Liver cancer mapping based on actual medical treatment choices

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ABSTRACT
The allocation of medical resources is usually inappropriate in China because it is mainly based on the population of each administrative area. In real life, individual patients make choices based on numerous other factors, such as the quality of medical service, the service capacity of certain hospitals and their own income level. This study aims to reveal the differences between theoretical medical resource allocation and the actual medical treatment choices of liver cancer patients in Shenzhen, China, based on case data from 2010 to 2012. Two categories with six group maps are used to illustrate this situation, including independent charts and analytical method-based thematic maps. Meaningful conclusions are then proposed to improve medical resource allocation.

1. Introduction
Liver cancer is one of the most common cancers in China, and it is responsible for substantial harm to the population. According to Chen, in China, liver cancer is the most commonly diagnosed cancer and the leading cause of cancer-related deaths in men before the age of 60 years; it is the second leading cause of cancer-related deaths for women between the ages of 30 and 44. The incidence rate in rural areas is 260.9/1000, which is higher than the rate in urban areas of 205.2/1000 (Chen et al., 2016); for detailed data, see Table 1. More than 50% of new liver cancer deaths worldwide occur in China. It is not clear what causes most cases of liver cancer. Based on recent studies, chronic infection with hepatitis B (HBV) or C (HCV) is the most common cause of liver cancer (Zuo, Zheng, Zeng, Zhang, & Chen, 2015). Excessive alcohol consumption and a family genetic history are also found in some cases. Therefore, liver cancer is a serious threat to human health and the development of society and the economy.

The southeastern coast of China has experienced accelerating development during the past 30 years. This has also become the area with the highest incidence of liver cancer in the world (Ren, Li, & Zhao, 2005). Shenzhen, a populous city and the most significant special economic zone in this area, has one of the highest incidences of liver cancer. To decrease the burden of liver cancer, adequate medical treatments are needed. Therefore, it is essential to explore the treatment of patients with liver cancer and the distribution of medical treatment in Shenzhen.

Medical resource allocation in healthcare is also known as PSRA (priority setting and resource allocation), and its key obstacle is finding a balance between ensuring sufficient patient volume and maintaining reasonable accessibility for all potential patients (Smith et al., 2016). Before the development of spatial analysis methods, traditional methods were primarily regional availability measures, which belong to classic statistical methods that essentially do not consider spatial variation (Luo, 2004). Spatial accessibility is the most common indicator of good medical resource allocation. The catchment areas calculated by this method are more optimal than administrative areas (Huotari, Antikainen, Keistinen, & Rusanen, 2017). The main aim of all efforts is to obtain relative equity in medical resource allocation based on utilitarian principles or egalitarian principles (Lane, Sarkies, Martin, & Haines, 2017). However, too many factors need to be considered to achieve ideal optimized resource allocation. As Escobedo concluded, the related factors can be divided into three categories: contextual access (i.e. area-based measures of poverty, education, racial/ethnic composition and acculturation) (McKernan et al., 2015), potential access (i.e. health insurance coverage, wait time and affordability of services) and spatial access (travel distance and neighborhood-level density of physicians) (Escobedo et al., 2017). In China, the real condition is more complex. Nearly 90% of medical services in China are provided by public hospitals, most of which are market- and profit-oriented, resulting in more unbalanced medical resource allocation (Pan, Zhao, Wang, & Shi, 2016).
This market-border effect is a more powerful factor in the creation of inequity than other border factors, such as administrative factors (McKernan et al., 2015). Therefore, strong measures should be taken to reduce the gap between regions and communities and to maximize the efficiency of medical resources.

Spatial accessibility, which can be divided into the categories of potential accessibility and actual accessibility, is one of the most reliable indicators of a balanced distribution of medical treatment (Pill, 1984; Song & Chen, 2009). Most studies of accessibility have focused on potential accessibility. Population and traffic costs are the two main factors taken into account in these studies (Higgs, 2004). However, more factors should be considered to reflect the actual supply and demand conditions of medical treatment. These include the quality of medical services (Akin, Guilkey, & Hazel Denton, 1995), the enabling resources of the residents (Han, 2010), the service capacity of certain hospitals, medical need as reflected by regional incidence (Andersen, 1974) and other factors. To reveal the actual conditions of medical treatment for liver cancer in Shenzhen, analytical methods and thematic mapping methods are applied to liver cancer case data from 2010 to 2012 in this paper.

The maps developed in this paper include independent charts and analytical method-based thematic maps. The charts show statistics to reflect the relationships between liver cancer and other data, such as gender, age, hospital stay length and costs. The theoretical and actual conditions of medical treatment allocation are represented as thematic maps using classical spatial accessibility and customer-defined methods, respectively. By comparing these maps, some inequities can be identified that could be addressed to improve spatial accessibility. Furthermore, the actual conditions of medical treatment for liver cancer are revealed to guide the future allocation of medical resources.

This paper is organized as follows. First, the experimental materials and detailed processing flow of this work are introduced. Second, independent charts are drawn based on liver cancer case data to reflect the relationships between the data attributes. Third, a detailed description of the mapping methods is presented. Finally, the conclusions are presented.

### 2. Materials

#### 2.1. Study area

Shenzhen is located in southeastern China (113°46′–114°37′E, 22°27′–22°52′S) and covers an area of 1996.85 km². Situated immediately north of the Hong Kong Special Administrative Region, this area became the first and one of the most successful Special Economic Zones (SEZ) in China (Fish, 2010). According to a government report published in 2014, Shenzhen has a population of 10,628,900 (Government of Shenzhen, 2014).

#### 2.2. Data sources

The experimental data used in this paper consist of thematic and spatial data. The thematic data include population, hospital and liver cancer case data from Shenzhen city collected between 2010 and 2012. The spatial data consist of traffic network and administrative divisions. The divisions have two levels, including 10 administrative divisions in the first level and sub-districts in the second level that belong to each administrative division. The area of each administrative division is 200 km², with an average population of one million.

The WGS-1984 and Gauss-Kruger projections are employed on a scale of 1:30,000. The study area is divided into irregular grids based on the residential quarters used in the national census.

Hospital and liver cancer case data were obtained from the Statistical Yearbooks of Shenzhen from 2010 to 2012. Population data were obtained from the 6th national census of Shenzhen in 2010 (www.sztj.gov.cn). Shenzhen city administrative division and traffic network data were obtained from the Shenzhen digital space information network (http://www.szgeoinfo.com). There are 115 hospitals in Shenzhen, and 64 of them provide cancer treatment service. These data were obtained from the ‘Statistical communiqué on national economic and social development of Shenzhen in 2012’ (http://www.sztj.gov.cn).

### Table 1. Estimated liver cancer data in China (thousands), 2015.

| Category                              | Total Male | Female | Total Male | Female |
|---------------------------------------|------------|--------|------------|--------|
| Liver cancer cases and deaths         |            |        |            |        |
| Incidence                             |            |        |            |        |
| Age-standardized incidence rates by area |            |        |            |        |
| Urban Areas                           | 343.7      | 122.3  | 292.1      | 111.5  |
| Rural Areas                           | 310.6      | 111.5  |            |        |
| Age-standardized mortality rates by area |            |        |            |        |
| Urban areas                           | 156.8      | 48.4   | 260.9      | 73.9   |
| Rural areas                           | 187.0      | 73.9   |            |        |
| New cancer cases and deaths by age group |          |        |            |        |
| Incidence                             |            |        |            |        |
| Age group                              |            |        |            |        |
| <30                                   | 4.4        | No data| 3.5        | 0.7    |
| 30–44                                 | 41.3       | No data| 32.5       | 5.8    |
| 45–59                                 | 130.4      | No data| 111.9      | 26.9   |
| 60–74                                 | 116.1      | No data| 106.4      | 44.8   |
| ≥75                                   | 51.6       | No data| 56.3       | 33.2   |
| All                                   | 343.7      | No data| 310.6      | 111.5  |
3. Map design

The Main Map consists of two parts, including independent charts placed on the right and thematic maps placed on the left.

The independent charts, mainly created using Excel, reflect statistical information about liver cancer cases and hospitals that provide medical treatment. The former includes the following charts: case ratio for males and females, case ratio for different age stages, length of stay and medical expenses for different age categories and medical expenses by gender. The latter includes the following charts: number of hospitals and cases in each hospital level, length of stay and medical expenses for different hospital levels, number of hospitals and hospital level compositions in each district and the relationship between the number of beds and cases of each hospital.

Thematic maps comprising four maps were designed based on spatial analysis methods and reflect the theoretical and actual trends of medical services provided by liver cancer hospitals. An OD matrix of network analysis (the impedance is traffic distance) was used to determine the best hospital for each grid of residents and to help show the theoretical trends in provided medical services. For the rose diagram map, each petal indicates the number of liver cancer cases received by a given hospital, and this method indicates the actual trends in medical treatment. The two-step floating catchment area (2SFCA) method was employed to explore the spatial conditions of medical resource allocation from a supply-and-demand perspective. A comparison map was generated using an algebraic calculation to describe the differences between the hospital’s distribution and liver cancer cases and then reflect the unreasonable allocation of medical services for liver cancer patients.

4. Independent charts

4.1. Cancer case charts

The liver cancer case data contain a set of fields that includes patient case number, gender, age, length of stay and costs. According to the data, four stand-alone charts can be produced, as shown in the right part of the Main Map.

In total, 3239 liver cancer cases occurred in Shenzhen from 2010 to 2012. This included 2536 male patients (78%) and 703 female patients (22%). According to the Chinese Standard of Ages, liver cancer cases can be divided into five chronological stages: childhood (0–6 years old), junior (7–17 years old), youth (18–40 years old), middle-aged (41–65 years old) and elderly (older than 66 years old). These five stages featured totals of 6, 6, 592, 1779 and 856 cases, respectively. According to the results, liver cancer is more prevalent in males than in females. The middle-aged group is the most vulnerable and accounts for up to 55% of all cases.

On average, male patients spend more on medical expenses than female patients. The average medical expense for each patient is 23,928 Chinese Yuan.

The data show that the length of stay in the hospital and the medical expenses are positively related to patient age (as represented by the stage of life) and that the average length of stay is positively correlated with average medical expense. These results agree with our experience.

4.2. Hospital data charts

The hospital data include the hospital name, administrative division, hospital level, number of beds and number of liver cancer patients by gender. Accordingly, four stand-alone charts were produced, as shown in the right part of the Main Map. According to the 1989 Measures for the Administration of Hospital Grades, Chinese hospitals are divided into three levels. A first-level hospital is a basic-level hospital or primary health care institution. A second-level hospital is a technology center for regional medical prevention and provides medical treatment for several communities. A third-level hospital provides medical treatment for entire regions, provinces, cities and even the whole country. The higher-level hospitals provide more services and cover a greater area and population.

As Table 2 shows, 64 hospitals provided medical treatment to liver cancer patients from 2010 to 2012 in Shenzhen. Specifically, 243 patients received medical treatment from 8 third-level hospitals, 744 patients received medical treatment from 21 second-level hospitals, and 2252 patients received medical treatment from 35 first-level hospitals. Therefore, a relatively small number of higher-level hospitals actually treat the majority of the patients. It was also found that more patients prefer medical treatments from higher-level hospitals, even though there are relatively few of these hospitals. The hospital level is one of the most important factors patients consider when they are choosing a hospital.

The average length of stay and medical expenses are positively related to the hospital level. This may occur because the serious conditions of these patients require better and more intensive care, for which higher-level hospitals charge a premium.

| Hospital level | Number of hospitals | Ratio (%) | Number of patients | Ratio (%) |
|---------------|---------------------|-----------|--------------------|-----------|
| 1st level     | 35                  | 55        | 243                | 7         |
| 2nd level     | 21                  | 33        | 744                | 23        |
| 3rd level     | 6                   | 12        | 2252               | 70        |
| Total         | 64                  | 100       | 3239               | 100       |
Among the 10 districts of Shenzhen city, Longgang District has the most hospitals (17) and Futian District has the second most (11). However, Futian District has the most third-level hospitals (4 of a total of 8). Longgang, Bao’an, Nanshan and Luohu District each have one hospital.

The economic conditions of each district are listed in Table 3 according to 2014 Shenzhen GDP data. The results show that districts with higher GDP have more high-level hospitals.

The number of hospital beds is positively correlated with the number of cases treated. It follows that hospitals with more beds can provide more medical treatments.

5. Thematic maps

The thematic maps are divided into four categories: the theoretical trend of provided medical treatments, actual trend of provided medical treatments, theoretical spatial accessibility of medical treatments and rationality of the distribution of medical treatment. All maps were produced based on hospital and liver cancer case data from 2010 to 2012, calculated using grids and sub-district units.

As the first map in the Main Map shows, the theoretical trend of provided medical treatment contains both the radiation range map and the map of the service scope of each hospital. The maps were produced based on all residents in each grid unit, the traffic network and the 64 hospitals of Shenzhen city regardless of hospital level. The two maps use the OD matrix of network analysis (the impedance is traffic distance) to determine the best hospital for each grid. The origins are the geometric center of grids, and the destinations are hospitals. One origin matches only one destination based on the shortest traffic distance between the origins and destinations. Theoretically, if transport distance is the only basis by which patients choose hospitals, the radiation range represents a state of aggregation centered on each hospital, and the service scope of each hospital is a complete continuous region. The hospital has a small service scope if it is in an area with a dense hospital distribution. Otherwise, the service scope is larger. In this scenario, every resident chooses the nearest hospital.

The second map in the Main Map shows the actual trend of the medical treatments of the hospitals. The map was produced based on hospital and liver cancer case data from 2010 to 2012.

As Table 4 shows, eight hospitals accounted for 2488 (76.89%) of the 3236 cases. The other 56 hospitals received 748 cases, or 23.11% of the total. Additionally, five of the eight busiest hospitals were third-level hospitals, further indicating that hospital level was the most important factor considered by liver cancer patients.

The rose diagram map indicates the actual trend of medical treatment. Each rose diagram has eight petals. The radius of each petal indicates the number of liver cancer cases received by a given hospital. Every hospital is identified by a different color. Green represents hospitals that received fewer cases, and red represents hospitals that received more cases.

The third map in the Main Map shows the spatial accessibility of the medical treatments. It was produced on the basis of all 64 hospitals, the traffic network and all residents calculated by grid units. The 2SFCA method (Luo & Wang, 2003; Radke & Mu, 2000) was employed to explore the spatial conditions of medical resource allocation from a supply-and-demand perspective. This method is based on indexes of population, traffic distance and the number of hospital beds. Green represents higher spatial accessibility values, and red represents lower spatial accessibility values. Areas with higher values are mainly concentrated in Luohu District, Futian District, Nanshan District and the Nan’ao sub-district of Longgang District. The central city area has a higher spatial accessibility value, whereas the value in the urban fringe area is lower. This may simply mean that more hospitals are located in the center area of the city. Additionally, the value is higher in Nan’ao because the population is small.

The fourth map in the Main Map contains maps representing the kernel density of hospitals, the incidence of liver cancer and the comparison between hospital distribution and liver cancer incidence. On the map of the incidence of liver cancer in Shenzhen, the lighter hue represents lower incidence, and the darker

Table 3. GDP of each district of Shenzhen in 2014.

| Rank | District     | GDP (billion CNY) | Area (km²) |
|------|--------------|-------------------|------------|
| 1    | Nanshan      | 3464.09           | 185.49     |
| 2    | Futian       | 2958.85           | 78.66      |
| 3    | Bao’an       | 2380              | 398.38     |
| 4    | Longgang     | 2338              | 387.82     |
| 5    | Luohu        | 1625.34           | 78.76      |
| 6    | Longhua      | 1400              | 175.58     |
| 7    | Guangming    | 632.77            | 155.45     |
| 8    | Yantian      | 446               | 74.64      |
| 9    | Pinghu       | 405               | 167.01     |
| 10   | Dapeng       | 260               | 295.06     |

Table 4. Number of liver cancer cases among the 64 hospitals.

| Hospital                                      | Level | Case count | Ratio (%) |
|-----------------------------------------------|-------|------------|-----------|
| Longgang District Central Hospital of Shenzhen| 2     | 129        | 76.89     |
| The People’s Hospital of Bao’an Shenzhen      | 2     | 147        | 47.70     |
| Shenzhen Nanshan Hospital                     | 2     | 227        | 70.55     |
| Shenzhen Second People’s Hospital             | 3     | 240        | 80.55     |
| Shenzhen Third People’s Hospital              | 3     | 291        | 90.91     |
| Shenzhen Traditional Chinese Medicine Hospital| 3     | 314        | 97.27     |
| Peking University Shenzhen Hospital           | 3     | 340        | 105.92    |
| Shenzhen People’s Hospital                    | 3     | 800        | 252.00    |
| Other hospitals                               | –     | 748        | 23.11     |
hue represents higher incidence. We can see that areas with higher incidence are mainly concentrated in Luohu District, Futian District and the sub-districts of Shiyan, Yuehai, Pingdi and Nanao.

The map of the kernel density of hospital distribution uses the method of kernel density analysis in ArcGIS, no hospital weight setting, a cell size of 220 and a search radius of 8000 meters. On this map, red represents a higher kernel density value and blue represents a lower value. The hospital level is identified by symbols of different sizes and colors. Larger red symbols represent third-level hospitals, while smaller symbols represent the other hospitals. In this map, the areas with higher kernel density values are mainly concentrated in Futian District, part of Luohu District and Nanshan District. Six third-level hospitals are in areas with high kernel density values. The kernel density value is very low in Yantian District, Pingshan New District and Dapeng New District, where fewer hospitals are located.

The map of the comparison between hospital distribution and liver cancer incidence is produced by comparing the first two maps using an algebraic calculation:

\[ C_j = K_j - I_j; \]  (1)

where \( K_j \) is the kernel density of hospital distribution, \( I_j \) is the incidence of liver cancer and \( C_j \) is the comparison value.

\[ I_j = \frac{m_j}{n_j} \times k; \]  (2)

where \( m \) is the number of cases, \( n \) is the total population, and \( k = 100\% \).

Both values in the first two maps were normalized using the following normalization formula:

\[ y = \frac{(x_{\text{max}} - x_{\text{min}})}{(x_{\text{max}} + x_{\text{min}})} . \]  (3)

In this map, a gray color represents relatively reasonable medical resource allocation (medium difference values), blue represents surplus medical resources and red represents areas with insufficient medical resources that the government should address. Our results show that medical resource allocation in Shenzhen is uneven, with very clear spatial differentiation. For example, the incidence of liver cancer is highest in Donghu sub-district, but there is no hospital capable of liver cancer treatment in this area. Therefore, the medical resources allocated to Donghu sub-district are insufficient.

6. Conclusions

In this paper, thematic maps and independent charts are produced to depict the treatment conditions for liver cancer patients and their medical treatment choices in Shenzhen city, Guangdong province.

Based on a comparison of the theoretical and actual trends of medical treatments performed for liver cancer patients, transportation costs and hospital level are the two most important factors driving the treatment choices of liver cancer patients. High-quality medical resources are concentrated in the city center, and 75% of liver cancer patients compete for these resources. This exacerbates urban problems, such as traffic jams and insufficient transportation resources.

The real supply and demand conditions of medical resources for liver cancer treatment are represented by the analysis of the spatial accessibility of medical treatment and the rationality of the medical resource allocation. Hospitals are mainly concentrated in Futian District, part of Luohu District and Nanshan District, whereas areas with high liver cancer incidence are mainly concentrated in Luohu District, Futian District and the Shiyan, Yuehai, Pingdi and Nan’ao sub-districts. There are surplus medical resources in the central city, including Futian District and Luohu District. Conversely, there are inadequate treatment resources in Yantian District, Dapeng District and part of Pingshan District and severely insufficient resources in Donghu and Nan’ao sub-districts. Therefore, the medical resources for liver cancer treatment are highly concentrated in the city center and scarce in the urban fringe. This suboptimal allocation of medical resources may result in social problems, such as higher medical expenses per capita (Feng, 2006), low medical resource utilization (Luo, 2002) and increasingly expensive and difficult-to-obtain medical treatment (Liu, 2000).

Based on the independent charts, maps and analysis above, government departments should address the important tasks of controlling the incidence of liver cancer and optimizing the allocation of medical resources. They should consider the following recommendations in particular:

1. Male and middle-aged groups should receive high-priority attention. These groups have the highest incidence rates of liver cancer.
2. Increase the construction of basic-level hospitals in urban fringe areas to alleviate the problem of concentrating high-quality medical services in the central area of the city. Reduce the waste of medical resources and increase the medical resource utilization rate.
3. Perfect hospital hierarchy, clarify the medical responsibility of each level of medical institution and guide residents to develop ‘basic to high’ medical treatment behavior. Correct the problem whereby patients become concentrated in high-level hospitals and reduce additional expenditures incurred by patients who see doctors beyond their local regions.
(4) Rationally allocate medical resources. More medical resources should be assigned to high liver cancer incidence areas, such as Nan’ao sub-district and Donghu sub-district.

(5) Liver cancer prevention and information are needed. The government should guide residents to develop healthy living habits and inform them about disease prevention.

**Software**

Microsoft Office 2013: Excel was used for basic data processing and the basic statistical charts. ESRI ArcGIS 10.0 was used for spatial analysis, statistical analysis, and mapping of all spatial datasets. CorelDraw X5 and Photoshop were used for map finishing.

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