 29.94) and 118.08 (−132.30 to 740.89). In the simple regression analysis for predictors of a high productivity change, only the increased number of phaco machine had statistical significance (p=0.003). In addition, only the gross domestic product per capita in 2016 was associated with an increased improvement in efficiency of outpatient services (p=0.008).

Conclusions This study demonstrated that the ophthalmologist productivity and the efficiency of outpatient services were unequally geographically distributed, and their predictors were identified. Further studies to elucidate the extent of the problem and improve the health service delivery models are required.

Strengths and limitations of this study

- This study included all representative county hospitals in Guangdong Province, China.
- The data directly come from a standardised government monitoring database in this study.
- The study only included hospitals in rural areas of one province in China.
- The observation time span is only 2 years, and long-term changes must be verified.
- Patient-level information may further increase the effectiveness of this study.

INTRODUCTION

China has the largest number of people with blindness, and half of the cases are due to cataracts.[1] The number of operable cataracts can be at least four times the number of blind people.[1] The only effective treatment for cataract is surgery.[2] The principal source of eye care for rural dwellers in China is county-level facilities, of which there are approximately 2400, with each covering an average population of approximately 500 000.[3 4] County-level hospitals with eye services accounted for 51% of the total number of hospitals in 2015.[3 4] There are approximately 30 000 eye doctors in China, but fewer than half can independently perform cataract operations, and those that can are mostly based in large cities.[5 6] These differences in health service capacities indicate substantial gaps between the patients' needs and the current service provisions, especially at the county level, which can cause urban/rural health inequalities.

High-quality care, including effective, patient-centred, timely, efficient and equitable ophthalmic services, is an important factor to eliminate blindness in counties.[7] In September 2015, the Ministry of Health (MOH) of China issued the 70th version of 'Guidelines on how to promote the tiered medical service scheme', which encourages counties 'to keep 90% of patients in the county, with capacity to provide services for serious diseases, including cataracts'.[8] Therefore, the service capacity at county-level hospitals must be greatly improved to satisfy this requirement. However, the lack

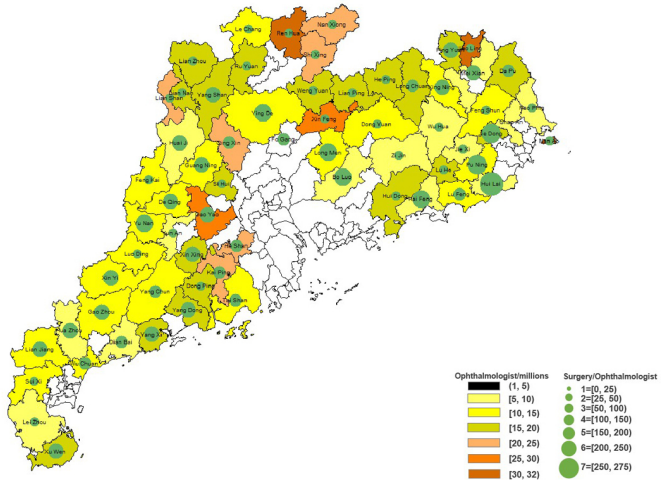

Figure 1 Geographical distribution of the cataract surgery productivity in 2016.

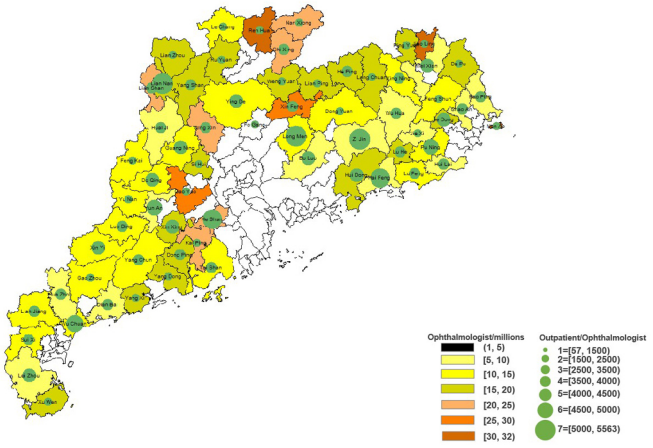

Figure 2 Geographical distribution of the ophthalmic service efficacy in 2016.

of surgical training, lack of surgical quality and patient safety monitoring, poor patient experiences, lack of outpatient options and lack of transparency in patient outcomes have been reported, which causes mistrust between doctors and patients.[9–12]

To achieve the objective by MOH of China, the Guangdong Provincial Government initiated the people's livelihood projects including the Enhancement of the Capacity of the County-level Hospital Project in 2016, which is a quantitative and qualitative study of the efficacy and predictors of a 2-year increase in ophthalmic capacity in more than 60 county/prefecture-level hospitals in Guangdong Province, China. This report aimed to evaluate the geographical distribution of the productivity of cataract surgeons and efficiency of outpatient ophthalmic services and identify the factors that predicted the increases in these parameters over 2 years.

METHODS

This study was performed between January 2016 and December 2018. Oral informed consent was obtained from all participating administrators and ophthalmologists. The tenets of the Declaration of Helsinki were followed throughout.

Participant hospitals and ophthalmic service data

Guangdong is a province at the southernmost tip of mainland of China, adjacent to Hong Kong and Macau; it has 21 prefecture-level divisions encompassing 119 county-level divisions.[13] It topped the total gross domestic product (GDP) rankings among all provincial-level divisions, which makes its economy approximately equivalent to that of Australia. Public hospitals in distinct areas of Guangdong were selected to represent the range of available care in rural China. The annual cataract surgical volume was recorded at the time of ascertainment of baseline data and 24 months later. These data were directly obtained from Guangdong Provincial Government Health Monitoring Database, which provided the demographic and professional information, including the population of the catchment area (typically a county in this case), infrastructure, annual outpatient clinical volume in the ophthalmology department, per capita GDP and total annual cataract surgical output for the hospital catchment area.

Enhancement of the Capacity of the County-level Hospital Project

In 2016, the Guangdong Provincial Government launched the Enhancement of the Capacity of County-level Hospital Programme to improve the capacity of ophthalmic services at 65 county hospitals in Guangdong Province, which represent the basic level of Guangdong Province and socioeconomic level of non-urban areas of China. China has now achieved a 98% coverage rate of basic health insurance for both rural and urban populations nationwide.[14] In Guangdong Province, the medical cost of cataract surgery was 100% covered by the government insurance for all residents in the area. Zhongshan Ophthalmic Center (ZOC), which is the largest ophthalmic

Table 1 Basic characteristics of the included hospitals in Guangdong (65 counties)

Features of cities/county	Average	SD	Maximum	Minimum
Population	3 496 827	1 968 515	7 946 200	1 026 504
Ophthalmologists	48	40	167	12
Cataract surgery rate	2561	1782	7169	140
Outpatient visit rate	136 070	120 687	441 732	14 760

Table 2 Cataract surgery productivity stratified by the county-level and hospital factors during 2016–2018

Characteristics	Productivity		Absolute difference	P value*
	Year 2016	Year 2018		
Region of hospital location				
Pearl River Delta	63.57±38.57	53.93±19.54	−9.64±27.68	0.489
Eastern Guangdong	70.68±19.95	70.55±74.57	−0.12±76.13	0.996
Western Guangdong	42.84±38.20	104.83±81.94	61.99±91.91	0.054
Northern Guangdong	30.36±28.16	50.55±22.00	20.18±22.71	0.107
Economic levels (GDP per capita, RMB)				
Highest quartile	157.45±102.10	106.11±62.88	28.96±94.68	0.191
The third quartile	143.89±90.65	182.09±143.01	38.2±105.52	0.507
The second quartile	126.31±108.29	216.42±175.79	90.12±197.81	0.183
The lowest quartile	174.51±158.09	333.48±279.89	158.98±315.43	0.162
Resident population				
Highest quartile	70.47±34.90	64.46±64.41	−6.01±65.08	0.788
Third quartile	41.88±22.43	103.27±79.48	61.39±79.98	**0.038**
Second quartile	49.58±35.08	53.49±39.14	3.910±49.28	0.807
Lowest quartile	43.69±41.73	59.39±33.86	15.70±51.39	0.450
Department of ophthalmology				
Incorporated to ENT department	43.82±33.16	70.53±63.34	26.71±69.60	0.057
Independent department	70.14±34.66	67.74±55.86	−2.40±59.54	0.896
No of trained personnel during the project				
>5–≤10	46.46±43.37	78.86±80.84	32.40±42.88	0.366
>3–≤5	99.33±161.70	149.75±165.25	50.42±151.25	0.546
3	84.94±59.06	79.19±75.911	−5.76±72.95	0.852
0–2	92.24±99.45	63.31±31.14	−28.93±99.77	0.326
Change in hospital beds during the project				
Increased	44.59±25.35	156.01±162.58	111.41±166.31	**0.035**
Unchanged	59.05±42.50	267.37±238.47	208.32±244.10	**0.002**
Reduced	52.07±33.83	182.40±160.37	130.33±157.89	**0.008**
Increase in phaco machines during the project				
≥2	44.96±18.17	36.15±15.31	−49.82±92.91	0.141
1	55.78±33.66	75.82±65.77	40.35±298.30	0.501
0	45.90±51.11	72.50±55.26	26.59±78.20	0.060
Change in surgical microscope accessibility during the project				
Increased	53.05±30.68	98.02±75.90	54.49±84.94	0.119
Unchanged	52.45±37.36	60.72±52.41	8.27±58.83	0.477
Increase in ophthalmic devices during the project				
≥10	49.93±28.47	41.79±17.20	−8.14±37.74	0.472
≥5–10	53.19±36.65	96.03±78.61	42.84±84.22	**0.049**
≥0–5	53.72±39.37	55.48±36.66	55.48±36.66	0.907

Continued

Table 2 Continued

Characteristics	Productivity			
	Year 2016	Year 2018	Absolute difference	P value*
Change in nurse-to-doctor ratio during the project				
Increased	106.24±90.83	328.85±417.33	222.61±447.46	0.190
Unchanged	176.74±128.09	247.79±188.22	71.044±214.14	0.207
Reduced	225.69±277.63	124.59±115.23	−101.09±326.62	0.255

The bold indicates the statistical significance.
*Paired t-test.
†bold indicates the statistical significance
ENT, ear, nose and throat; GDP, gross domestic product; RMB, renminbi.

hospital, was responsible for managing this project. The training model consisted of four components: (1) an assessment of hospitals in terms of equipment, facilities, staff, surgeon experience and administrative support; (2) education for trainees regarding screening for cataracts, preoperative assessment, cataract surgery and postoperative management; (3) 2-month didactic and wet lab training on the principles of cataract surgery and refractive examination at ZOC; (4) hands-on training by ZOC trainers during supervised surgeries at the county hospitals. All the hospitals received the same and standardised evaluation and training. The overall aim of this proposed programme was to improve the surgical productivity of ophthalmologists and capacity of ophthalmic services in county hospitals in China.

Statisticalanalyses

The density of ophthalmologists was defined as the number of ophthalmologists per million people. The cataract surgical rate (CSR, measured in cases per million population per year) for each hospital was calculated by dividing the annual total cataract surgical volume of each hospital from the surgical records by the catchment area population. The outpatient visit rate for each hospital was calculated by dividing the annual total outpatients who attended each hospital from the electronic health record (EHR) by the catchment area population. The surgical productivity of the ophthalmologists was defined as the number of cataract surgeries per year per ophthalmologist.[15 16] The efficiency of outpatient services was defined as the number of outpatient visits per ophthalmologist.[17 18] The principal study outcome was the 2-year change in productivity and efficiency in each hospital, and the pure arithmetic increase in number of surgeries was considered an increase in productivity.

The baseline hospital, patient and surgeon characteristics were described as the means (SDs) if they were continuous variables with a normal distribution, medians (IQRs) if they were continuous variables with a non-normal distribution, and frequencies (percentages) if they were categorical variables. The 2-year changes with each outcome were calculated for each hospital, and the means and medians (IQRs) were reported. Simple linear regression models were used to investigate the effects of the macro-level indicators on the baseline productivity/efficiency and 2-year changes in productivity/efficiency for hospitals. All variables with a p value of <0.05 in the simple regression models of the primary and secondary outcomes were included in the multiple regression analysis. All analyses were performed using the Stata V.14.0 software (StataCorp, College Station, Texas, USA).

Patient and public involvement

Patients were not involved in the preparation of the study protocol.

RESULTS

Table 1 shows the demographic and professional information and the socioeconomic factors in the catchment areas of the participating hospitals. In total, 65 hospitals were included in the study. The median size of the patient catchment area was 530 000 (IQR, 380 000–850 000) people, the median CSR for areas surrounding the hospitals was 643 (IQR, 356–1005) cases per million per year, and the facilities performed a median of 191 cataract surgeries and examined 9484 outpatients per year.

Figure 1 shows the geographical distribution of the surgical productivity of ophthalmologists. The ophthalmologist density and surgical productivity of the ophthalmologists varied across counties. Figure 2 presents the geographical distribution of the efficiency of outpatient services. The baseline efficiency of outpatient services was disproportionately distributed with higher productivity in area with higher GDP per capita.

Table 2 shows the 2-year changes in surgical productivity during the period stratified by the macro-indicators. Figure 3 shows the 2-year change in surgical productivity of ophthalmologists at 56 participating hospitals in rank order. The median (IQR) change was 31.627 (−3.33 to 29.94), and the range was −110.46 to 829.88. Table 3 shows the per cent changes in outpatient service efficacy during the period stratified by the macro-indicators. Figure 4 shows the 2-year per cent change in outpatient

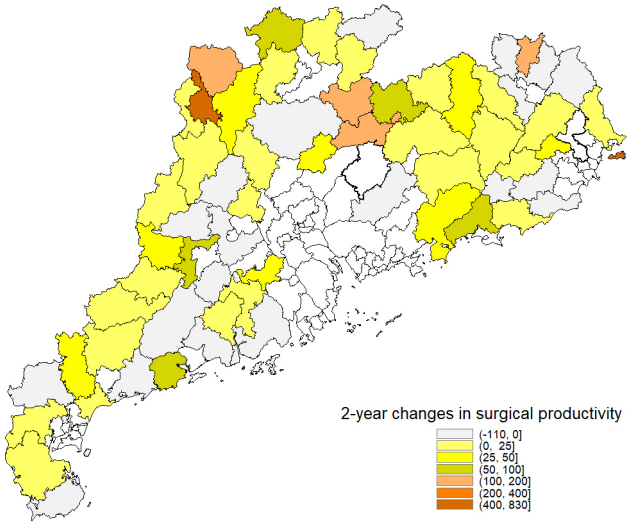

Figure 3 Two-year change in surgical productivity of the ophthalmologists.

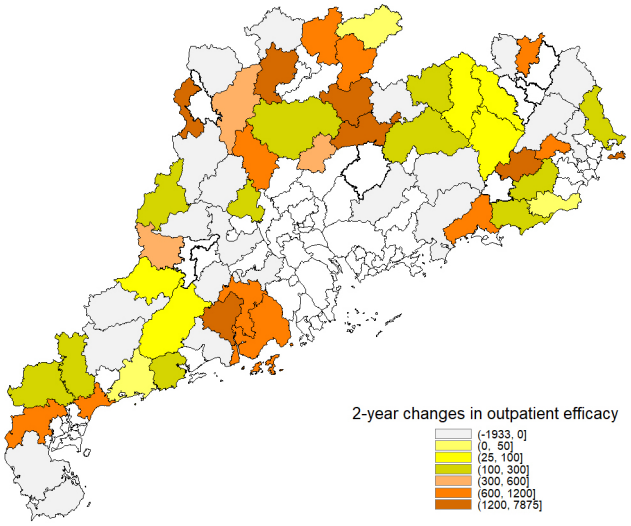

Figure 4 Two-year change in outpatient service efficacy of the ophthalmologists.

service efficacy in rank order. The median (IQR) change was 118.08 (−132.30 to 740.89), and the range was from −1932.93 to 7874.02.

In the simple regression analysis for predictors of a high productivity change, only the increased number of phaco machine had statistical significance (p=0.003) (table 4). Using similar models, predictors of high improvement in the efficiency of outpatient services in the simple regression models included the region of the hospital, GDP per capita in 2016 and number of ophthalmologists (all p<0.05, table 5). In multiple models, only the GDP per capita in 2016 was associated with an increased improvement in efficiency of outpatient services (p=0.008).

DISCUSSION

After receiving support and training, the annual surgical output generally increased in these facilities at a median rate of 118.08 over 2 years. Our findings indicate that all factors that predicted our main outcome, which is the 2-year change in surgical productivity, were under the direct control of the hospitals. The infrastructure, that is, the number of phaco machines, was the only predictor of the ophthalmologist productivity, while the GDP per capita was the only predictor of the efficiency of outpatient services. Our results highlight the importance of increasing hardware for surgical services in addition to the capacity to supply them in this setting.

The distribution of the CSR and ophthalmologist density varied across counties, which is consistent with previous studies.[19–21] The CSR is a key indicator to monitor eye care services; it represents the number of cataract

Table 3 Ophthalmic service efficacy stratified by the county-level and hospital factors during 2016–2018

	Efficiency of outpatient service			
Characteristics	**Year 2018**	**Year 2016**	**Absolute difference**	**P value***
Number of doctors	7.66±0.53	6.68±0.44	0.98±0.22	**<0.001**
Number of nurses	7.71±0.68	7.51±0.69	0.67±0.54	**0.038**
Number of optometrists	0.87±0.17	0.73±0.16	0.10±0.79	0.162
Number of phaco machines	1.07±0.09	0.80±0.10	0.06±0.45	**<0.001**
Number of surgeons	2.64±0.25	2.17±0.18	0.47±0.16	**0.006**
Number of surgeries	418.26±56.76	318.49±49.12	22.47±181.16	**<0.001**
Number of yearly outpatient visits	14522.1±1615.3	12195.9±1239.0	530.85±4279.84	**<0.001**
Number of phaco machines per surgeon	52.46±6.17	44.76±6.39	3.95±31.86	0.055
Number of outpatient visits per doctor	1986.9±145.8	1978.2±154.3	78.48±632.74	0.912
Number of phaco surgeries per million population	93.66±17.21	57.91±8.20	17.06±136.52	**0.040**
Number of outpatient visits per million population	3518.8±532.1	157.6±423.6	167.23±1295.33	**0.035**

Bold indicates statistical significance.
*Paired t-test.

Table 4 Linear regression analysis of the factors associated with the changes in cataract surgeon productivity during the period between 2016 and 2018

Factors	Coefficient	95% CI	P value
Region of hospital location			
Pearl River Delta	Reference		
Eastern Guangdong	42.08	−54.74 to −138.91	0.388
Western Guangdong	97.72	−8.42 to −203.85	0.070
Northern Guangdong	7.39	−95.65 to −110.42	0.886
Training sessions during the project			
N≤1	Reference		
N=2	−29.6	−124.61 to −65.39	0.535
N=3	−68.93	−163.93 to −26.07	0.152
Department (independent vs ENT)	−36.4	−117.05 to −44.24	0.370
Change in hospital beds during the project	−0.95	−4.99 to −3.09	0.640
Increase in phaco machines during the project	111.4	38.86 to −183.94	**0.003**
GDP per capita in 2016	0.003	−0.012 to −0.018	0.679
Number of ophthalmologists in 2016	−9.17	−28.53 to −10.19	0.347
Number of nurses in 2016	−1.09	−66.38 to −64.20	0.973
Number of optometrists in 2016	−7.67	−51.27 to −35.93	0.726

Productivity of cataract surgeons=number of cataract surgeries per million population per ophthalmologist.
Bold indicates statistical significance.
ENT, ear, nose and throat; GDP, gross domestic product.

extractions performed per million population per year at a given location.[21] To reduce visual impairment due to cataracts, the CSR must be greater than the incidence rate of cataracts. It was reported that the highest concentrations of ophthalmologists were in regions with higher GDPs and consequently higher CSRs in Brazil.[22] The

Table 5 Linear regression analysis of the factors associated with the increased efficiency of outpatient visits

Factors	Coefficient	95% CI	P value
Region of hospital location			
Pearl River Delta	Reference		
Eastern Guangdong	607.1	−323.8 to −1538.1	0.197
Western Guangdong	1083.1	62.5 to −2103.7	**0.038**
Northern Guangdong	292.4	695.0 to −1279.8	0.555
Training sessions during the project			
N≤1	Reference		
N=2	314.5	−621.2 to −1250.3	0.504
N=3	−249.3	−1191.0 to −692.5	0.598
Department (independent vs ENT)	−181	−959.3 to −597.2	0.643
Change in hospital beds during the project	−6.13	−44.6 to −32.4	0.751
Increase in phaco machines during the project	345	−429.4 to −1119.4	0.376
GDP per capita in 2016	0.193	0.053 to −0.333	**0.008**
Number of ophthalmologists in 2016	−290.41	−467.34 to −113.4	**0.002**
Number of nurses in 2016	−183.1	−804.6 to −438.3	0.558
Number of optometrists in 2016	45.9	−373.0 to −464.8	0.827

Efficiency of outpatient visits=number of outpatients per ophthalmologist.
Bold indicates statistical significance.
ENT, ear, nose and throat; GDP, gross domestic product.

reality is that the GDP most likely correlates with poor access to services and not necessarily with the paying capacity.[21]

Due to the low number of ophthalmologists, a high number of patients do not receive eye care services, and the ophthalmologists are overworked.[5] This study shows that the shortages and uneven distributions of ophthalmologists greatly affect the areas with poor socioeconomic status. As ageing progresses, the number of incidences of age-related eye diseases such as age-related macular degeneration and cataracts increases, and the demand for ophthalmologists increases accordingly.[5] The density of ophthalmologists varied with socioeconomic development from 9 per million people in developing counties to 79 per million people in developed counties.[5] A study of the Singaporean population showed that the ageing population ultimately doubled the number of patients with eye diseases, which increased the demand for eye care in public health institutions.[23] In Canada, workforce planning, resource allocation and data collection are very important tasks, but these tasks are insufficient to address the shortage of ophthalmologists.[24–27] Therefore, it is necessary to increase the number of ophthalmologists and improve the problem of uneven distribution.

The productivity of ophthalmologists and efficiency of ophthalmic services were also unevenly distributed across counties in Guangdong Province. Since cataracts remain the most important cause of blindness worldwide, it is important to increase the number of cataract surgeons.[28] To cope with the severe shortage of cataract surgeons, some African countries have adopted a task-shifting strategy to train nurses and physicians in cataract surgery.[29–31] For countries that cannot quickly increase the number of ophthalmologists, increasing the surgical productivity of ophthalmologists can improve the efficiency of blindness prevention.[15] The Global Action Plan 2006–2011 estimates that the worldwide goal of ophthalmic human resources is ≥4 ophthalmologists per million population based on 2–3 units/hour per cataract physician.[32] If the surgical productivity of each ophthalmologist increases, the target demand for human resources will decrease.

Few studies have investigated factors that potentially affect the cataract surgery output in rural hospitals.[15 16] In a cross-sectional study of hospitals in East Africa, Courtright *et al*[15] found that increased productivity was associated with having two or more cataract surgery equipment sets, a well-functioning operating microscope, three or more nursing support staff, and the ability to transport patients. Eliah *et al*[31] reported that high-quality training was necessary but not sufficient to improve the cataract surgery rates to satisfy the population needs and maintain surgical skills. Supporting institutions and staff, functioning equipment and programmes to recruit and transport patients are essential for improving the productivity of cataract surgeons.[15–17 33] This study indicates that the strategies for training, supporting and supervising cataract surgeons in China must be revised to create conditions amenable to increased productivity. Rural hospitals are most likely to benefit from an investment in phaco machines.

The strengths of the current study are its prospective design and the enrolment of many hospitals in Guangdong Province. The collected data covered most of the macro-level factors that were posited as important in driving the demand for ophthalmic services, and they were used as much as possible. However, this study has limitations. First, all hospitals were in Guangdong Province, which is a relatively high-income province in China. These hospitals were not identified using a randomised sampling strategy; thus, care must be taken in generalising these results to over 2000 existing county hospitals in China. Second, patient-level factors were not obtained; however, it was not practical for us to record exhaustive information on the patients who actually presented to the eye departments for care. Such information might have improved our models, although patient factors generally are not under the control of the facilities. Third, only county-level data were available, which increased the risk of ecological fallacy. However, the ecological analyses inform us about forces that act on the entire populations. Fourth, we only included public hospitals in Guangdong Province, but the vast majority of patients in China are treated in public hospitals and few private hospitals, so we believe that it will not greatly affect our conclusion. Fifth, the information on the populations living in the hospital catchment areas was limited, such as the data for transport networks and distance to the hospital were unavailable. Though it was reported that the driving time to the nearest optometrist/ophthalmologist may affect the eye access in the USA,[34–36] transportation factors were not considered to be the important barriers for cataract surgery in southern China.[37] Future incorporation of geographical information systems mapping could help to clarify the role of these factors.[38] Finally, many factors related to the ophthalmologist productivity and efficiency of outpatient services were not considered. For example, the Lean Six Sigma process has been reported to yield significant improvements in healthcare.[18] EHRs and scheduling templates can improve the clinical efficiency and operation.[17 39]

CONCLUSIONS

This study is the first report to map the geographical distribution of surgical productivity and efficiency of outpatient services in rural Chinese hospitals. The infrastructure, that is, the number of phaco machines, and socioeconomic status, that is, GDP per capita potentially contributed to the increasing rural cataract surgical capacity over time. Our conclusions provide a potential guide for government investment to increase the number of surgeries and outpatient services.

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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 required.

Ethics approval This study was reviewed by the Zhongshan Ophthalmic Ethical Committee and was determined to be exempt from approval, as this study did not involve human subject research.

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