Congenital Heart Disease

Tech Science Press

DOI: 10.32604/chd.2024.057403

ARTICLE

# Temporal and Regional Differences in Congenital Heart Surgery in China (2017–2022): Trends and Implications

**Zheng Guo[1], Li Xie[2], Ju Zhao[3], Xing Hao[3], Xiaotong Hou[3] and Wei Wang[1,*]**

[1]Department of Pediatric Thoracic and Cardiovascular Surgery, Shanghai Children's Medical Center, Shanghai Jiaotong University School of Medicine, Shanghai, 200127, China

[2]Clinical Research Center, Shanghai Jiao Tong University School of Medicine, Shanghai, 200030, China

[3]Department of Extracorporeal Circulation, Center for Cardiac Intensive Care, Beijing Anzhen Hospital, Capital Medical University, Beijing, 100029, China

[*]Corresponding Author: Wei Wang. Email: wangwei@scmc.com.cn

Received: 16 August 2024 Accepted: 01 October 2024 Published: 31 October 2024

## ABSTRACT

**Background:** With the decline of birth population and the development of medical technology in China, studies assessing how these changes have affected the adoption of congenital heart disease surgery at the national or regional scale are lacking. **Methods:** We investigated the status of congenital heart surgery in China in the period from 2017–2022, through investigation of the total rates of cardiac surgeries, cardiopulmonary bypass (CPB), adult congenital heart surgeries (CHS), and pediatric CHS (<18 years old), as recorded by the Extracorporeal Circulation Branch of the Chinese Society of Biomedical Engineering. Subsequently, we evaluated correlations between these factors with economic, demographic, and other factors. **Results:** From 2017 to 2022, the total number of cardiac operations increased from 230,772 to 263,292, representing an increase of 14.09% over 6 years; the CHS dropped from 76,365 to 68,940 (10.19% decrease), and the proportion of CHS in the total cardiac surgeries dropped from 33.26% to 26.18% (7.08% decrease). Finally, cases of pediatric CHS decreased from 61,825 to 38,174 (38.25% decrease). The annual percentage change (APC) of the total amount of pediatric CHS cases was −10.03 (−15.95 to −3.69, $p = 0.013$). Adult CHS increased from 14,940 to 30,766 (105.93% increase). The proportion of adult CHS cases of the total number of cardiac surgeries increased from 6.47% to 11.68% (5.21% increase). From a regional perspective, the APC for the proportion of pediatric CHS in the local population was generally lower in western China. The proportion of CHS in the local population generally decreases from the north to the south, although the lowest incidence is found in the northeast region. **Conclusions:** Due to demographic changes, medical technology and economic factors, the number of surgical operations for congenital heart disease (CHD) in children decreased significantly from 2017 to 2022, and may decline further in the future. Nevertheless, in the same period, a significant increase in the number of operations for CHD in adults was observed, which brings new opportunities and challenges to the development of congenital cardiac surgery and cardiac critical care.

## KEYWORDS

Congenital heart surgery; cardiac surgery; epidemiology

**Nomenclature**

| | |
|---|---|
| CHS | Congenital heart surgeries |
| CPB | Cardiopulmonary bypass |
| APC | Annual percentage change |

## 1 Introduction

The birth rate in China decreased from 12.64% in 2017 to 6.77% in 2022 (https://data.stats.gov.cn/) (accessed on 30 September 2024). This drastic change in population demographics has inevitably had an important impact on the incidence, diagnosis, and treatment of congenital malformation-related diseases. In addition, the extensive development of modern prenatal screening and catheterization techniques, has also had a profound impact on congenital heart surgeries (CHS) [1,2]. Nevertheless, studies assessing how these changes in demography and technology have affected the adoption of CHS at the national or regional scale are lacking. Therefore, the present study aimed to investigate the status of cardiac and congenital heart surgeries in various regions of China from 2017 to 2022, using data from the Extracorporeal Branch of the Chinese Society of Biological Engineering, which has long collected data on cardiac surgery from hospitals at all levels [3]. We characterized the development track of CHS at this stage in China, and prospectively investigated the possible development direction of CHS.

## 2 Methods

### *2.1 Study Sites*

From 2017 to 2022, 693–728 hospitals that perform heart surgery in China were selected as the study sites, respectively. The hospitals included are tertiary hospitals, including some secondary hospitals that perform heart surgery in various regions of the country.

### *2.2 Data and Calculations*

We analyzed the trends in CHS based on the annual rates of cardiac surgeries, cardiopulmonary bypass (CPB), adult CHS, and pediatric CHS, as recorded by the Extracorporeal Circulation Branch of the Chinese Biomedical Engineering Society for 2017–2022. The data was subsequently compared between the seven representative regions of China: North China (Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia), Northeast (Heilongjiang, Jilin, Liaoning), Northwest (Xinjiang, Qinghai, Gansu, Ningxia, Shaanxi), East China (Shandong, Jiangsu, Anhui, Zhejiang, Jiangxi, Fujian, Shanghai), South China (Guangdong, Guangxi, Hainan, Hong Kong), Southwest (Sichuan, Chongqing, Yunnan, Guizhou, Xizang), and Central China (Hunan, Hubei, Henan). The data for this study comes from a survey questionnaire provided by hospitals at all levels across the country and does not involve the ethical statement and approved body institution.

The proportions of Extracorporeal Circulation (%) were calculated as the number of CPB surgeries divided by the total number of cardiac surgeries, the congenital heart disease (CHD) surgery (%) as the number of CHS procedures divided by the total number of cardiac surgeries, and the Child CHD surgery (%, patients <18 years) as the number of pediatric CHS procedures divided by the total number of cardiac surgeries.

### *2.3 Statistical Analysis*

In the descriptive analysis, we assessed the number of CHS and their corresponding proportions from 2017 to 2022. Joinpoint regression analysis (Joinpoint Regression Program, version 5.2.0; National Cancer Institute, Bethesda, MD, USA) was further performed to examine temporal trends in CHS. Separate analyses were conducted based on region and age group. Based on the national population statistics from 2017 to 2022 (https://population.gotohui.com/) (accessed on 30 September 2024), the

proportion of CHS relative to the total population in each region, as well as the proportion of surgeries among children aged under 18 years, were plotted in heatmaps. Descriptive graphs were generated using GraphPad Prism software (version 10.1.0; GraphPad Software, San Diego, CA, USA). A two-sided $p < 0.05$ was considered statistically significant.

## 3 Results

### *3.1 Total Number of Cardiac Surgeries in China*

#### *3.1.1 Total Number of Cardiac Surgeries*

From 2017 to 2022, the number of cardiac operations in China gradually increased, although this trend was affected by the COVID-19 pandemic (Fig. 1). In total, there were 263,292 cases in 2022 compared with 230,772 in 2017, representing an increase of 14.09% over 6 years.

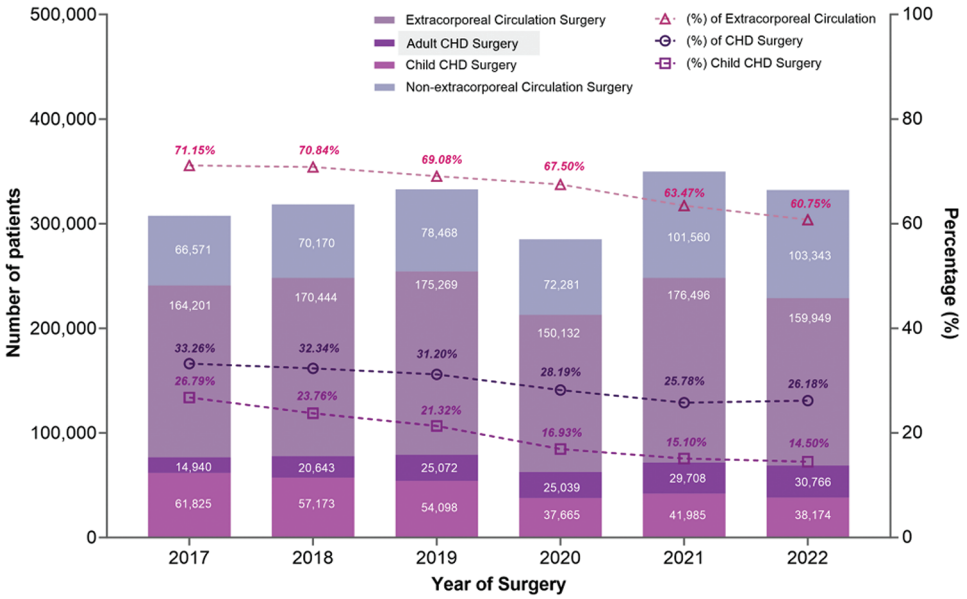



**Figure 1:** Total number of CHS in China from 2017 to 2022, by age and type of surgery

#### *3.1.2 Total Number of CPB Surgeries*

The total number of CPB operations in 2017 and 2022 was 164,201 and 159,949, respectively, representing a 2.59% decrease. However, there were 176,496 surgeries in 2021, representing an increase of 7.49% compared to 2017, owing to the greater impact of the COVID-19 pandemic in 2022. Overall, the trend in CPB surgeries was almost uniform, with only a slight upward trend. However, the proportion of total CPB surgeries from the total number of cardiac surgeries decreased annually, from 71.15% in 2017 to 60.75% in 2022 (Fig. 1).

#### *3.1.3 Total Number of CHS*

The number of CHS procedures decreased from 76,365 in 2017 to 68,940 in 2022, representing a decrease of 10.19%, with an average annual decline of 1.7%. The annual percentage change (APC) was –2.86 (–7.83 to 2.37, $p = 0.199$) (Figs. 1 and 2). The proportion of CHS in total cardiac surgeries decreased from 33.26% to 26.18% (7.08% decrease).

### 3.1.4 Total Number of Pediatric CHS

The number of pediatric CHS dropped from 61,825 in 2017 to 38,174 in 2022, representing a decrease of 38.25%, with an average annual decrease of 6.38%. The proportion of pediatric CHS in CHS decreased from 80.54% in 2017 to 55.37% in 2022, representing an annual decrease of 4.20%, with an APC of –10.03 (–15.95 to 3.69) ($p = 0.013$). This downward trend was more obvious than the annual decline in the number of operations for CHD ($p < 0.001$) (Figs. 1 and 2).

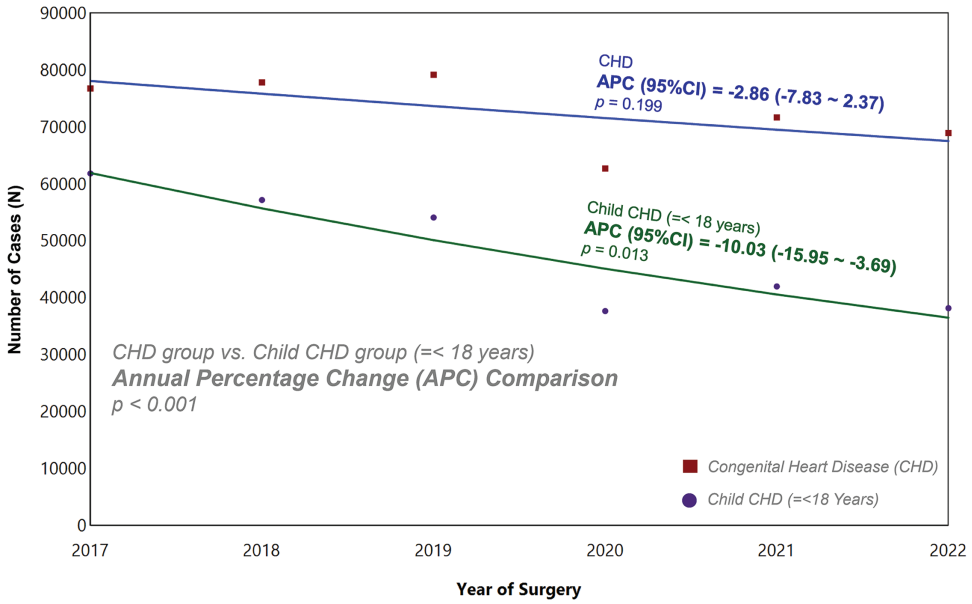



**Figure 2:** The temporal trends in CHD surgeries and pediatrics CHD surgeries in China from 2017–2022 (APC = annual percentage change; CHD = congenital heart disease)

### 3.1.5 Total Number of Adult CHS

The number of adult CHS cases increased from 14,940 in 2017 to 30,766 in 2022, representing an increase of 105.93%, with an average annual increase of 17.66%. The proportion of adult CHS in CHS also increased from 19.46% in 2017 to 44.63% in 2022, representing an increase of 25.17%.

## 3.2 Comparative Analysis of Surgery Rates across Different Regions

### 3.2.1 Total Number of CHS Procedures in Different Regions

Between 2017 and 2022, the total number of CHS performed varied in each region (Fig. 3), showing decreases of 35.86%, 18.19%, and 8.16% in North, South, and East China, respectively, and increases of 7.78% and 3.39% in Northwest and Southwest China, respectively. Central and Northeast China showed comparable rates of between –1% and –3%.

### 3.2.2 Proportions of CHS in Cardiac Surgeries in Different Regions

Between 2017 and 2022, the proportion of CHS in cardiac surgeries declined in all seven regions (Fig. 3). South China, North China, Central China, Southwest China, and East China showed declines of 10.63%, 9.42%, 8.22%, 7.38% and 6.73%, respectively. Conversely, Northeast and Northwest China decreased less, by 2.06% and 0.69%, respectively.

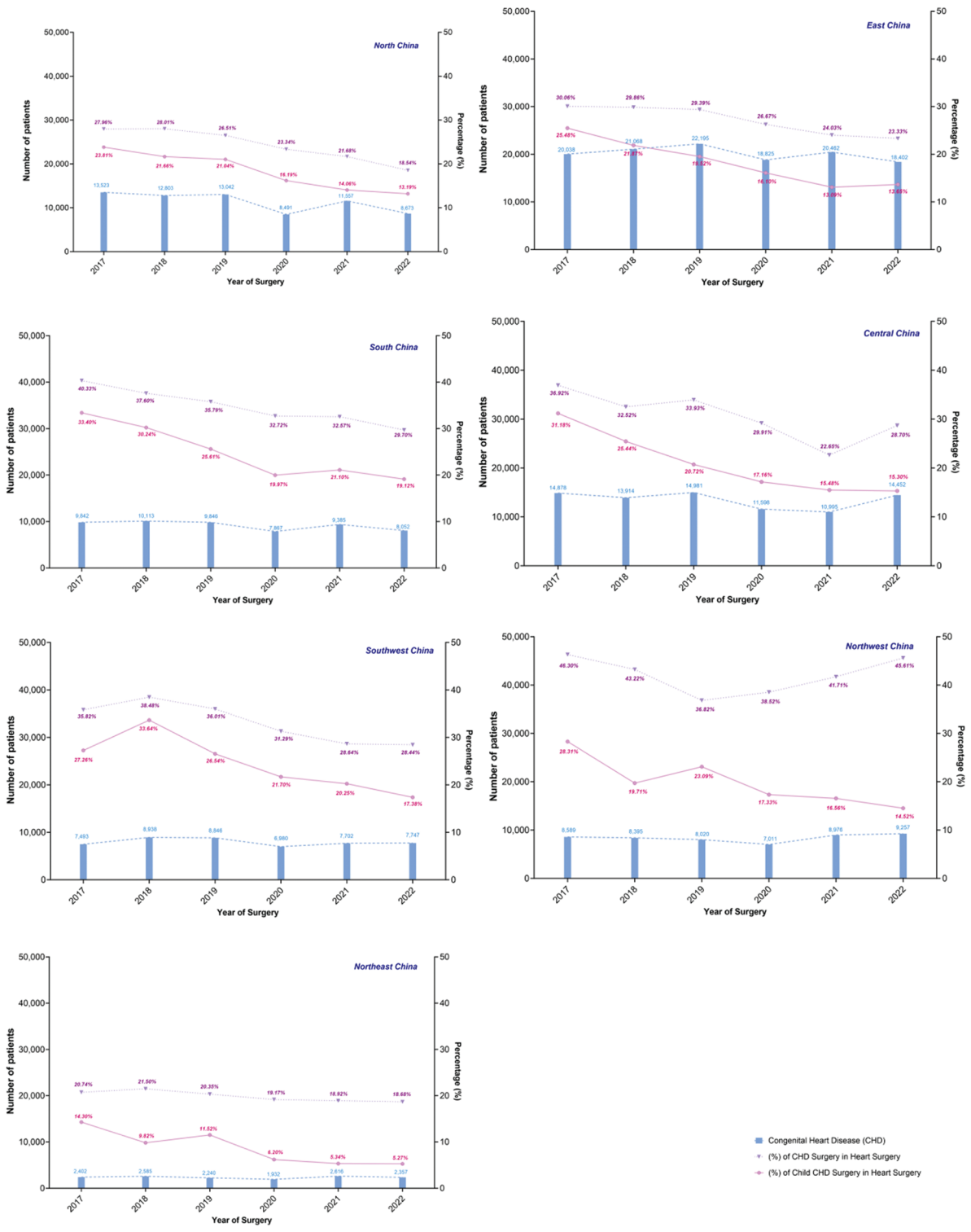



**Figure 3:** Regional differences in congenital heart disease surgeries in China (2017–2022)

*3.2.3 Proportions of Pediatric CHS in Cardiac Surgeries in Regions*

Between 2017 and 2022, the proportion of pediatric CHS cases declined significantly in all seven regions. Central, South and Northwest China decreased by 15.88%, 14.28% and 13.79%, respectively. While the Southwest and Northeast China declined more slightly, falling by 9.88% and 9.03%, respectively. The other two regions declined by 10%–12%.

*3.2.4 Proportions of Adult CHS in Cardiac Surgeries in Regions*

Between 2017 and 2022, the proportion of adult CHS in cardiac surgeries increased in all seven regions. Northwest China rose the most, from 17.99% to 30.09%, an increase of 12.1%. North, Southwest, and South China showed relatively small increases of 1.1%, 3.50%, and 3.65%, respectively. The other two regions showed increases of 5%–8%.

### *3.3 CHS Rates in Regions*

The proportion of CHS per 1000 individuals was highest in Northwest China, and lowest in Northeast China (Fig. 4). Excluding Northeast China, the ratio decreased from north to south; however, the ratio was lowest for both adults and children in Northeast China.

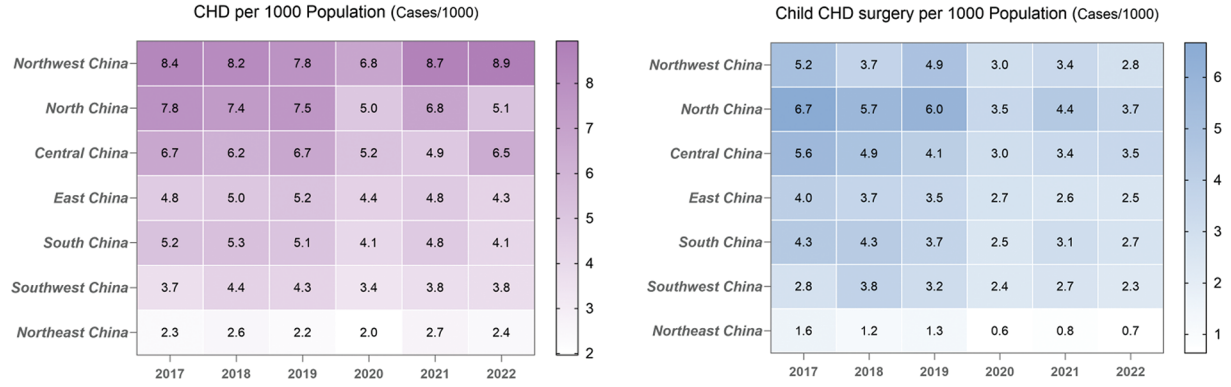



**Figure 4:** Temporal and regional differences in CHS per 1000 individuals in China (2017–2022)

Overall, the trends in APC (Fig. 5A) revealed that the proportion of CHS showed some differentiation among the local populations. Indeed, the downward trend was more obvious in North and South China, where the APCs were –7.54 ($p$ = 0.035) and –4.79 ($p$ = 0.083), respectively. There were no significant differences in the trends of the other five regions.

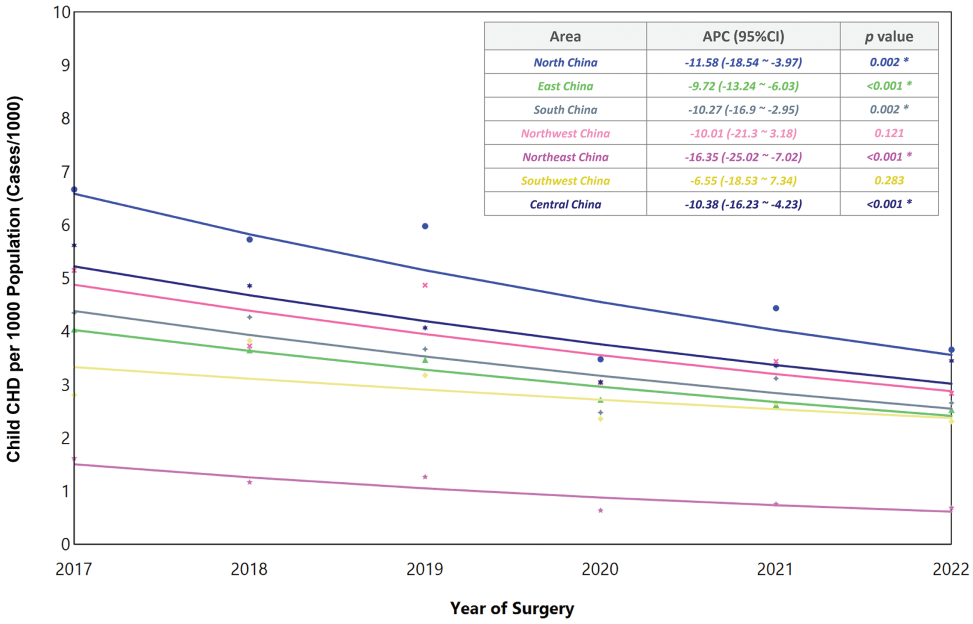
The proportion of pediatric CHS decreased in most areas ($p < 0.01$, Fig. 5B); however, there was no statistical difference in the APCs in Northwest and Southwest China.

## 4 Discussion

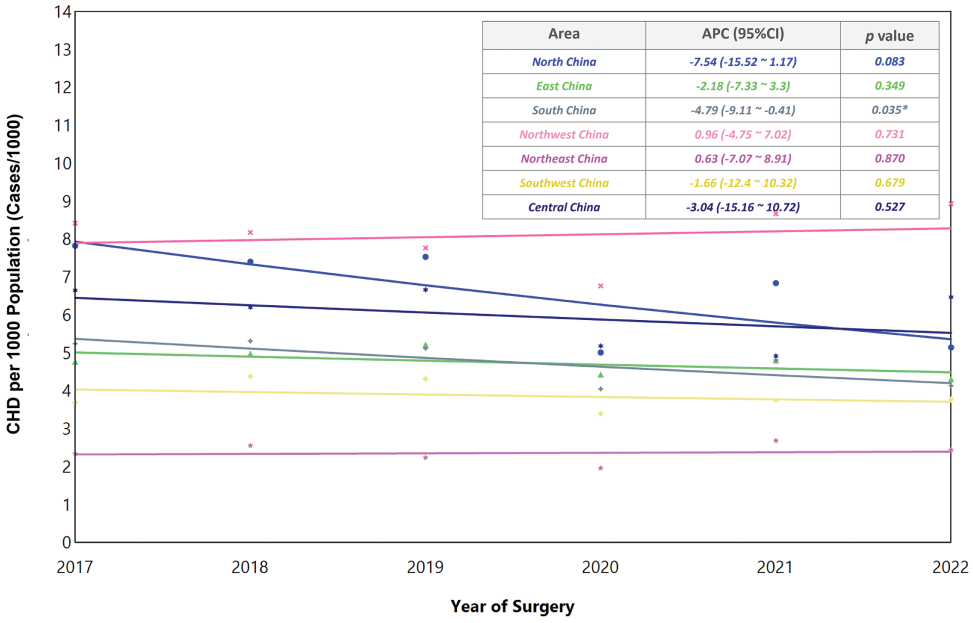
During the study period, the number of births in China declined from 17.23 million in 2017 to 9.56 million in 2022 (https://data.stats.gov.cn/), representing a total decline of 44.52%, with an annual decline of 7.42%. This change in birth status affects the trends in the diagnosis and treatment of pediatric congenital diseases. Based on data from 2017 to 2022, this study reviewed the development track of CHS in China at this stage, provided speculation regarding the possible developmental direction of CHS, and provided a reference for the formulation of corresponding policies.

From 2017 to 2022, both the total number of pediatric CHS and the proportion of pediatric CHS among all cardiac surgeries decreased significantly, in a manner directly related to the sharp decline in the national birth rate, as well as the increasing popularity of fetal heart ultrasound screenings under the national eugenics

policy and the widescale adoption of modern interventional techniques [1,2]. Accordingly, we hypothesized that the number of pediatric CHS may decline further in the future.




(A)




(B)

**Figure 5:** APC in CHS per 1000 individuals in different regions in China (2017–2022). (A) CHS; (B) pediatric CHS (*values meet statistical significance)

Conversely, the number of adult CHS increased significantly. Owing to the initially limited diagnosis and treatment capabilities, children with complex CHD were unlikely to survive to adulthood. Fortunately, improvements in clinical techniques have increased the long-term survival rates to >90%

following surgical treatment [4–7]. In the United States, approximately three of every 1000 adults have CHD [8], with an estimated 1 and 1.2 million adult cases of CHD in the United States and Europe, respectively [9]. Although data on the adult CHD populations in China are limited, from the significant increase in the number of surgeries observed in the present study, we concluded that this population is increasing rapidly, and will continue to do so [10].

A considerable number of adult patients with complex CHD following surgery require two or more operations, owing to early palliative surgery, heart valve regurgitation, left and right ventricular outflow tract obstruction, progressive ventricular dilatation and dysfunction, and exercise intolerance [11]. Shanghai Children's Medical Center and other specialized pediatric institutions have extended the age of patients for continuous treatment from 18 to 35 years, to optimize treatment outcomes. Given the prevalence of complex CHD, poor maintenance of cardiac function, and the large number of patients with single ventricular physiological circulation after palliative surgery, such as Fontan, heart failure is inevitable in some patients [11]. These patients must receive mechanical circulatory support, or a heart transplantation [12–14]. The pathophysiological characteristics of adult patients with CHD commonly differ from those of children, and the risk of pulmonary hypertension is higher [15]. Total heart failure is the final progression of right heart failure caused by pulmonary hypertension. The emergence of Eisenmenger syndrome is associated with severe cyanosis and disease [16–18]. General treatment for patients with pulmonary hypertension primarily includes supportive and targeted drug therapy; however, for patients with severe pulmonary hypertension and poor responses to targeted drug therapy, treatment is limited to palliative measures, such as Potts surgery, lung transplantation, or combined heart-lung transplantation [19,20]. Overall, the considerable annual increase in the number of adult patients with CHD requires the coordinated action of clinical institutions and relevant national departments to produce and share more data, and to formulate representative policies to facilitate present and future action.

Based on the APC trend observed in this study, the number of operations in children with CHD has shown a significant downward trend. However, regional analysis showed that the total number of operations for CHD in the western region did not decrease in the past six years, instead increasing slightly. The decline in the annual change of the proportion of CHS in the local population was even smaller in the western regions. The decline of the proportion of CHS in cardiac surgeries was also low in the northwest region, while the proportion of adult CHS in cardiac surgeries has increased the most in the northwest region over the past six years. These results may be related to the economic development of the western region. As the economy continues to develop, the reservoir of CHD patients in the less developed areas of the western regions has increasingly been able to access surgery. However, if the current situation is caused by a relative time lag, as many CHD patients are gradually treated, the number of CHS procedures may decline further in the next few years.

Except for the northeast region, in the other six regions, the proportion of CHS in the local population, whether in adults or children, generally decreased from north to south. This trend reflects the status of the regional economies, which are strong in the south and relatively weak in the north. In economically developed areas, due to the lower birth rate, prenatal heart ultrasound screening is carried out earlier and more thoroughly, interventional technology is applied earlier and more widely, the stock of patients is lower, and the proportion of CHS in the local population is also lower.

In terms of the proportion of CHS in the local population, the northeast region was the lowest for both adults and children. The main reason for this may be the high rates of emigration of the registered residence population in the three northeastern provinces [21], leading to a low birth rate of the local population. In addition, cross-regional surgery for CHD patients in Northeast China may also be one of the influencing factors.

Based on the fact that the national birth population continues to decline, while prenatal screening is actively promoted under the national policy of eugenics, the number of CHD operations for children has declined; it will also have a different impact on the incidence rate and disease spectrum of congenital malformations for the whole population, and may affect the medical status of pediatrics.

This study has some limitations. Firstly, the data collected were only related to CHS, the number and annual changes in interventional procedures in the cardiology departments are unknown, and data on the types of heart diseases are not clear. Therefore, our findings only reflect the general trends in heart surgery, and thus require further validation with more complete data and robust analytical approaches. In addition, cross-regional surgery data are needed, as these may bias the regional results.

## 5 Conclusions

In recent years, although the number of cardiac surgeries in China has been increasing, the number of surgical operations in children with CHD has declined significantly. With the continuous decrease in the number of births and the increasingly widespread use of prenatal fetal ultrasound and intervention techniques, this rate may further decrease. However, we observed an obvious upward trend in the number of CHS in adults, which also brings new opportunities and challenges to the development of cardiac surgery and cardiac critical care.

**Acknowledgement:** We wish to express our gratitude to the following individuals for their contributions to the statistical analyses: Long Cun, Zhude Ming, Heifei Long, Yangshu Ya, Liangfeng Ling, and Zhangyu Qing.

**Funding Statement:** The authors received no specific funding for this study.

**Author Contributions:** The authors confirm contribution to the paper as follows: study conception and design: Wei Wang; data collection: Ju Zhao, Xing Hao, Xiaotong Hou; analysis and interpretation of results: Li Xie; draft manuscript preparation: Zheng Guo. All authors reviewed the results and approved the final version of the manuscript.

**Availability of Data and Materials:** The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request with appropriate permissions.

**Ethics Approval:** The data for this study comes from a survey questionnaire provided by hospitals at all levels across the country and does not involve the ethical statement and approved body institution.

**Conflicts of Interest:** The authors declare that they have no conflicts of interest to report regarding the present study.

## References

1. Chen JM. The integrated pre- and post-natal management program on congenital heart disease: a consensus of Chinese experts. Chin J Cardiovasc Res. 2022 Feb;20(2):97–103 (In Chinese). doi:10.3969/j.issn.1672-5301.2022.02.001.
2. Yan YM, Ouyang WB, Zhang FW, Fang F, Pan XB. Current situation and prospect of interventional therapy for congenital heart disease in China. Chin J Clin Thorac Cardiovasc Surg. 2022;29(10):1243–53 (In Chinese). doi:10.7507/1007-4848.202205081.
3. Wang W, Zhu DM, Hei FL, Long C. The development situation of cardiac surgery in China from 2004 to 2013. Chin J Extracorporeal Circ. 2014;21(4):193–7 (In Chinese). doi:10.134998/j.cnki.chin.j.ecc.2014.12.4.

4. Baggen VJM, Venema E, Zivna R, van den Bosch AE, Eindhoven JA, Witsenburg M, et al. Development and validation of a risk prediction model in patients with adult congenital heart disease. Int J Cardiol. 2019;276:87–92. doi:10.1016/j.ijcard.2018.08.059.
5. Awerbach JD, Krasuski RA, Camitta MGW. Coronary disease and modifying cardiovascular risk in adult congenital heart disease patients: should general guidelines apply? Prog Cardiovasc Dis. 2018;61(3–4):300–7. doi:10.1016/j.pcad.2018.07.018.
6. Bouma BJ, Mulder BJ. Changing landscape of congenital heart disease. Circ Res. 2017;120(6):908–22. doi:10.1161/CIRCRESAHA.116.309302.
7. Warnes CA. The adult with congenital heart disease: born to be bad? J Am Coll Cardiol. 2005;46(1):1–8. doi:10.1016/j.jacc.2005.02.083.
8. van der Bom T, Bouma BJ, Meijboom FJ, Zwinderman AH, Mulde BJM. The prevalence of adult congenital heart disease, results from a systematic review and evidence based calculation. Am Heart J. 2012;164(4):568–75. doi:10.1016/j.ahj.2012.07.023.
9. Budts W, Roos-Hesselink J, Rädle-Hurst T, Eicken A, McDonagh TA, Lambrinou E, et al. Treatment of heart failure in adult congenital heart disease: a position paper of the Working Group of Grown-Up Congenital Heart Disease and the Heart Failure Association of the European Society of Cardiology. Eur Heart J. 2016;37(18):1419–27. doi:10.1093/eurheartj/ehv741.
10. Hou XT. White book of Chinese cardiovascular surgery and extracorporeal circulation in 2022. Chin J ECC. 2023 Aug 28;21(4):197–200 (In Chinese). doi:10.13498/j.cnki.chin.j.ecc.2023.04.2.
11. Babu-Narayan SV, Diller GP, Gheta RR, Bastin AJ, Karonis T, Li W, et al. Clinical outcomes of surgical pulmonary valve replacement after repair of tetralogy of Fallot and potential prognostic value of preoperative cardiopulmonary exercise testing. Circulation. 2014;129(1):18–27. doi:10.1161/CIRCULATIONAHA.113.001485.
12. Meshulami N, Shah P, Kaushik S, Murthy R. Cardiac transplantation in adult congenital heart disease: a narrative review. J Thorac Dis. 2023 Sep;15(9):5074–87. doi:10.21037/jtd-23-513.
13. Woods RK, Ghanayem NS, Mitchell ME, Kindel S, Niebler RA. Mechanical circulatory support of the fontan patient. Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu. 2024 May;29(3):707–11. doi:10.1053/j.pcsu.2016.09.009.
14. Dipchand AI, Honjo O, Alonso-Gonzalez R, McDonald M, Roche SL. Heart transplant indications, considerations, and outcomes in fontan patients: age-related nuances, transplant listing, and disease-specific indications. Can J Cardiol. 2022 Jul;38(7):1072–85. doi:10.1016/j.cjca.2022.02.019.
15. Krieger EV, Leary PJ, Opotowsky AR. Pulmonary hypertension in congenital heart disease: beyond eisenmenger syndrome. Cardiol Clin. 2015;33(4):599–609. doi:10.1016/j.ccl.2015.07.003.
16. Ministeri M, Alonso-Gonzalez R, Swan L, Dimopoulos K. Common long term complications of adult congenital heart disease: avoid falling in a H.E.A.P. Expert Rev Cardiovasc Ther. 2016;14(4):445–62. doi:10.1586/14779072.2016.1133294.
17. Roth TS, Aboulhosn JA. Pulmonary hypertension and congenital heart disease. Cardiol Clin. 2016;34(3):391–400. doi:10.1016/j.ccl.2016.04.002.
18. Kaemmerer H, Apitz C, Brockmeier K, Eicken A, Gorenflo M, Hager A, et al. Pulmonary hypertension in adults with congenital heart disease: updated recommendations from the Cologne Consensus Conference 2018. Int J Cardiol. 2018;272(18):79–88. doi:10.1016/j.ijcard.2018.08.078.
19. Aldeolmillos E, Le Pavec J, Audié M, Savale L, Jais X, Montani D, et al. Thirty years of surgical management of pediatric pulmonary hypertension: mid-term outcomes following reverse Potts shunt and transplantation. J Thorac Cardiovasc Surg. 2023 Dec;168(3):943–54. doi:10.1016/j.jtcvs.2023.11.045.
20. Diller GP, Gatzoulis MA. Pulmonary vascular disease in adults with congenital heart disease. Circulation. 2007;115(8):1039–50. doi:10.1161/CIRCULATIONAHA.105.592386.
21. Liu T, Yang M, Peng RX. Structure and destination choices of out-migrants from Northeast China: based on long-term comparative analysis of census data. Sci Geogr Sin. 2024;44(6):1016–25 (In Chinese). doi:10.13249/j.cnki.sgs.20221091.