Associations of centralization with health care quality for gastric cancer patients receiving gastrectomy in China

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Abstract

Objective: Limited evidence is available regarding the associations of centralization with gastric cancer patients’ quality of care in high surgical volume settings. The current study aimed to explore the effects of hospital volume and the Herfindahl-Hirschman index (HHI) on in-hospital mortality, total cost, and length of stay for Chinese gastrectomy patients in a nationwide database.

Methods: We extracted data on gastrectomy for gastric cancer from the Hospital Quality Monitoring System Database between 2013 and 2018. Hospital volume was divided into 4 quartiles: low (1−83 cases per year), medium (84−238 cases), high (239−579 cases), and very high (580−1,193 cases). The HHI was divided into 3 categories: highly concentrated (>2,500), moderately concentrated (1,500−2,500), and unconcentrated (<1,500). We used mixed-effects models to analyze the data while accounting for data clustering.

Results: We analyzed 125,683 patients in 515 institutions. In the multivariable analyses, hospital volume was significantly associated with in-hospital mortality [medium vs. low: odds ratio (OR)=0.61, 95% confidence interval (95% CI)=0.43−0.84, P=0.003; high: OR=0.57, 95% CI=0.38−0.87, P=0.009; and very high: OR=0.33, 95% CI=0.18−0.61, P<0.001] and length of stay (high vs. low: β=0.036, 95% CI=0.071−0.002, P=0.039) but not with total cost. Hospitals located in unconcentrated provinces had higher in-hospital mortality (OR=1.52, 95% CI=1.03−2.26, P=0.036) and longer lengths of stay (β=0.024, 95% CI=0.001−0.047, P=0.041) than hospitals located in highly concentrated provinces.

Conclusions: Centralization of gastrectomy, measured by hospital volume and the HHI, was associated with decreased in-hospital mortality and shortened length of stay without increasing total cost. These results support the strategy of centralizing gastrectomy in high-volume settings.

Keywords: Centralization; gastric cancer; Herfindahl-Hirschman index; hospital volume; quality of care

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Introduction

Gastric cancer is one of the most common cancers and the leading cause of cancer death worldwide (1). Eastern Asian countries, particularly China, have been facing a heavy burden of gastric cancer. The incidence of gastric cancer (679,000 new diagnoses per year) remains high in China, and the absolute number of patients is increasing because of rapid population aging and prolonged life expectancy (2). It is projected that the number of incident cases in China will increase by 53% from 2010 to 2035 (3).

High-quality health care is desirable. A recent systematic
analysis reported that the deaths attributable to receiving poor-quality health care constituted 58% (5.0 million) of all amenable mortality in 137 low- and middle-income countries (4). Surgery is the primary and only potentially curative treatment for patients with gastric cancer (5). According to the data collected by the National Clinical Database, approximately 50,000 to 60,000 gastrectomies are performed annually in Japan (6). Inadequate quality surgery is associated with unsatisfactory short- and long-term patient outcomes (7-9). A retrospective medical record review of 1,685 patients diagnosed with gastric cancer in Japan found that 66% of surgical treatments met the quality standards (10). However, limited data have been reported regarding surgical volume and quality in China.

Gastrectomy is a highly complex surgical procedure. It has been hypothesized that the centralization of technically demanding surgeries may improve patient outcomes and health care quality by facilitating the use of standard care, whereas decentralization may likewise improve health outcomes by increasing efficiency and competition. For gastric cancer patients receiving surgical treatment, previous studies have been conducted in countries where gastric cancer is far less prevalent than in high-incidence countries such as China (11-18). It is questionable whether centralization can improve the quality of care in high-incidence countries where health professionals are more likely to be overworked in high-volume hospitals.

Thus, the current study aimed to report the surgical volume of gastrectomies and explore the association of centralization/decentralization on the quality of surgical care for Chinese patients hospitalized with gastric cancer from 2013 to 2018.

Materials and methods

Data sources

The current study used the Hospital Quality Monitoring System (HQMS) Database, which is a national patient-level database that was launched in 2013 by the National Health Commission of China. The database collects patients’ discharge information (called “front page”) in a national standardized electronic format, mainly from tertiary hospitals in China. The “front page” information contains variables including demographic characteristics, clinical diagnoses (both at admission and discharge), procedures, pathological diagnoses, and expenditure breakdowns. All clinical diagnoses and operating procedures are coded according to the International Classification of Diseases-10 (ICD-10) coding system.

We also extracted information on regional characteristics, including the number of certified assistant doctors per 10,000 people and provincial gross domestic product (GDP), from the public data provided by the National Bureau of Statistics of China (http://www.stats.gov.cn/english/).

This study was approved by the Peking University Cancer Hospital Ethics Committee (No. 2020YJZ67) for the Protection of Human Subjects (Beijing, China).

Study population

The study population is Chinese primary gastric adenocarcinoma patients aged 18–99 years who received surgical treatment (i.e., laparoscopic surgery, open surgery) in secondary and tertiary hospitals from 2013 to 2018. The ICD-10 coding system for the disease name, pathological type, and surgery type was used to select eligible patients for the analysis.

Measures of centralization

Hospital volume: number of gastrectomies performed annually in each hospital. We categorized hospital volume into four equal-sized quartiles: low (1–83 cases per year), medium (84–238 cases), high (239–579 cases), and very high (580–1,193 cases). A high hospital volume showed the centralization of the procedure.

The Herfindahl-Hirschman index (HHI): this indicator measures hospital market concentration (19). By definition, the HHI is the sum of the squares of each hospital’s market share, calculated by summing the squares of the number of procedures performed per hospital divided by the total number of procedures. In the current study, each hospital’s share was the hospital volume divided by the total number of gastrectomies performed within the province each year. We then calculated the HHI by adding up the squared share of each hospital within the province and multiplying the total sum by 10,000. An HHI greater than 2,500, of 1,500 to 2,500, and less than 1,500, was categorized as highly concentrated (i.e., noncompetitive), moderately concentrated (or moderately competitive), and unconcentrated (or highly competitive), respectively. A high HHI value indicated the centralization of the procedure.

Quality of care indicators

The quality of care indicators included hospitalization cost,
hospital mortality, and hospital length of stay. Due to the nonnormal distribution of hospitalization cost and length of stay, we log-transformed these two variables before the analysis.

**Covariates**

Patient, hospital, and regional characteristics were used as the covariates for adjustment. Patient characteristics included patient age, sex, number of comorbidities, pathological type, surgery type, esophageal resection, and spleen resection. Hospital characteristics included hospital type (cancer hospital, general hospital, other specialized hospitals), hospital grade (A, B, no grade, others), and hospital level (secondary vs. tertiary). Regional characteristics included the number of certified assistant doctors per 10,000 people, provincial GDP, and year.

**Statistical analysis**

The variables at the patient, hospital and regional levels were summarized using descriptive statistics. Binary and categorical variables are presented as frequencies and percentages, and continuous variables are presented as the mean and standard deviation (SD) as well as the median and interquartile range (IQR).

Because the data were clustered, i.e., patients were nested in hospitals and hospitals were nested within geographical areas, mixed-effects models were used to explore the association of centralization (including hospital volume and the HHI) with the quality of care (including hospitalization mortality, length of hospital stay, and total hospitalization costs). For hospital mortality, a logistic mixed-effects model with robust variance estimators was used. For the length of hospital stay and total hospitalization costs, linear mixed-effects models with robust variance estimators were used. In all models, variables at the organizational level were treated as random effects. Both univariable and multivariable analyses were conducted. For the multivariable analyses, each model was adjusted for the patient, hospital, and regional characteristics mentioned above.

All statistical analyses were conducted in Stata 16.0 (StataCorp LLC., Texas, USA), with a two-sided $P<0.05$ claimed as statistically significant.

**Results**

**Population characteristics**

The patient, hospital and regional characteristics are shown in Table 1. We analyzed a total of 125,683 gastric cancer patients in 515 hospitals from 2013 to 2018. A total of 99.9% of these hospitals were tertiary hospitals, and 89.3% were grade A hospitals. The majority of patients were male (73.0%). The mean age of the patients was 60.9±10.7 years. Eleven percent of patients underwent laparoscopic surgery. The in-hospital mortality rate was 0.3%. The mean length of hospital stay for patients was 22.1±10.2 (IQR, 16–25) d. The mean total hospitalization cost was 64,794.4±28,782.7 (IQR, 46,257–76,340) Chinese Yuan (CNY). A total of 50.3%, 24.9%, and 24.8% of the patients were treated in highly concentrated (an HHI of >2,500), moderately concentrated (an HHI of 1,500–2,500), and unconcentrated (an HHI of <1,500) hospitals, respectively. No patients were treated in hospitals with an HHI of <100. The hospital’s mean annual gastric cancer surgery volume from 2013 to 2018 was 355±319 (IQR, 84–597).

**Hospital volume vs. in-hospital mortality**

The number (%) of in-hospital deaths was 138 (0.44%), 88 (0.29%), 76 (0.24%), and 47 (0.15%) in the low, medium, high, and very high hospital volume groups, respectively (Figure 1A). In the univariable analysis by the mixed-effects model, the odds of death were 36%, 42%, and 68% lower in the medium-, high-, and very high-volume groups, respectively, than the odds in the low-volume group (Table 2). These odds ratios (ORs) were similar after adjusting for the covariates (Table 3). The OR comparing the very high (580–1,193) volume group to the medium (84–238) volume group was 0.55 [95% confidence interval (95% CI)=0.30–0.99, $P=0.046$]. However, no significant difference was found when comparing the very high (580–1,193) volume group to the high (239–579) volume group (OR=0.58, 95% CI=0.32–1.05, $P=0.072$) or comparing the high (239–579) volume group to the medium (84–238) volume group (OR=0.94, 95% CI=0.63–1.41, $P=0.776$).

**HHI vs. in-hospital mortality**

The number (%) of in-hospital deaths was 180 (0.28%), 92 (0.29%), and 77 (0.25%) in the HHI categories of >2,500, 1,500–2,500, and <1,500, respectively (Figure 1B). In the univariable analysis by the mixed-effects model, the odds of death in the HHI categories of 1,500–2,500 and <1,500 were not significantly different from the odds of death in the highest HHI category (all $P>0.05$, Table 2). After adjusting for the covariates (Table 4), the odds of death in the HHI category of <1,500 was 1.52 times the odds of
### Table 1 Patient, hospital, and regional characteristics

| Variables                        | n (%)          |
|----------------------------------|----------------|
| **Gender**                       |                |
| Male                             | 91,739 (73.0)  |
| Female                           | 33,944 (27.0)  |
| **Age (year)**                   | 60.9±10.7      |
| Median (IQR)                     | 62 (54–68)     |
| **Adenocarcinoma type**          |                |
| Adenocarcinoma                   | 99,482 (79.2)  |
| Other adenocarcinoma*            | 26,201 (20.8)  |
| **No. of comorbidities**         |                |
| 0                                | 80,328 (63.9)  |
| 1                                | 32,835 (26.1)  |
| 2                                | 10,282 (8.2)   |
| ≥3                               | 2,238 (1.8)    |
| **Surgery type**                 |                |
| Open gastrectomy                 | 111,878 (89.0) |
| Laparoscopic gastrectomy         | 13,805 (11.0)  |
| **Laparoscopic exploration**     |                |
| No                               | 121,596 (96.7) |
| Yes                              | 4,087 (3.3)    |
| **Esophageal resection**         |                |
| No                               | 122,697 (97.6) |
| Yes                              | 2,986 (2.4)    |
| **Spleen resection**             |                |
| No                               | 123,549 (98.3) |
| Yes                              | 2,134 (1.7)    |
| **Length of stay (d)**           |                |
| x±s                              | 22.1±10.2      |
| Median (IQR)                     | 20 (16–25)     |
| **In-hospital death**            |                |
| No                               | 125,333 (99.7) |
| Yes                              | 349 (0.3)      |
| **Total hospitalization cost**   |                |
| x±s                              | 64,794.4±28,782.7 |
| Median (IQR)                     | 59,798 (46,257–76,340) |
| **Hospital type**                |                |
| General hospital                 | 93,502 (75.8)  |
| Cancer hospital                  | 29,606 (24.0)  |
| Other specialized hospitals*     | 220 (0.2)      |

### Table 1 (continued)

| Variables                        | n (%)          |
|----------------------------------|----------------|
| **Hospital level**               |                |
| Tertiary                         | 125,612 (99.9) |
| Secondary                        | 71 (0.1)       |
| **Hospital grade**               |                |
| A                                | 112,220 (89.3) |
| B                                | 7,943 (6.3)    |
| Ungraded                         | 4,990 (4.0)    |
| Others                           | 530 (0.4)      |
| **Annual hospital volume**       |                |
| (cases per year)                 |                |
| x±s                              | 355±319        |
| Median (IQR)                     | 240 (84–597)   |
| **HHI**                          |                |
| >2,500                           | 63,259 (50.3)  |
| 1,500–2,500                      | 32,166 (24.9)  |
| <1,500                           | 31,158 (24.8)  |
| **Provincial GDP (CNY)**         |                |
| x±s                              | 35,997.0±22,776.5 |
| Median (IQR)                     | 29,609.4 (19,627.8–49,935.9) |
| **No. of certified assistant**   |                |
| doctors per 10,000               |                |
| x±s                              | 25.6±7.2       |
| Median (IQR)                     | 24 (22–27)     |
| **Year**                         |                |
| 2013                             | 15,050 (12.0)  |
| 2014                             | 20,928 (16.7)  |
| 2015                             | 23,688 (18.8)  |
| 2016                             | 25,596 (20.4)  |
| 2017                             | 20,434 (16.3)  |
| 2018                             | 19,987 (15.9)  |

IQR, interquartile range; CNY, Chinese Yuan; HHI, Herfindahl-Hirschman index; GDP, gross domestic product. * Including papillary adenocarcinoma, tubular adenocarcinoma, signet ring cell carcinoma, mucinous adenocarcinoma, hepatoid adenocarcinoma, adenosquamous carcinoma, squamous cell carcinoma, small cell carcinoma, undifferentiated carcinoma, malignant carcinoid, choriocarcinoma; † including Traditional Chinese Medicine Hospitals, Integrated Traditional Chinese and Western Medicine Hospitals, Infectious Disease Hospitals, Rehabilitation Hospitals, Cardiovascular Diseases Hospitals, Mental Diseases Hospitals, Tuberculosis Hospitals, Thoracic Hospitals, Mongolian Hospitals, Township Health Centers, and other specialized hospitals that are not specified; a, 1 missingness; b, 2,355 missingness.

death in the highest HHI category (95% CI=1.03–2.26, P=0.036).
**Hospital volume vs. total cost**

The median (IQR) total cost was 52,352 (39,998–68,592) CNY, 56,795 (43,883–72,871) CNY, 67,007 (51,748–83,606) CNY, and 62,224 (50,862–77,810) CNY in the low, medium, high, and very high hospital volume groups, respectively (Figure 1C). In the univariable analysis, the log total cost was 0.10 and 0.16 units higher in the high and

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**Figure 1** The number (%) of in-hospital deaths, average (95% CI) in-hospital mortality rate, median (IQR) total cost, and median (IQR) length of stay in the low, medium, high, and very high hospital volume groups and in the HHI categories, respectively. The number (%) of in-hospital deaths and average (95% CI) in-hospital mortality rate in the low, medium, high, and very high hospital volume groups (A) and in the HHI categories (B); median (IQR) total cost in the low, medium, high, and very high hospital volume groups (C) and in the HHI categories (D); median (IQR) length of stay in the low, medium, high, and very high hospital volume groups (E) and in the HHI categories (F). IQR, interquartile range; 95% CI, 95% confidence interval; HHI, Herfindahl-Hirschman index; CNY, Chinese Yuan. Values outside the whiskers are not shown in C, D, E, and F.
The median (IQR) length of stay was 20 (17−24) d in the HHI categories of >2,500, 1,500−2,500, and <1,500, respectively (Figure 1F). In the univariable analysis, no significant differences were found in the log length of stay when the <1,500 or 1,500−2,500 groups were compared to the >2,500 group (all P>0.05) (Table 2). After adjusting for the covariates (Table 4), the log length of stay was 0.024 units higher in the <1,500 HHI group than in the >2,500 HHI group (95% CI=0.001−0.047, P=0.041).

Discussion

Our study is among the first to investigate the associations of gastrectomy centralization with in-hospital deaths, total hospitalization expenses, and number of hospitalization days in a high surgical volume setting using a nationwide database. We found that after taking patient, hospital, and regional characteristics into account, higher annual hospital volumes of gastrectomy and HHI values were significantly associated with lower numbers of in-hospital deaths and hospitalization days without increasing hospitalization total cost.

A fair number of studies have investigated the associations of hospital volume and in-hospital deaths (18,20-24). Most studies found that a higher hospital volume was associated with a lower number of in-hospital deaths. However, these studies were conducted in relatively low-gastrectomy-volume countries and used volume cutoffs lower than 100. The current study used cutoffs of 84, 239, and 579 and resulted in the same conclusions. The associations remained significant after the adjustment of hospital levels and types, which could partially rule out the
Table 3 Multivariable analyses of association of gastrectomy annual hospital volume with quality of care indicators

| Variables                        | In-hospital mortality | Log (cost) | Log (los) |
|----------------------------------|------------------------|------------|----------|
|                                  | OR P 95% CI            | Coef. P 95% CI | Coef. P 95% CI |
| Hospital volume (cases per year) |                        |            |          |
| 1–83                             | 1                      | 1          | 1        |
| 84–238                           | 0.61 0.003 0.43, 0.84  | −0.01 0.686 −0.04, 0.03 | −0.01 0.540 −0.02, 0.01 |
| 239–579                          | 0.57 0.009 0.38, 0.87  | −0.02 0.636 −0.08, 0.05 | −0.036 0.039 −0.071, −0.002 |
| 580–1,193                        | 0.33 <0.001 0.18, 0.61 | 0.00 0.992 −0.08, 0.08 | −0.01 0.630 −0.07, 0.05 |
| Age                              | 0.91 0.006 0.85, 0.97  | −0.01 <0.001 −0.01, −0.01 | −0.01 <0.001 −0.01, −0.01 |
| Age squared                      | 1.00 <0.001 1.00, 1.00 | 0.0001 <0.001 0.0001, 0.0001 | 0.00 <0.001 0.00, 0.00 |
| Gender                           |                        |            |          |
| Male                             | 1                      | 1          | 1        |
| Female                           | 0.94 0.617 0.73, 1.20  | −0.02 <0.001 −0.02, −0.01 | 0.00 0.037 0.00, 0.01 |
| No. of comorbidities             |                        |            |          |
| 0                                |                        |            |          |
| 1                                | 1.71 <0.001 1.30, 2.24 | 0.05 <0.001 0.04, 0.05 | 0.05 <0.001 0.04, 0.06 |
| 2                                | 2.64 <0.001 1.94, 3.59 | 0.10 <0.001 0.09, 0.11 | 0.10 <0.001 0.09, 0.11 |
| ≥3                               | 3.38 <0.001 2.17, 5.25 | 0.16 <0.001 0.14, 0.17 | 0.14 <0.001 0.12, 0.16 |
| Adenocarcinoma type              |                        |            |          |
| Other adenocarcinoma#            | 1                      | 1          | 1        |
| Adenocarcinoma                   | 0.88 0.379 0.66, 1.17  | −0.00 0.283 −0.01, 0.00 | −0.00 0.245 −0.01, 0.00 |
| Surgery type                     |                        |            |          |
| Open gastrectomy                 | 1                      | 1          | 1        |
| Laparoscopic gastrectomy         | 1.07 0.752 0.72, 1.58  | 0.05 <0.001 0.04, 0.07 | −0.03 0.024 −0.05, −0.00 |
| Esophageal resection             |                        |            |          |
| No                               | 1                      | 1          | 1        |
| Yes                              | 1.91 0.016 1.13, 3.24  | 0.03 0.48  −0.06, 0.13 | 0.06 0.021 0.01, 0.11 |
| Spleen resection                 |                        |            |          |
| No                               | 1                      | 1          | 1        |
| Yes                              | 2.85 <0.001 1.78, 4.55 | 0.19 <0.001 0.17, 0.21 | 0.13 <0.001 0.11, 0.16 |
| Hospital type                    |                        |            |          |
| General hospital                 | 1                      | 1          | 1        |
| Cancer hospital                  | 0.98 0.922 0.60, 1.58  | 0.14 0.006 0.04, 0.24 | −0.05 0.137 −0.12, 0.02 |
| Other specialized hospitals#     | NE                     | 0.05 0.387 −0.07, 0.17 | 0.09 0.075 −0.01, 0.19 |
| Hospital level                   |                        |            |          |
| Tertiary                         | 1                      | 1          | 1        |
| Secondary                        | NE                     | −0.53 <0.001 −0.57, −0.50 | −0.02 0.134 −0.04, 0.01 |
| Hospital grade                   |                        |            |          |
| B                                | 1                      | 1          | 1        |
| Others                           | NE                     | 0.11 0.155 −0.04, 0.26 | 0.11 0.050 0.00, 0.22 |
| Ungraded                         | 1.08 0.853 0.48, 2.40  | 0.10 0.056 −0.00, 0.21 | 0.04 0.195 −0.02, 0.09 |

Table 3 (continued)
Table 3 (continued)

| Variables                          | In-hospital mortality | Log (cost)  | Log (los)  |
|------------------------------------|----------------------|-------------|------------|
|                                    | OR       | P  | 95% CI    | Coef. | P  | 95% CI   | Coef. | P  | 95% CI   |
| No. of certified assistant doctors per 10,000 | 1.01   | 0.255 | 0.99, 1.03 | 0.02 | 0.040 | 0.00, 0.04 | 0.01 | <0.001 | 0.01, 0.02 |
| Provincial GDP                     | 1.00   | <0.001 | 1.00, 1.00 | 1.10e-07 | 0.945 | -3.02e-06, 3.24e-06 | -7.76e-06 | <0.001 | -0.00001, -4.46e-06 |
| Provincial GDP squared             | 5.38e-11 | <0.001 | 2.88e-11, 7.88e-11 |

GDP, gross domestic product; OR, odds ratio; 95% CI, 95% confidence interval; los, length of stay; NE, not estimable. Including papillary adenocarcinoma, tubular adenocarcinoma, signet ring cell carcinoma, mucinous adenocarcinoma, hepatoid adenocarcinoma, adenosquamous carcinoma, squamous cell carcinoma, small cell carcinoma, undifferentiated carcinoma, malignant carcinoid, choriocarcinoma; including Traditional Chinese Medicine Hospitals, Integrated Traditional Chinese and Western Medicine Hospitals, Infectious Disease Hospitals, Rehabilitation Hospitals, Cardiovascular Diseases Hospitals, Mental Diseases Hospitals, Tuberculosis Hospitals, Thoracic Hospitals, Mongolian Hospitals, Township Health Centers, and other specialized hospitals that are not specified.

The associations of the HHI with in-hospital deaths, hospitalization days, and hospitalization costs for gastric cancer patients. One United States national study conducted in 1999 found that a greater hospital volume was associated with a decreased cost for gastric cancer surgery patients (28). Our study found that a higher hospital volume was associated with a higher total cost in the univariable analysis but not in the multivariable analysis. This suggested that the seemingly higher cost in the high-volume group could be explained by the patient, hospital, and regional characteristics adjusted in the model.

The associations of the HHI with in-hospital deaths, hospitalization days, and hospitalization costs for gastric cancer have been examined in very few studies. Our study revealed that the benefit of a high hospital volume remained in high-volume settings such as China.

Few studies have examined the association of hospital volume with length of hospital stay, and inconsistent results were obtained. Some have found that higher hospital volume was associated with a lower length of hospital stay (23,27), and others showed a non-significant association (26,27). In our study, the high volume group, but not the very high volume group, had a significantly lower length of stay than the low volume group. One potential explanation is that hospitals in the highest-volume group tend to admit more patients with factors associated with a longer hospital stay, such as poor health conditions. Although the current analysis adjusted for the number of comorbidities, the indicator was simply a crude measure of health conditions, and there may be residual confounding.

During the literature review, we found very few studies exploring the association between hospital volume and total hospitalization cost for gastric cancer patients. One United States national study conducted in 1999 found that a greater hospital volume was associated with a decreased cost for gastric cancer surgery patients (28). Our study found that a higher hospital volume was associated with a higher total cost in the univariable analysis but not in the multivariable analysis. This suggested that the seemingly higher cost in the high-volume group could be explained by the patient, hospital, and regional characteristics adjusted in the model.

The associations of the HHI with in-hospital deaths, hospitalization days, and hospitalization costs for gastric cancer have been examined in very few studies. Our study found that a decreased HHI, which indicates a decreased centralization or concentration of gastrectomy, was associated with a higher in-hospital mortality and prolonged hospital stay. Similar results were reported by Kitazawa et al., who found an upward trend in the HHI (increased concentration) was associated with a greater
| Variables                          | In-hospital mortality |              |              | Log (cost) |              |              | Log (los) |              |
|-----------------------------------|-----------------------|--------------|--------------|-----------|--------------|--------------|-----------|--------------|
|                                   | OR                    | P            | 95% CI       | Coef.     | P            | 95% CI       | Coef.     | P            | 95% CI       |
| HHI                               |                       |              |              |           |              |              |           |              |              |
| >2,500                            | 1                     | 1            |              |           | 1            |              |           |              |              |
| 1,500–2,500                       | 1.15                  | 0.399        | 0.83, 1.61   | -0.02     | 0.257        | -0.05, 0.01  | 0.00      | 0.895        | -0.02, 0.02  |
| <1,500                            | 1.52                  | 0.036        | 1.03, 2.26   | 0.02      | 0.410        | -0.02, 0.06  | 0.024     | 0.041        | 0.001, 0.047 |
| Age                               | 0.91                  | 0.004        | 0.85, 0.97   | -0.01     | <0.001       | -0.01, -0.08 | -0.01     | <0.001       | -0.01, -0.06 |
| Age squared                       | 1.00                  | <0.001       | 1.00, 1.18   | 0.0001    | <0.001       | 0.0001, 0.0001 | 0.0001   | <0.001       | 0.0000, 0.0001 |
| Gender                            |                       |              |              |           |              |              |           |              |              |
| Male                              | 1                     | 1            |              |           | 1            |              |           |              |              |
| Female                            | 0.94                  | 0.604        | 0.73, 1.22   | -0.02     | <0.001       | -0.02, -0.01 | 0.00      | 0.038        | 0.00, 0.01  |
| No. of comorbidities              |                       |              |              |           |              |              |           |              |              |
| 0                                 | 1                     | 1            |              |           | 1            |              |           |              |              |
| 1                                 | 1.73                  | <0.001       | 1.31, 2.27   | 0.05      | <0.001       | 0.04, 0.05   | 0.05      | <0.001       | 0.04, 0.06  |
| 2                                 | 2.68                  | <0.001       | 1.95, 3.67   | 0.10      | <0.001       | 0.09, 0.11   | 0.10      | <0.001       | 0.09, 0.11  |
| ≥3                                | 3.52                  | <0.001       | 2.24, 5.54   | 0.16      | <0.001       | 0.14, 0.17   | 0.14      | <0.001       | 0.12, 0.16  |
| Adenocarcinoma type               |                       |              |              |           |              |              |           |              |              |
| Other adenocarcinoma#             | 1                     | 1            |              |           | 1            |              |           |              |              |
| Adenocarcinoma                    | 0.89                  | 0.434        | 0.67, 1.19   | -0.00     | 0.279        | -0.01, 0.00  | -0.00     | 0.222        | -0.01, 0.00  |
| Surgery type                      |                       |              |              |           |              |              |           |              |              |
| Open gastrectomy                  | 1                     | 1            |              |           | 1            |              |           |              |              |
| Laparoscopic gastrectomy          | 1.03                  | 0.896        | 0.69, 1.52   | 0.05      | <0.001       | 0.04, 0.07   | -0.03     | 0.026        | -0.05, -0.00 |
| Esophageal resection              |                       |              |              |           |              |              |           |              |              |
| No                                | 1                     | 1            |              |           | 1            |              |           |              |              |
| Yes                               | 1.84                  | 0.028        | 1.07, 3.16   | 0.03      | 0.481        | -0.06, 0.13  | 0.06      | 0.020        | 0.01, 0.11  |
| Spleen resection                  |                       |              |              |           |              |              |           |              |              |
| No                                | 1                     | 1            |              |           | 1            |              |           |              |              |
| Yes                               | 2.87                  | <0.001       | 1.80, 4.57   | 0.19      | <0.001       | 0.17, 0.21   | 0.13      | <0.001       | 0.11, 0.16  |
| Hospital type                     |                       |              |              |           |              |              |           |              |              |
| General hospital                  | 1                     | 1            |              |           | 1            |              |           |              |              |
| Cancer hospital                   | 0.68                  | 0.100        | 0.43, 1.76   | 0.14      | 0.005        | 0.04, 0.24   | -0.06     | 0.074        | -0.13, 0.01  |
| Other specialized hospitals#      | NE                    | 0.06         | 0.327       | -0.06     | 0.17         | 0.10         | 0.058     | -0.00        | 0.19         |
| Hospital level                    |                       |              |              |           |              |              |           |              |              |
| Tertiary                          | 1                     | 1            |              |           | 1            |              |           |              |              |
| Secondary                         | NE                    | -0.55        | <0.001      | -0.58     | -0.51        | -0.03        | 0.022     | -0.05        | -0.00        |
| Hospital grade                    |                       |              |              |           |              |              |           |              |              |
| B                                 | 1                     | 1            |              |           | 1            |              |           |              |              |
| Others                            | NE                    | 0.11         | 0.137       | -0.04     | 0.26         | 0.11         | 0.041     | 0.01         | 0.22         |
| Ungraded                          | 1.16                  | 0.725        | 0.51, 2.67   | 0.10      | 0.060        | -0.00, 0.21  | 0.04      | 0.180        | -0.02, 0.10  |
| A                                 | 1.44                  | 0.188        | 0.84, 2.49   | 0.25      | <0.001       | 0.18, 0.31   | -0.02     | 0.198        | -0.06, 0.01  |
| No. of certified assistant doctors per 10,000 | 1.01 | 0.588 | 0.99, 1.24 | 0.02 | 0.045 | 0.00, 0.03 | 0.01 | 0.001 | 0.01, 0.02 |
including a lower major complication rate and 30-day volume was associated with better patient outcomes, previous studies have found that a higher surgeon volume is associated with better patient outcomes, and increased hospitalization costs. Advocating for the centralization of gastrectomy could improve patient outcomes and reduce in-hospital mortality.

The current study has some limitations. A number of factors at the patient, hospital, and regional levels were adjusted in the analysis. However, due to the issue of data availability, these variables are either crude estimates or proxies of what we wanted to measure. For instance, patient condition is undoubtedly associated with in-hospital mortality, cost, and length of stay. We used age and the number of comorbidities as measures of patient conditions. For cancer patients, the cancer stage is also an important indicator of disease severity, but this variable was not included in the analysis due to unavailability. However, as the current study only included gastrectomy patients, the corresponding cancer stages were expected to be stages II and III. It is also notable that variables at the surgeon level were not considered. One important variable at this level is the annual surgeon volume, defined as the total number of surgeries that a surgeon performs annually. For gastric cancer, previous studies have found that a higher surgeon volume was associated with better patient outcomes, including a lower major complication rate and 30-day mortality rate (31-33). However, the association of surgeon volume with patient outcomes became non-significant after accounting for hospital volume, suggesting that the impact of hospital volume is crucial compared with surgeon volume (22).

**Conclusions**

The current study found that the centralization of gastrectomy, measured by hospital volume and the HHI, was associated with decreased in-hospital mortality and shortened length of stay but not with increased total cost. These results have potential political implications in that centralization of gastrectomy could improve patient outcomes and decrease medical resource utilization without increasing hospitalization costs. Advocating for the centralization of gastrectomy is reasonable.

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**Footnote**

*Conflicts of Interest:* The authors have no conflicts of

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**Table 4 (continued)**

| Variables                                           | In-hospital mortality | Log (cost) | Log (los) |
|-----------------------------------------------------|-----------------------|------------|-----------|
|                                                     | OR        | P    | 95% CI | Coef. | P | 95% CI | Coef. | P | 95% CI |
| No. of certified assistant doctors per 10,000 squared | NI        | -0.0002 | 0.049 | -0.0004 | -0.0002 | -0.0001 | 0.01 | -0.0001 | 0.0001 |
| Provincial GDP squared                              | 1.00 | <0.001 | 1.00, 1.00 | 2.15e-07 | 0.896 | 3.02e-06, 3.45e-06 | -7.89e-06 | <0.001 | -0.00001, -4.44e-06 |
| Year                                                |          |       |       |       |       |       |       |       |       |
| 2013                                                | 1        |       |       |       |       |       |       |       |       |
| 2014                                                | 0.78     | 0.249 | 0.52, 1.19 | 0.10 | <0.001 | 0.08, 0.13 | 0.00 | 0.665 | -0.01, 0.02 |
| 2015                                                | 0.84     | 0.401 | 0.56, 1.26 | 0.15 | <0.001 | 0.12, 0.19 | -0.01 | 0.488 | -0.03, 0.01 |
| 2016                                                | 0.91     | 0.566 | 0.65, 1.27 | 0.21 | <0.001 | 0.16, 0.25 | -0.02 | 0.139 | -0.04, 0.01 |
| 2017                                                | 0.80     | 0.329 | 0.52, 1.25 | 0.23 | <0.001 | 0.17, 0.28 | -0.04 | 0.003 | -0.06, -0.01 |
| 2018                                                | 0.89     | 0.585 | 0.59, 1.34 | 0.23 | <0.001 | 0.15, 0.31 | -0.05 | 0.002 | -0.08, -0.02 |

HHI, Herfindahl-Hirschman index; GDP, gross domestic product; OR, odds ratio; 95% CI, 95% confidence interval; los, length of stay; NE, not estimable; NI, not included. including papillary adenocarcinoma, tubular adenocarcinoma, signet ring cell carcinoma, mucinous adenocarcinoma, hepatoid adenocarcinoma, adenosquamous carcinoma, squamous cell carcinoma, small cell carcinoma, undifferentiated carcinoma, malignant carcinoid, choriocarcinoma; including Traditional Chinese Medicine Hospitals, Integrated Traditional Chinese and Western Medicine Hospitals, Infectious Disease Hospitals, Rehabilitation Hospitals, Cardiovascular Diseases Hospitals, Mental Diseases Hospitals, Tuberculosis Hospitals, Thoracic Hospitals, Mongolian Hospitals, Township Health Centers, and other specialized hospitals that are not specified.
interest to declare.

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