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REVIEW ARTICLE

Surgery for congenital heart disease in Pakistan—the challenges and solutions

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Abstract
Managing pediatric and congenital heart disease (CHD) in low- and middle-income countries like Pakistan requires a nuanced approach that extends beyond simply adopting management styles and guidelines developed for high-income countries. This review aims to examine the challenges associated with the surgical management of CHD in Pakistan, addressing the evolving and persistent disease burden while also offering context-specific solutions.

Keywords Congenital heart disease · Global surgery · Access to care

Introduction and background

Congenital heart disease (CHD) stands as the most common major congenital anomaly, impacting around 1 in 100 live births globally [1]. As per the Global Burden of Disease (GBD) projections in 2017, close to 300,000 individuals succumb to CHD annually, with roughly two-thirds of these fatalities involving infants under the age of 1 year. The highest mortality rates are documented in low- and middle-income countries (LMICs) [2]. According to the GBD projections in 2019, Nigeria, China, Pakistan, and India collectively contributed to 39.7% of worldwide deaths attributed to CHD. In Pakistan specifically, an estimated 11,000 deaths (with a range of 7000 to 19,000) were recorded in 2019 [3]. However, the actual burden of CHD in Pakistan is likely to be higher than these estimates, as many cases of CHD go undiagnosed and untreated, particularly in rural and underserved areas.

Addressing the challenges associated with surgical interventions for CHD in Pakistan, a country characterized by its unique geographical, demographic, and socio-economic landscape, is imperative. The history of congenital cardiac surgery in Pakistan provides context for these challenges and underscores the progress made, and the gaps that still exist. In the late 1950s and 1960s, a few sporadic closed heart surgeries, including closed mitral valvotomy, patent ductus arteriosus closure, and pericardial effusion drainage, were performed in Karachi, Lahore, Rawalpindi, and Dhaka [4]. Open-heart adult cardiac surgery was initiated in Pakistan by Dr. Donald E. Bowes, a Canadian missionary surgeon, in 1967 at the United Christian Hospital in Lahore. The first congenital open-heart surgery performed by a local team, an atrial septal defect repair led by Dr. Lieutenant Colonel Ali Masood Akram, took place at the Rawalpindi Military Hospital in March 1970, marking the beginning of a steady growth in CHD-related surgical capacities in Pakistan ever since [4].

Despite these early efforts, Pakistan, as an LMIC, grapples with a diverse set of healthcare challenges shaped by factors such as population dynamics, economic constraints, and infrastructural limitations. A recent nationwide status report demonstrated a significant deficit in the availability and provision of healthcare services to patients with CHD in Pakistan, including the lack of skilled manpower, operative volumes, and intensive care availability [5].

Given these complex and interrelated problems, the management of CHD in LMICs requires a nuanced approach. With this review, we seek to contribute valuable knowledge to the global discourse on CHD surgery and provide an accurate depiction of CHD care in Pakistan. Our aim is to

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identify obstacles and present viable solutions, offering a perspective that can inform stakeholders and policymakers. Ultimately, this can lead to increased accessibility and quality of surgical interventions for CHD in Pakistan.

Review—Main text

Country-specific sociodemographic and geographic factors

As a South Asian LMIC with a population exceeding 240 million, Pakistan faces considerable health challenges due to its large population size. The high under-five mortality rate of 63.3 deaths per 1000 live births underscores the urgency of addressing healthcare needs, including CHD, among vulnerable pediatric populations [6].

Similar to many LMICs, Pakistan experiences stark disparities within its population. Over 37% of the population lives below the poverty line (1.90 United States Dollars [USD] purchasing power parity per person per day). A paucity of financial resources results in patients, especially from lower socioeconomic strata, being frequently severely malnourished, having received little to no prior care, and presenting with serious and late disease-related complications, all of which adversely affect outcomes [5, 7, 8]. In fact, quantified by the Community Health Index (CHI), Pakistan exhibits a striking inequality ratio of 16.59, indicating that districts with better resources are nearly 17 times healthier than those with fewer resources [9].

Geographic constraints and population density further exacerbate these challenges. With greater than 60% of the Pakistani population residing in rural areas, patients and families have to travel long distances to access surgical care in urban centers, even for emergencies such as acute abdomen. This is due to a lack of adequate surgical care closer to home, understaffing of surgeons at public hospitals, and the high out-of-pocket expenses incurred at private hospitals [10, 11]. Similarly, a 1999 study from rural Northern Pakistan revealed a large unmet surgical need, with only about 13% of patients being able to access the surgical care they required [12]. A lack of access to timely surgical care results in patients with CHD in rural areas suffering from substantially poorer health outcomes compared to their urban counterparts. Additionally, Punjab, the most populous province, hosts more than 50% of the country's specialized CHD centers, while Balochistan, the largest province by area, lacks a single center [5].

Infrastructure and workforce

Comprehensive care for CHD necessitates robust infrastructures that support early diagnosis, timely referral, effective surgical intervention, and ongoing follow-up care. A multidisciplinary workforce is crucial for this, including community healthcare workers, specialized nurses, pediatric intensivists, cardiac surgeons, pediatric cardiologists, and other specialists. Furthermore, the integration of infrastructure with the existing workforce is essential for effective CHD management.

However, a nationwide study assessing hospital resources and surgical practices for CHD surgery across Pakistan found significant gaps [5]. The country has fewer than 20 congenital cardiac programs for a population of over 240 million people, with almost a complete absence in rural areas and less population-dense areas like Balochistan (Fig. 1).

Most pediatric cardiac surgeons operate in centers performing fewer than 350 cases annually, with only seven of the seventeen surgeons surveyed by Malik et al. working in higher-volume centers [5]. Surgeons in public hospitals handle a greater volume of cases and a higher proportion of neonatal surgeries. However, fewer than one-third of these hospitals have Neonatal Intensive Care Unit (NICU)/Paediatric Intensive Care Unit (PICU) services available. Additionally, CHD programs at standalone children's hospitals, though fewer in number (4 out of 17), have higher overall volumes, better intensive care unit (ICU) support, and perform more neonatal surgeries. Given the annual new-case burden of approximately 2200, the disparity between the need for and availability of infrastructure is glaringly apparent.

These figures mirror those in other LMICs such as sub-Saharan Africa, India, and Nigeria, where the cardiac surgeon-to-population ratios are 1:35 million in Africa and 1:25 million in Asia. This starkly contrasts with a ratio of 1:3.5 million in the USA and Europe [1]. With one of the fastest-growing populations in the world, Pakistan's gap between resource availability and demand for CHD care is only expected to widen.

Tackling the provision of services for CHD surgery in Pakistan demands a comprehensive approach to overcome existing challenges and to implement effective solutions. Developing services along the patient care continuum is key to improving access to CHD care while maintaining a focus on quality. As proposed by Mohsin et al., a comprehensive framework should be developed with measures that are easy to implement and can build on existing health systems (Fig. 2) [13].

Patient care should be viewed as a continuum, starting from birth and early diagnosis to long-term care, rather than as a single surgical event, all centered on providing high-quality care.

This begins with training healthcare workers in rural settings to suspect CHD using simple measures such as pulse oximetry, followed by the development of seamless referral systems where babies with suspected CHD are referred to specialized centers [14]. Hasan et al. have proposed a tiered

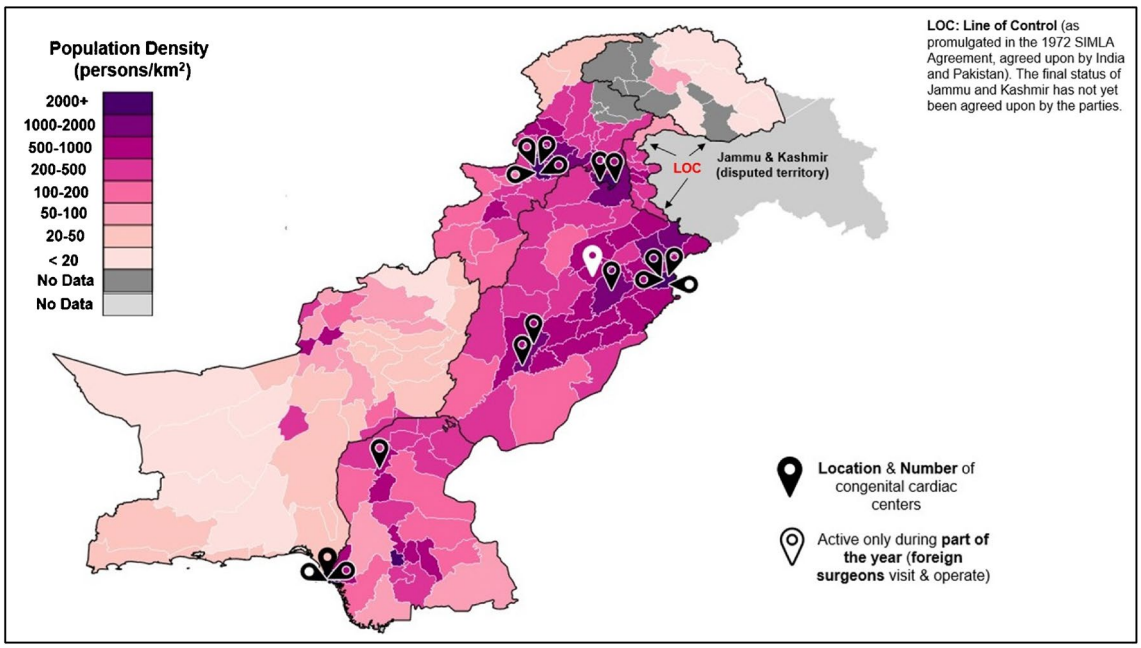

Fig. 1 Geographic distribution of various congenital heart surgery centers in Pakistan (used with permission [5])

approach to care levels, ranging from primary healthcare centers to advanced surgical centers (Fig. 3) [15].

Each level of the framework has specific benchmarks that centers must achieve before progressing to the next level, with each benchmark representing measurable quality audit variables. Integrating these levels with existing public healthcare systems is crucial for developing a sustainable system capable of delivering comprehensive care along the CHD care continuum.

Additionally, collaboration between government authorities and privately operated Nongovernmental Organizations (NGOs) is crucial. A notable example of such a partnership is the public health initiative launched by the government of Kerala, India, in collaboration with Children's Heartlink, a US-based NGO, to start the "Hyridiam" Program [16]. To replicate this success, a thorough assessment of existing capacities is necessary to identify and address barriers to care.

Funding of congenital heart disease care

Understanding the financial aspect of funding CHD care in Pakistan is essential for addressing the challenges and opportunities in providing adequate healthcare services. Pakistan faces significant economic constraints with a gross domestic product (GDP) of 338.24 billion USD and a GDP per capita of 1460 USD as per the International Monetary Fund (IMF) in 2023 [17]. Allocations to the health sector in Pakistan have historically been low, representing less than 5% of overall government spending in 2019 and remaining at around or less than 1% of GDP [18]. According to the most recently available data from the World Health Organization's (WHO) Global Health Expenditure Database, Pakistan's health expenditure was a meagre 2.91% of the GDP and 43.09 USD per capita in 2021 [19]. This is just below the WHO's recommended minimum of 44 USD per capita needed for essential healthcare services.

This insufficient investment in the public health system has led to a shortage of health infrastructure, medications, medical tools, and well-trained healthcare professionals. Although there has been some increase in human resources from 2014 to 2021, this growth has not matched the annual population growth rate of 2% [20]. Additionally, with limited resources to address the healthcare needs of one of the world's largest populations, Pakistan prioritizes funding for combating infectious diseases, which constitute the greatest disease burden. These diseases include tuberculosis (TB), human immunodeficiency virus (HIV), malaria, and hepatitis B and C [21].

It is clear then that specialized care, such as the surgical treatment of CHD, faces significant funding shortages in Pakistan. While philanthropic efforts by charitable organizations, Islamic groups, and individuals help a small number of patients receive CHD care, the lack of government funding, combined with previously discussed factors, makes affordable and accessible healthcare unattainable for the majority of CHD patients. This situation forces many patients and families to incur substantial out-of-pocket payments (OOPP). In 2018, an estimated 5.4% of the population faced catastrophic health expenditures exceeding 10%

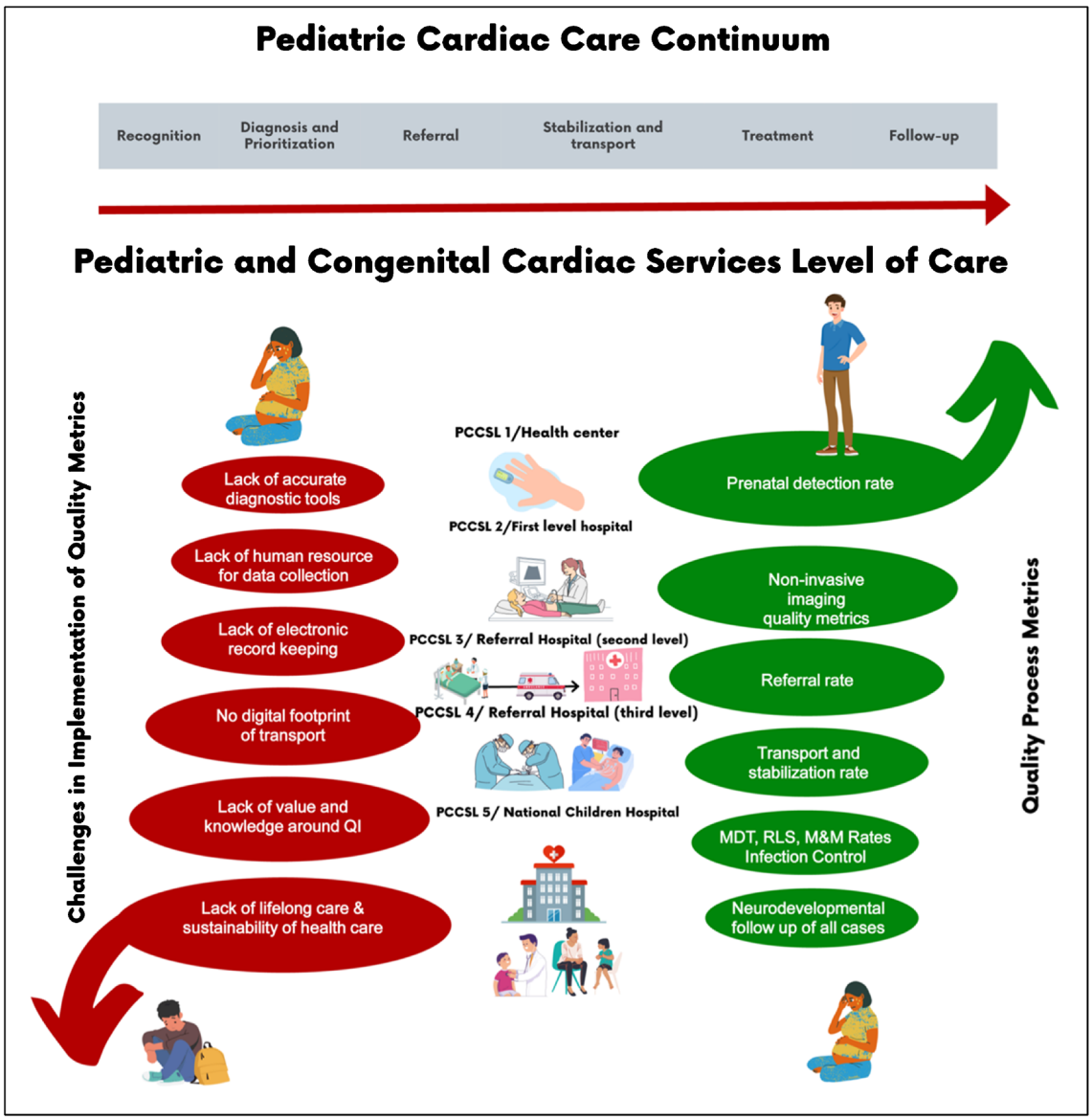

Fig. 2 Metrics for quality improvement framework at each congenital heart disease care level in LMICs (used with permission [13])

of their household budget, reflecting a steady increase since 2007 [18].

Addressing the financial aspect of CHD care in Pakistan requires a multi-pronged approach. The first step is to convince stakeholders that pediatric cardiac care programs can be both cost-effective and economically beneficial. For example, a modeling study indicated that investing in secondary and tertiary care for rheumatic heart disease (RHD) in the African Union would produce significant health and economic benefits that far exceed the healthcare costs and offer greater returns on investment compared to investments in primary prophylaxis of acute rheumatic fever alone [22]. Improving the quality of care can enhance outcomes and avoid unnecessary spending.

To achieve this, innovative and cost-effective solutions need to be sought and implemented. This includes increasing government investment in healthcare and fostering partnerships between the public and private sectors to leverage resources more effectively. Additionally, innovative financing mechanisms, such as health insurance schemes and public–private partnerships, can help mobilize additional funds for CHD care and improve access to essential services for all segments of the population.

One notable example of such an initiative is the Universal Health Care (UHC) program, also known as the Sehat Sahulat Program (SSP), launched in 2020 [23]. Through this program, the government aims to utilize private sector providers to offer free tertiary healthcare to patients and their families

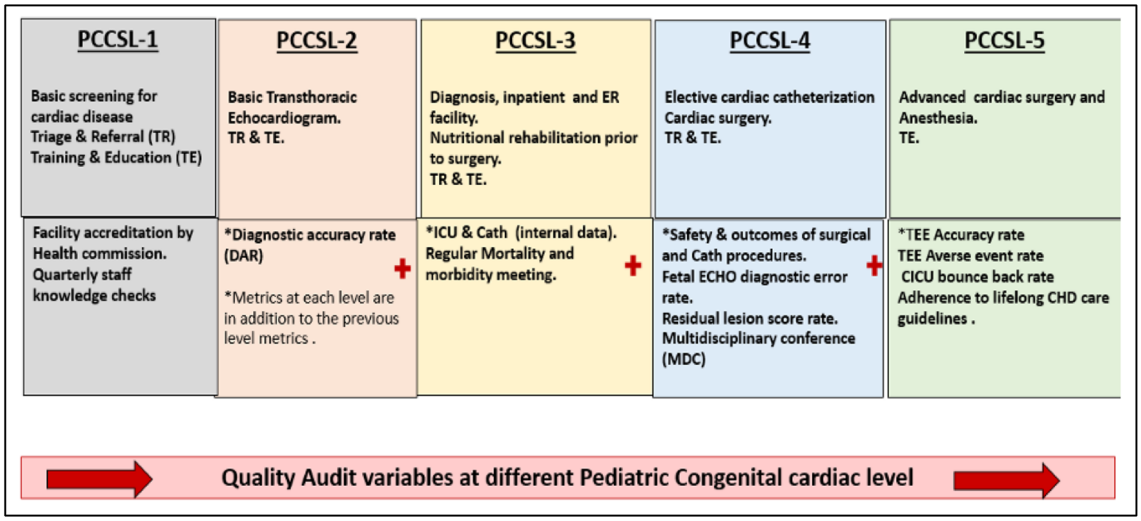

Fig. 3 Pediatric and congenital cardiac service levels and corresponding quality audit variables (used with permission [15]). *Abbreviations*: PCCSL, pediatric and congenital cardiac service levels; CHD, congenital heart disease; CICU, cardiac intensive care unit; ICU, intensive care unit; TEE, transesophageal echocardiography

within a certain budget. Moreover, in 2021, the Ministry of National Health Services, Regulation and Coordination, in collaboration with the Global Surgery Foundation, Indus Hospital and Health Network, and the Harvard Program in Global Surgery and Social Change, launched Pakistan's National Surgical Plan (NSP). This plan aims to identify current gaps in surgical care delivery and provide a strategic direction to strengthen surgical systems in the country.

While CHD was not specifically highlighted within either of these programs, relevant stakeholders can utilize the existing framework to extend surgical care to patients with CHD. By adopting a comprehensive approach that includes increased government investment, public–private partnerships, and innovative financing mechanisms, Pakistan can improve access to and the quality of CHD care, ultimately benefiting patients and their families.

Education and training

Globally, there are around 4000 pediatric cardiac surgeons, with a considerable disparity in provider density. This ranges from 9.51 surgeons per million population in high-income countries to merely 0.07 per million population in low-income countries, indicating a more than 130-fold difference in the distribution of healthcare providers [24]. The difference in distribution accentuates the pronounced healthcare disparities globally, and the discrepancy in provider density has direct implications for CHD surgical interventions, particularly in resource-constrained settings like Pakistan.

Training programs in LMICs, especially in Pakistan, are limited, leading to many healthcare professionals pursuing specialized training, such as pediatric cardiac surgery and pediatric cardiology, abroad—often in high-income countries [25]. A recent survey by Malik et al. showed there are only five programs in Pakistan which have congenital heart surgery trainees [5]. However, several barriers hinder entry into training programs elsewhere. These barriers include language proficiency requirements, cultural adjustments, the need for accreditation or licensing exams, and often years of research to enhance competitiveness for limited slots in training programs. Each of these barriers involves significant financial and administrative burdens, such as visa requirements. These challenges pose considerable difficulties for aspiring surgeons in LMICs, including Pakistan, who seek advanced training in CHD surgery.

Post-training, there is a risk of brain drain, as individuals may be enticed to stay in their training country or may perceive greater opportunities in terms of compensation or academic pursuits [25]. Approximately 32,879 physicians graduate annually in Pakistan, with 40% opting to pursue opportunities abroad due to factors such as low income, extended working hours, and issues related to inequality [26]. This poses a dual challenge for countries like Pakistan, as they not only face a shortage of trained surgeons, but also contend with the potential loss of skilled professionals who choose to pursue careers abroad.

Addressing the complex challenges in training physicians for CHD care in Pakistan requires a multifaceted approach. Prioritizing the strengthening of local training programs is essential, necessitating strategic investments to create structured initiatives that bridge the existing workforce gap. Simultaneously, it is crucial to incentivize healthcare professionals through competitive compensation, conducive work environments, and academic opportunities. This

will help mitigate factors contributing to brain drain, foster retention, and acknowledge their expertise. Furthermore, advocating for policy reforms at national and international levels is integral. Streamlining accreditation and licensing processes will reduce administrative barriers, ensuring that regulatory frameworks align with evolving healthcare education dynamics and enhance accessibility for professionals seeking training abroad.

Congenital heart surgery outcomes

The absence of comprehensive data on postoperative outcomes of CHD surgeries in Pakistan reflects broader challenges within the country's healthcare infrastructure. Unlike many developed nations with established national databases, Pakistan lacks centralized systems for collecting, analyzing, and disseminating surgical data. This fragmented data landscape not only impedes the assessment of surgical outcomes, but also hinders the formulation of evidence-based policies and interventions aimed at improving patient care.

Ideally, healthcare outcomes should be tracked and maintained in local and institutional databases to inform institutional practices and for research. Unfortunately, there is no such database within Pakistan that combines data from different centers. However, multiple institutions are participating with international databases such as the International Quality Improvement Collaborative (IQIC) for CHD, which has 73 contributing centers across more than 25 LMICs [27]. Participating centers collect standardized data that records surgical as well as catheter-based intervention outcomes, while also participating in virtual capacity building and on ground data validation and training. Data from the IQIC registries have formed the basis for multiple large volume studies from Pakistan that shed light on surgical outcomes in Pakistan [28, 29].

One of these studies, published in 2023, revealed an in-hospital mortality rate of 6.7%. Additionally, a significant proportion of patients experienced postoperative complications, with 4.4% suffering from bacterial sepsis and 0.8% developing surgical site infections. This study highlighted the heightened risk of adverse outcomes among specific patient groups, including those undergoing high-risk procedures, infants and children, individuals with genetic syndromes, and those with low oxygen saturation levels [29].

Another study, conducted in 2022, focused on early postoperative arrhythmias after pediatric congenital heart surgery, providing insights into a common complication encountered in this patient population. Among 812 children who underwent CHD surgery, 22.8% developed arrhythmias within the early postoperative period. Junctional ectopic tachycardia emerged as the most prevalent arrhythmia, affecting 64.9% of patients, followed by complete heart block in 17.8% of cases [30].

The relative paucity of comprehensive data on postoperative outcomes of CHD surgeries in Pakistan underscores the need for concerted action. Addressing the lack of data in Pakistan requires an approach that involves collaboration between healthcare stakeholders, policymakers, researchers, and international organizations. Establishing centralized registries and surveillance systems dedicated to tracking surgical outcomes is paramount. These systems should encompass standardized data collection protocols, ensure data integrity and confidentiality, and facilitate interoperability between healthcare facilities. By addressing the underlying challenges in data collection, analysis, and dissemination, Pakistan can enhance its capacity to deliver evidence-based care, improve patient outcomes, and mitigate the burden of CHD on individuals and families across the country.

The future of congenital heart disease care in Pakistan

The future of CHD surgery in Pakistan holds promise and potential, yet it also presents challenges that must be addressed to ensure optimal outcomes for patients. As the country grapples with the burden of CHD and strives to improve access to surgical interventions, several key factors will shape the landscape of CHD surgery in the coming years.

CHD service development can only thrive with sustainable and equitable healthcare financing and planning, which remains a significant concern for most LMICs. A concerted effort is needed to bring CHD to the forefront for policymakers and healthcare managers, ensuring it becomes a national priority. Adopting a life-course approach, where CHD is regarded along a continuum, is crucial. Policy framework recommendations from the Global Initiative for Children's Surgery Cardiac Surgery working group should be considered and implemented, customized to Pakistan's existing healthcare framework.

Such frameworks help distribute the burden of disease across the entire system while providing CHD patients with the lifelong care they need. By consolidating expertise, resources, and infrastructure, centers can offer comprehensive care tailored to the unique needs of pediatric patients with CHD, according to their capacities. Collaborative efforts among pediatric cardiologists, cardiac surgeons, anesthesiologists, nurses, and allied healthcare professionals are essential for optimizing patient outcomes and ensuring continuity of care throughout the surgical journey.

Another significant driver of progress in CHD surgery is advancements in medical technology and surgical techniques. Innovations such as minimally invasive procedures, three-dimensional printing for surgical planning, and advances in imaging modalities have the potential to revolutionize CHD surgery in Pakistan. These technologies

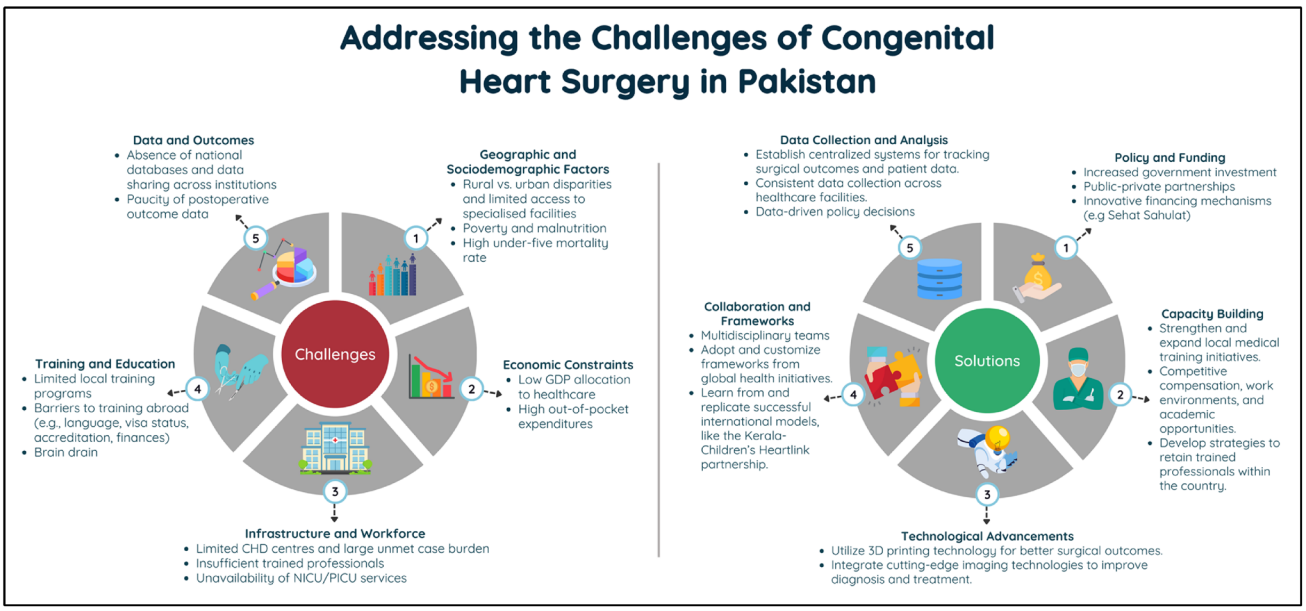

Fig. 4 Addressing the challenges of congenital heart surgery in Pakistan

can improve surgical precision, reduce complications, and enhance patient outcomes, particularly in complex cases [31, 32].

Furthermore, initiatives aimed at capacity-building and workforce development are crucial for expanding access to CHD surgery in Pakistan. Training programs for healthcare professionals, including surgeons, nurses, and technicians, can help build local expertise and reduce reliance on foreign assistance. Investing in medical education, residency programs, and continuing professional development opportunities can strengthen the country's surgical workforce and foster a culture of excellence in CHD care.

Addressing barriers to access, including financial constraints, geographic and sociodemographic disparities, and understaffing, is paramount for ensuring equitable access to CHD surgery across Pakistan. Government-led initiatives, public–private partnerships, and community outreach programs can play a vital role in raising awareness about CHD, promoting early detection and intervention, and facilitating access to specialized care for underserved populations.

However, several challenges must be overcome to realize the full potential of CHD surgery in Pakistan. These include addressing healthcare infrastructure gaps, enhancing healthcare financing mechanisms, improving data collection and surveillance systems, and strengthening regulatory frameworks to ensure quality and safety standards are met. The challenges and potential solutions covered in this review have been summarized in Fig. 4.

Conclusion

The future of CHD care in Pakistan holds tremendous potential for improving outcomes and transforming the lives of those affected by CHD. By leveraging technological advancements, fostering collaboration, investing in capacity-building initiatives, and addressing barriers to access, Pakistan can emerge as a regional leader in CHD care. With dedicated efforts from healthcare stakeholders, policymakers, and the community, Pakistan can ensure that every child with CHD receives timely, high-quality surgical care. This united approach promises a healthier future for all, making a profound impact on countless lives.

Author contribution MAM initially conceptualized and designed the study. MAM, Asad SF, and Alizeh SF performed the initial literature search to retrieve relevant articles for the review. All authors (MAM, Asad SF, Alizeh SF, SGS, and AMS) contributed substantially to the write-up of the manuscript and critically revising it for intellectual content, while Asad SF and Alizeh SF were responsible for data visualization and figure design. All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Data availability The data that support the findings of this review were sourced directly from previously published literature that is publicly available.

Declarations

Ethics approval This manuscript was exempted from ethical approval by the Institutional Review Board at the Rawalpindi Institute of Cardiology.

Informed consent Not applicable.

Statement of human and animal rights Not applicable.

Competing interests All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

References

1. Hoffman JI. The global burden of congenital heart disease. Cardiovasc J Afr. 2013;24:141–5.
2. Zimmerman MS, Smith AGC, Sable CA, Echko MM, Wilner LB, Olsen HE, et al. Global, regional, and national burden of congenital heart disease, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet Child Adolesc Health. 2020;4:185–200.
3. Su Z, Zou Z, Hay SI, Liu Y, Li S, Chen H, et al. Global, regional, and national time trends in mortality for congenital heart disease, 1990–2019: an age-period-cohort analysis for the Global Burden of Disease 2019 study. EClinicalMedicine. 2022;43:101249.
4. Hosain N. The early days of cardiac surgery in South Asia: the history and heritage. Ann Thorac Surg [Internet]. 2017;104:361–6. Available from: https://doi.org/10.1016/j.athoracsur.2017.01.039.
5. Malik MA, Fatimi AS, Martins RS, Amanullah M, Jalal A. Hospital resources and practice patterns for congenital cardiac surgery in Pakistan: a nationwide status report. World J Pediatr Congenit Heart Surg. 2024;15:184–92.
6. Pakistan (PAK) - Demographics, health & infant mortality - UNICEF DATA. [cited 2024 Jan 26]; Available from: https://data.unicef.org/country/pak/.
7. Nguyen N, Leon-Wyss J, Iyer KS, Pezzella AT. Paediatric cardiac surgery in low-income and middle-income countries: a continuing challenge. Arch Dis Child. 2015;100:1156.
8. Iyer KS. Pediatric cardiac surgery in low- and middle-income countries – fighting the odds. Ann Pediatr Cardiol. 2019;12:1–2.
9. Khan SU, Hussain I. Inequalities in health and health-related indicators: a spatial geographic analysis of Pakistan. BMC Public Health. 2020;20:1800.
10. Khan MS, Haider SA, Ashfaq A, Khan S, Shariff AH. Geospatial mapping of patients presenting for emergency laparotomy to a private sector tertiary care hospital in Pakistan. J Pak Med Assoc [Internet]. 2019;69:S37–40. Available from: http://europepmc.org/abstract/MED/30697017.
11. Rashid U, Qureshi AU, Hyder SN, Sadiq M. Pattern of congenital heart disease in a developing country tertiary care center: factors associated with delayed diagnosis. Ann Pediatr Cardiol. 2016;9:210–5.
12. Ahmed M, Ali Shah M, Luby S, Drago-Johnson P, Wali S. Survey of surgical emergencies in a rural population in the northern areas of Pakistan. Trop Med Int Health [Internet]. 1999;4:846–57. Available from: https://doi.org/10.1046/j.1365-3156.1999.00490.x.
13. Mohsin S, Hasan B, Zheleva B, Kumar RK. Enhancing quality of congenital heart care within resource-limited settings. Pediatr Cardiol [Internet]. 2023; Available from: https://doi.org/10.1007/s00246-023-03351-2.
14. Hesselink G, Schoonhoven L, Barach P, Spijker A, Gademan P, Kalkman C, et al. Improving patient handovers from hospital to primary care. Ann Intern Med [Internet]. 2012;157:417–28. Available from: https://www.acpjournals.org/doi/abs/10.7326/0003-4819-157-6-201209180-00006.
15. Hasan BS, Bhatti A, Mohsin S, Barach P, Ahmed E, Ali S, et al. Recommendations for developing effective and safe paediatric and congenital heart disease services in low-income and middle-income countries: a public health framework. BMJ Glob Health [Internet]. 2023;8:e012049. Available from: http://gh.bmj.com/content/8/5/e012049.abstract.
16. Nair SM, Zheleva B, Dobrzycka A, Hesslein P, Sadanandan R, Kumar RK. A population health approach to address the burden of congenital heart disease in Kerala. India: Glob Heart; 2021.
17. IMF DataMapper [Internet]. [cited 2024 Jun 15]. Available from: https://www.imf.org/external/datamapper/profile/PAK.
18. World Health Organization. Health financing progress matrix assessment: Pakistan 2023 summary of findings and recommendations. 2023 [cited 2024 Jun 15]; Available from: https://iris.who.int/bitstream/handle/10665/374813/9789240084933-eng.pdf?sequence=1.
19. Global Health Expenditure Database [Internet]. [cited 2024 Jun 15]. Available from: https://apps.who.int/nha/database/Select/Indicators/en.
20. Pakistan Economic Survey 2021–2022. Health and Nutrition. 2022.
21. Hafeez A, Dangel WJ, Ostroff SM, Kiani AG, Glenn SD, Abbas J, et al. The state of health in Pakistan and its provinces and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet Glob Health [Internet]. 2023;11:e229–43. Available from: https://doi.org/10.1016/S2214-109X(22)00497-1.
22. Coates MM, Sliwa K, Watkins DA, Zühlke L, Perel P, Berteletti F, et al. An investment case for the prevention and management of rheumatic heart disease in the African Union 2021–30: a modelling study. Lancet Glob Health [Internet]. 2021;9:e957–66. Available from: https://doi.org/10.1016/S2214-109X(21)00199-6.
23. Forman R, Ambreen F, Shah SSA, Mossialos E, Nasir K. Sehat sahulat: a social health justice policy leaving no one behind. Lancet Regional Health - Southeast Asia [Internet]. 2022;7. Available from: https://doi.org/10.1016/j.lansea.2022.100079.
24. Vervoort D, Meuris B, Meyns B, Verbrugghe P. Global cardiac surgery: access to cardiac surgical care around the world. J Thorac Cardiovasc Surg. 2020;159:987–96.
25. McMahon CJ, Tretter JT, Redington AN, Bu'Lock F, Zühlke L, Heying R, et al. Medical education and training within congenital cardiology: current global status and future directions in a post COVID-19 world. Cardiol Young. 2022;32:185–97.
26. Nadir F, Sardar H, Ahmad H. Perceptions of medical students regarding brain drain and its effects on Pakistan's socio-medical conditions: a cross-sectional study. Pak J Med Sci. 2023;39:401.
27. International Quality Improvement Collaborative for Congenital Heart Disease [Internet]. [cited 2024 Jun 15]. Available from: https://iqic.chboston.org/.
28. Khan A, Abdullah A, Ahmad H, Rizvi A, Batool S, Jenkins KJ, et al. Impact of international quality improvement collaborative on congenital heart surgery in Pakistan. Heart [Internet]. 2017;103:1680. Available from: http://heart.bmj.com/content/103/21/1680.abstract.
29. Furnaz S, Shaikh AS, Qureshi R, Fatima S, Bangash SK, Karim M, et al. Factors associated with poor outcomes after congenital heart surgery in low-resource setting in Pakistan: insight from the IQIC Registry – a descriptive analysis. BMJ Open [Internet].

2023;13:e078884. Available from: http://bmjopen.bmj.com/content/13/12/e078884.abstract.
30. Ishaque S, Akhtar S, Ladak AA, Martins RS, Memon MKY, Kazmi AR, et al. Early postoperative arrhythmias after pediatric congenital heart disease surgery: a 5-year audit from a lower- to middle-income country. Acute Crit Care. 2022;37:217–23.
31. Giannopoulos AA, Mitsouras D, Yoo S-J, Liu PP, Chatzizisis YS, Rybicki FJ. Applications of 3D printing in cardiovascular diseases. Nat Rev Cardiol. 2016;13:701–18.
32. Padalino MA, Pittarello DG, Vida VL, Stellin G. Minimally invasive approach in surgery for congenital heart disease. In: Montalto A, Loforte A, Amarelli C, editors. Cardiac surgery procedures [Internet]. Rijeka: IntechOpen; 2020. p. Ch. 6. Available from: https://doi.org/10.5772/intechopen.87136.