Original Article

Beyond borders: an appraisal of the global congenital cardiac surgery workforce

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Background: Congenital heart disease (CHD) is the most common congenital abnormality worldwide. Patients in resource-constrained environments experience higher levels of mortality and morbidity from CHD. Many studies have quantified the incidence of CHD in resource-constrained environments and compared these to availability of surgeons per population. However, no study to date has compiled and created a repository of the global paediatric cardiac surgical workforce. We aimed to quantify the number and details of the congenital cardiac surgeons globally, compare the population of under 15's in each respective countries, and address the workforce gaps that currently exist within paediatric cardiac surgery.

Methods: Cardiothoracic Surgery Network (CTSNet) was searched in 2021 to extrapolate the current paediatric cardiac surgical workforce. The data was evaluated with the current literature to address current gaps in workforce planning and sustainability to produce this appraisal.

Results: A total of 4,027 congenital cardiac surgeons were identified from CTSNet with 75% residing in high-income countries (HICs) or upper-middle-income countries (UMICs) despite these income groups only accounting for 16% of the world population. Despite similar incidence and prevalence of CHD globally, we found an unequal distribution in the availability of congenital cardiac surgeons worldwide.

Conclusions: The disparity in the availability of surgeons between HICs and low-middle-income countries (LMICs) is a global health issue that will require serous thought and planning to resolve. The high proportion of preventable deaths from CHD cases is a regrettable figure that governments and medical organisations should further strive to decrease. Education and proactive investments in training up local teams in LMICs will allow for sustainability in global congenital cardiac surgery.

Keywords: Congenital cardiac surgery; congenital heart disease (CHD); global surgery; health care; workforce

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Introduction

Background

Despite major advancements in global health, 90% of children in low-middle-income countries (LMICs) lack access to the required treatment or receive suboptimal treatment. Almost 300,000 children die each year from congenital heart disease (CHD), with most deaths occurring in LMICs (1). The number of deaths due to CHD has declined by 34.5% since 1990, with a total of 180,624 deaths being among infants (aged <1 year). CHD mortality rates declined with increasing sociodemographic index (SDI) with most deaths occurring in countries in the LMIC SDI quintiles. Although the global deaths have decreased, much of these deaths still occur in LMICs, despite similar incidence of CHD across the globe.

Due to the expensive nature of cardiac surgery centers and the resources required to build and run one, accessible cardiac centers are far less common in LMICs than HICs. It is notable that CHD and acquired heart diseases, which affect a significant number of children, have largely been left to non-governmental organisations (NGOs) to address. This is due to the perceived challenges around cost, technology, availability of trained personnel, need for continuous follow-up, and the expertise required to affect change (2). Acute rheumatic fever (ARF), particularly when affecting the cardiovascular system, accounts for a major cause of infant and child mortality in LMICs, a pathology seldom seen in HICs. Despite this, many patients in LMICs who can afford treatment are travelling abroad for healthcare. To effect lasting change in LMICs, a special focus must be made on sustainable local care that can be effectively deployed and provided to assist CHD cases. Using funding in a more efficient manner than sending select patients abroad represents a logistical challenge which will take an organized effort and meaningful investment in the communities the practices will serve.

Consequently, for the patients with CHD reaching adulthood, a completely new and steadily growing patient population is forming patients with grown-up congenital heart disease (GUCH) or also known as adults with CHD (ACHD). The prevalence of GUCH is estimated to be 4 per 1,000 adults (3). Patients with GUCH often need long-term expert medical care and healthcare-related costs are high (4). Additionally, with the evolution of congenital cardiac surgery patients with GUCH are now developing ischemic heart disease (IHD) as they enter adulthood. This comes with complex concomitant congenital and ischemic heart disease which translates to an increasing global health burden (5). The organization of a medical network that can support such a patient is fathomable in HICs and in fact may be a luxury that is taken for granted. Such resources are not available for patients in LMICs, and patients will suffer without proper continued medical attention which they can readily access.

Crucially, in LMICs, most CHD cases are not diagnosed before birth owing to lack of antenatal screening. Early diagnosis of simple lesions could result in early referral to appropriate hospitals and treatment before the onset of irreversible sequelae. Other contributing factors include limitations in the existing infrastructure, lack of resources, low numbers of appropriately trained healthcare workers, and a general lack of awareness of heart disease in children. Meeting these challenges requires clinical evidence pertinent to the local settings, an adequate number of well-trained personnel, improvement in nursing and medical education, research, and quality improvement activities (6). All of these requirements are financially and organizationally demanding and therefore can be extremely difficult for LMICs to achieve. In total, 58% of the burden of disease of CHD could be averted by scaling up selected

Highlight box

Key findings

- A total of 4,027 congenital cardiac surgeons were identified from CTSNet, over 75% residing in high income countries (HICs) or upper-middle income countries (UMICs) despite these income groups only accounting for 16% of the world population.
- On average, HIC have 8.68 congenital cardiac surgeons per million population under 15 years, whereas low-income countries (LICs) have 0.13 congenital cardiac surgeons. About 93.4% of surgeons were male, and 6.6% were females.

What is known and what is new?

- Many studies have quantified the incidence of congenital heart disease in resource-constrained and compared these to the availability of surgeons per population in each world region.
- We quantified the availability of congenital cardiac surgeons worldwide and compared this data to the population under 15 years in each country to ascertain the ratio between disease burden and surgical availability.

What is the implication, and what should change now?

- The data further highlights the stark disparities in the availability of congenital cardiac surgeons available in low-middle-income countries (LMICs) compared to HICs. We propose various methods to address this gap including the globalization of the paediatric cardiac surgical workforce and globally coordinated training programmes.

surgical care in LMICs through various mechanisms (7).

There exists no database which provide the number of centers providing congenital cardiac surgery worldwide or for NGOs operating by humanitarian mission trips to provide paediatric cardiac services abroad. Cardiothoracic Surgery Network (CTSNet) (8) is a non-profit organization providing comprehensive information about cardiothoracic surgery worldwide. Individual users can subscribe to CTSNet, although the pool of surgeons and information on the website are overseen by the Society of Thoracic Surgeons (STS), the American Association for Thoracic Surgery (AATS), and the European Association for Cardio-Thoracic Surgery (EACTS). Twenty-two additional participating organizations are also involved in CTSNet. A recent study found a total of 12,180 adult cardiac surgeons were listed in the Cardiothoracic Surgery Network in August 2017, equaling 1.64 (0–181.82) adult cardiac surgeons and 0.52 (0–25.97) paediatric cardiac surgeons per million population globally (9). Large disparities existed between regions, ranging from 0.12 adult cardiac surgeons and 0.08 paediatric cardiac surgeons per million population (Sub-Saharan Africa) to 11.12 adult cardiac surgeons and 2.08 paediatric cardiac surgeons (North America). low-income countries (LICs) possessed 0.04 adult cardiac surgeons and 0.03 paediatric cardiac surgeons per million population, compared with 7.15 adult cardiac surgeons and 1.67 paediatric cardiac surgeons in HICs. The extrapolated data can be seen in *Table 1*.

Rationale and knowledge gap

Many studies have quantified the incidence of CHD in resource-constrained environments and compared these to availability of surgeons per population. However, no study to date has compiled and created a repository of the global paediatric cardiac surgical workforce.

Objective

We aimed to quantify the number and details of the congenital cardiac surgeons globally, compare the population of under 15's in each respective countries, and address the workforce gaps currently existing within pediatric cardiac surgery.

Methods

CTSNet was searched in 2021 to look up all congenital cardiac surgeons that were registered on the website. This included surgeons who operated on adult and congenital 78 patients, and those who operated on congenital patients exclusively. Information extracted include name of surgeon, sex, centre, city, country, world bank region, world bank income group, email address, and whether the surgeon operated on congenital patients exclusively. Sex of the surgeon was determined by searching the name on gender.api (10).

World bank data from 2021 (11) was used to classify each country into their appropriate world bank region, income group, and to ascertain the population of under 15 years in each respective country.

A scoping review was conducted to identify studies focusing on the global paediatric cardiac surgical workforce and CHD. A comprehensive search of electronic databases (PubMed, Science Direct, Cochrane Library, and Google Scholar) was searched with keywords "congenital heart disease", "CHD", "global cardiac surgery", "global congenital cardiac surgery", "global congenital cardiac workforce" from January 2024 to February 2024. No restrictions were placed on the searches, and evidence from these papers was analysed and summarised to produce this review.

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Informed consent and ethical approval was not required for this manuscript as the data collected and presented were entirely anonymous, with no identifiable information regarding individual surgeons.

Results

Table 1 demonstrates the availability of congenital cardiac surgeons in various countries/regions, categorized by World Bank regions and income groups. The data includes the number of surgeons, their gender distribution, population under 15 years, and the ratio of surgeons per million children in this age group.

Discussion

In total, 4,027 congenital cardiac surgeons were identified from CTSNet of which over 75% resided in HICs or UMICs despite these income groups only accounting for 16% of the world population. Several studies have attributed similar incidence and prevalence of CHD globally. Despite this, the unequal distribution in the availability of congenital cardiac surgeons is concerning and calls for better global

Table 1 Tabulated data of congenital cardiac surgeons extrapolated from CTSNet with world bank data for each respective country in 2021

Country/region	World bank region	World bank income group	No. of congenital cardiac surgeons	Male/female split	Population under 15 years	No. of surgeons per million population of under 15s
Afghanistan	South Asia	LIC	1	1:0	17,413,008	0.06
Albania	Europe & Central Asia	UMIC	4	4:0	457,788	8.74
Algeria	Middle East & North Africa	LMIC	16	16:0	13,567,972	1.18
Angola	Sub-Saharan Africa	LMIC	1	1:0	15,588,496	0.06
Argentina	Latin America & The Caribbean	UMIC	49	49:0	10,699,429	4.58
Armenia	Europe & Central Asia	UMIC	7	7:0	569,988	12.28
Australia	East Asia & Pacific	HIC	42	38:4	4,719,265	8.90
Azerbaijan	Europe & Central Asia	UMIC	10	9:1	2,425,452	4.12
Bahrain	Middle East & North Africa	HIC	1	1:0	298,172	3.35
Bangladesh	South Asia	LMIC	33	33:0	44,799,782	0.74
Barbados	Latin America & The Caribbean	HIC	2	0:2	48,260	41.44
Belarus	Europe & Central Asia	UMIC	7	6:1	1,566,586	4.47
Belgium	Europe & Central Asia	HIC	15	13:2	1,933,517	7.76
Bolivia	Latin America & The Caribbean	LMIC	6	5:1	3,759,372	1.60
Bosnia & Herzegovina	Europe & Central Asia	UMIC	1	1:0	488,002	2.05
Brazil	Latin America & The Caribbean	UMIC	153	148:5	44,024,037	3.48
Bulgaria	Europe & Central Asia	UMIC	8	7:1	962,521	8.31
Burkina Faso	Sub-Saharan Africa	LIC	1	1:0	9,744,403	0.10
Cambodia	East Asia & Pacific	LMIC	2	2:0	4,860,473	0.41
Cameroon	Sub-Saharan Africa	LMIC	1	1:0	11,540,518	0.09
Canada	North America	HIC	60	56:4	6,014,316	9.98
Chile	Latin America & The Caribbean	HIC	9	8:1	3,597,848	2.50
China	East Asia & Pacific	UMIC	199	186:13	249,536,785	0.80
Colombia	Latin America & The Caribbean	UMIC	26	25:1	11,125,504	2.34
Costa Rica	Latin America & The Caribbean	UMIC	2	1:1	1,059,059	1.89
Croatia	Europe & Central Asia	HIC	1	1:0	548,395	1.82
Cuba	Latin America & The Caribbean	UMIC	5	5:0	1,778,440	2.81
Cyprus	Europe & Central Asia	HIC	3	3:0	198,843	15.09
Czech Republic	Europe & Central Asia	HIC	5	5:0	1,681,233	2.97
Denmark	Europe & Central Asia	HIC	4	4:0	946,750	4.22
Dominican Republic	Latin America & The Caribbean	UMIC	5	4:1	3,041,808	1.64
Ecuador	Latin America & The Caribbean	UMIC	10	10:0	4,644,790	2.15
Egypt	Middle East & North Africa	LMIC	150	149:1	36,112,209	4.15
El Salvador	Latin America & The Caribbean	LMIC	2	2:0	1,626,626	1.23
Finland	Europe & Central Asia	HIC	4	3:1	854,904	4.68
France	Europe & Central Asia	HIC	54	43:11	11,772,947	4.59

Table 1 (*continued*)

Table 1 (*continued*)

Country/region	World bank region	World bank income group	No. of congenital cardiac surgeons	Male/female split	Population under 15 years	No. of surgeons per million population of under 15s
Georgia	Europe & Central Asia	UMIC	10	10:0	782,306	12.78
Germany	Europe & Central Asia	HIC	150	137:13	11,542,029	13.00
Ghana	Sub-Saharan Africa	LMIC	5	5:0	12,231,906	0.41
Greece	Europe & Central Asia	HIC	27	25:2	1,486,054	18.17
Guatemala	Latin America & The Caribbean	UMIC	1	1:0	5,634,189	0.18
Hong Kong	East Asia & Pacific	HIC	1	1:0	902,447	1.11
Hungary	Europe & Central Asia	HIC	5	5:0	1,413,125	3.54
Iceland	Europe & Central Asia	HIC	2	2:0	69,396	28.82
India	South Asia	LMIC	524	498:26	361,569,242	1.45
Indonesia	East Asia & Pacific	UMIC	32	30:2	69,742,692	0.46
Iran	Middle East & North Africa	UMIC	56	56:0	20,935,552	2.67
Iraq	Middle East & North Africa	UMIC	28	28:0	16,595,402	1.69
Ireland	Europe & Central Asia	HIC	13	12:1	1,002,263	12.97
Israel	Middle East & North Africa	HIC	21	21:0	2,639,906	7.95
Italy	Europe & Central Asia	HIC	155	142:13	7,481,434	20.72
Ivory Coast	Sub-Saharan Africa	LMIC	1	1:0	11,485,339	0.09
Jamaica	Latin America & The Caribbean	UMIC	4	3:1	574,011	6.97
Japan	East Asia & Pacific	HIC	148	127:21	14,797,709	10.00
Jordan	Middle East & North Africa	UMIC	9	9:0	3,635,351	2.48
Kazakhstan	Europe & Central Asia	UMIC	8	8:0	5,611,487	1.43
Kenya	Sub-Saharan Africa	LMIC	3	3:0	20,351,588	0.15
Kosovo	Europe & Central Asia	UMIC	4	4:0	392,962	10.18
Kuwait	Middle East & North Africa	HIC	2	2:0	897,630	2.23
Lebanon	Middle East & North Africa	UMIC	5	5:0	1,544,594	3.24
Lithuania	Europe & Central Asia	HIC	2	2:0	425,241	4.70
Macau SAR China	East Asia & Pacific	HIC	1	1:0	100,338	9.97
North Macedonia	Europe & Central Asia	UMIC	2	2:0	331,773	6.03
Malaysia	East Asia & Pacific	UMIC	28	28:0	7,709,094	3.63
Mauritius	Sub-Saharan Africa	HIC	1	1:0	210,689	4.75
Mexico	Latin America & The Caribbean	UMIC	62	59:2	31,616,904	1.96
Moldova	Europe & Central Asia	LMIC	3	3:0	514,126	5.84
Monaco	Europe & Central Asia	HIC	1	0:1	4,698	212.86
Mongolia	East Asia & Pacific	LMIC	1	1:0	1,085,725	0.92
Morocco	Middle East & North Africa	LMIC	18	14:4	9,956,001	1.81
Myanmar	Europe & Central Asia	LMIC	3	3:0	13,385,964	0.22

Table 1 (*continued*)

Table 1 (*continued*)

Country/region	World bank region	World bank income group	No. of congenital cardiac surgeons	Male/female split	Population under 15 years	No. of surgeons per million population of under 15s
Nepal	South Asia	LMIC	10	9:1	8,827,834	1.13
Netherlands	Europe & Central Asia	HIC	21	16:5	2,718,089	7.73
New Zealand	East Asia & Pacific	HIC	8	6:2	965,576	8.29
Nicaragua	Latin America & The Caribbean	LMIC	3	3:0	2,060,498	1.46
Nigeria	Sub-Saharan Africa	LMIC	25	23:2	92,372,972	0.27
Norway	Europe & Central Asia	HIC	5	5:0	917,593	5.45
Oman	Middle East & North Africa	HIC	8	8:0	1,210,110	6.61
Pakistan	South Asia	LMIC	49	47:2	85,480,175	0.57
Panama	Latin America & The Caribbean	HIC	3	3:0	1,149,092	2.61
Paraguay	Latin America & The Caribbean	UMIC	3	3:0	1,945,503	1.54
Peru	Latin America & The Caribbean	UMIC	12	12:0	8,877,308	1.35
Philippines	Europe & Central Asia	LMIC	20	20:0	34,889,268	0.57
Poland	Europe & Central Asia	HIC	23	20:3	5,801,467	3.96
Portugal	Europe & Central Asia	HIC	22	22:0	1,382,610	15.91
Qatar	Middle East & North Africa	HIC	8	7:1	423,907	18.87
Romania	Europe & Central Asia	HIC	20	17:3	3,064,651	6.53
Russia	Europe & Central Asia	UMIC	25	25:0	25,539,356	0.98
Saudi Arabia	Middle East & North Africa	HIC	53	53:0	9,411,988	5.63
Senegal	Sub-Saharan Africa	LMIC	2	2:0	7,047,810	0.28
Serbia	Europe & Central Asia	UMIC	4	3:1	975,162	4.10
Singapore	East Asia & Pacific	HIC	13	13:0	654,053	19.88
Slovakia	Europe & Central Asia	HIC	3	3:0	865,081	3.47
Slovenia	Europe & Central Asia	HIC	2	2:0	320,184	6.25
South Africa	Sub-Sharan Africa	UMIC	28	28:0	17,029,519	1.64
South Korea	East Asia & Pacific	HIC	47	44:3	6,153,685	7.64
Spain	Europe & Central Asia	HIC	68	59:9	6,688,904	10.17
Sri Lanka	South Asia	LMIC	14	12:2	5,143,439	2.72
Sudan	Sub-Saharan Africa	LIC	9	9:0	18,758,652	0.48
Sweden	Europe & Central Asia	HIC	13	11:2	1,845,060	7.05
Switzerland	Europe & Central Asia	HIC	29	28:1	1,311,402	22.11
Syria	Middle East & North Africa	LIC	26	23:3	7,042,047	3.69
Taiwan	East Asia & Pacific	HIC	15	15:0	No data	No data
Tajikistan	Europe & Central Asia	LIC	1	1:0	3,550,262	0.28
Tanzania	Sub-Saharan Africa	LMIC	3	3:0	27,729,190	0.11
Thailand	East Asia & Pacific	UMIC	19	18:1	11,313,244	1.68

Table 1 (*continued*)

Table 1 (*continued*)

Country/region	World bank region	World bank income group	No. of congenital cardiac surgeons	Male/female split	Population under 15 years	No. of surgeons per million population of under 15s
Trinidad and Tobago	Latin America & Caribbean	HIC	1	1:0	294,443	3.40
Tunisia	Middle East & North Africa	LMIC	10	10:0	3,055,772	3.27
Turkey	Europe & Central Asia	UMIC	229	205:24	19,758,223	11.59
Uganda	Sub-Saharan Africa	LIC	1	1:0	20,722,071	0.05
Ukraine	Europe & Central Asia	LMIC	28	26:2	6,671,328	4.20
United Arab Emirates	Middle East & North Africa	HIC	12	12:0	1,418,167	8.46
United Kingdom	Europe & Central Asia	HIC	131	117:14	11,837,654	11.07
United States	North America	HIC	718	673:45	60,572,632	11.85
Uruguay	Latin America & The Caribbean	LMIC	2	2:0	665,952	3.00
Uzbekistan	Europe & Central Asia	LMIC	7	7:0	10,499,310	0.67
Venezuela	Latin America & Caribbean	UMIC	14	14:0	7,944,108	1.76
Vietnam	East Asia & Pacific	LMIC	7	6:1	21,974,314	0.32
Yemen	Middle East & North Africa	LIC	3	3:0	13,150,475	0.23
Zimbabwe	Sub-Saharan Africa	LMIC	2	2:0	6,540,280	0.31

LIC, low-income country; LMIC, low-middle-income country; UMIC, upper-middle-income country; HIC, high-income country.

distribution of fair access to congenital cardiac surgery.

On average, HICs have a significantly higher number of congenital cardiac surgeons per million children under 15 with 8.68 surgeons per million population. UMIC have 3.80, LMICs 1.99, and LICs 0.13 surgeons per million population. The comparison to surgical availability and paediatric population is important. For example, although India has 524 congenital cardiac surgeons, when comparing this figure to the population of under 15 years, we find that the ratio is only 1.45 surgeons per million population under 15 years.

An important consideration is also that, accordingly with the CTSNet survey, many surgeons defined themselves as "congenital", despite their larger surgical activity was dedicated to adult patients. In these cases, we can easily speculate that the proportion of daily practice dedicated to surgery of congenital lesions was limited to the simplest malformations, therefore those surgeons do not really provide the care required by a large pediatric patient population with complex congenital heart defects.

The disproportional number of surgeons highlight the significant implications for public health. It is well known that untreated or inadequately treated CHD can lead to severe health complications, decreased quality of life, and ultimately increased mortality rates and increased costs of care. Several factors may contribute to the availability of trained personnel including the training opportunities and funding requirements to become a congenital cardiac surgeon, healthcare infrastructure, and crucially, limited geographic coverage of individual centers. A global study indicated that a paediatric surgical workforce density (PSWD) equal to or greater than 4 significantly correlated to odds of survival (12).

This study also highlights a broader issue of global healthy inequity whereby patients have access to essential surgical care determined by their geographical location and economic status. It raises questions regarding the ethical implications on the density of resource available and the global responsibility to address this issue. Disparities within the same region are also evident from our data. For example, in Latin America and The Caribbean, Barbados has 41.44 surgeon per million children under 15, whilst Bolivia only has 1.60.

In many countries, there may be significant differences in access to congenital cardiac surgeons between urban and rural areas, further exacerbating disparities. For example, Senegal has one congenital cardiac surgery centre in the capital, Dakar, to serve over seven million under 15 years

with a land area of just under two-hundred thousand square kilometer. Critically, recent modelling has suggested that despite the high number of centers in the USA, only one-third of the existing centers are required to provide safe care for patients with CHD given that two-thirds of the centers are within 25 miles of each other (13). A more sustainable approach could involve fostering the growth of a global cardiac surgical workforce where residents and attending surgeons extend their expertise to underserved regions grappling with a disproportionate burden of CHD.

Recognizing this inequality calls for prompt action from governments, healthcare organisations, and the international community. Steps can include investment in medical education and training programmes in LMICs, the establishment of specialized pediatric cardiac centers in underserved areas, and the international collaborations to ensure equitable access to cardiac care. Ongoing research and advocacy efforts are essential to raise awareness of this issue and to monitor progress in reducing the disparities in access to congenital cardiac surgery. Engaging in data-driven research and sharing success stories from regions that have improved access can inspire positive change.

Our study found that 93.4% of surgeons were male and only 6.6% were females. It is well established that women are significantly underrepresented in cardiac surgery and is largely influenced by a range of factors including long-standing gender stereotypes, biases within the medical profession, and lack of higher training opportunities for women around the world. Female congenital cardiac surgeons who have successfully navigated the challenges in their field can serve as a powerful role model for aspiring women in congenital cardiac surgery. Encouragingly, there have been efforts in HICs and UMICs in recent years to address this imbalance. However, there is still much work to be done to achieve gender equality in the field of congenital cardiac surgery.

Lack of resources and personnel are among the biggest and most prominent barriers in delivering satisfactory care to all patients. Studies showed positive correlation between mortality rates and number of congenital cardiac services available in their country. The intricate nature of pediatric cardiac surgery demands a skilled workforce, a resource often scarce in LMICs. The shortage of cardiac surgeons, anesthetists, perfusionists, technicians and specialized nursing staff significantly impedes the delivery of surgical intervention, contributing to the healthcare disparity (14). Screening of CHD is an equally important aspect of workforce planning. One study found that the addition of pulse oximetry increased the diagnosis of CHD to between 75.5% to 84.6% (15). By integrating noninvasive and cost-effective screening method into routine health assessments for newborns and infants, healthcare providers can identify CHD cases that might otherwise go undetected until later stages, potentially leading to more severe health complications. We recognize that access to medical equipment varies across different settings and our study seeks to shed light on the disparities and limitations that exist in this regard. We believe that by highlighting these challenges, our study can contribute to a more informed discussion on strategies to improve access to essential medical equipment, whether through targeted investments, technology transfer initiatives, or other collaborative efforts. However, further studies are required to holistically cover the challenges of setting up a CHD centre in a resource-constrained environment.

We found that although the prevalence of CHD is very similar between LMICs and HICs, most deaths were occurring in LMICs. Due to socioeconomic constrains in LMICs, CHD services are often grouped in tertiary/quaternary care centers which means they are only available in specific locations. Additionally, CHD have largely been left to NGOs to address due to the challenges surrounding cost, technology, availability of trained personnel, and the expertise required to affect change. A 2014 survey found 80 NGOs existed that provided paediatric cardiovascular care in LMICs (16).

Historically, patients were flown into hospitals in high-income countries (HICs). However, this proved to be too expensive and not sustainable in training up the local teams in LMICs. The cost of sending a cardiac surgical team to operate on 10–20 children in LMICs is equal to sending a single patient to HIC centers for their surgical care (17). Humanitarian mission trips bring lifesaving pediatric cardiac surgery to the underserved population. These trips are a response to the unique challenges of paediatric cardiac surgery including the need for specialized personnel and infrastructure, cost and resources of surgery and post-operative care, absence of healthcare insurance, training of local teams, and knowledge transfer initiatives.

A key aim within NGOs providing cardiac surgical care in resource-constrained environments is to train up the local surgical team. For example, Mécénat Chirurgie Cardiaque (MCC), a French based NGO, developed a distant training programme for physicians from LMICs to provide comprehensive online lectures within paediatric cardiology. Best scoring candidates in their final exam

following the lectures are invited to France for a month to visit the local pediatric cardiology facilities. Other NGOs report utilizing lost-cost high-fidelity surgical simulation tools to train up the local teams at an accelerated pace. Sustainable impact requires continuous education and training programs for local healthcare professionals. The primary goal of mission trip is to provide training so that the local teams can function autonomously, self-finance, and train surgeons to come. Beyond clinical skills, these programs should encompass managerial and administrative aspects, empowering local professionals for self-reliance and capacity building. Studies have suggested key aspects in structuring a long-term sustainable partnership with centers in LMICs include appropriate site selection where the team are keen on developing a long-term programme of congenital cardiac surgery, demographic research to ascertain the burden of CHD in a given area and the logistics of providing care, a comprehensive site assessment to assess the infrastructure and equipment for long-term success, and organization of surgical teams (18).

Additionally, continuous data collection during the peri-operative is required to understand limitations in current practice and to identify avenues for improvement. Organisations such as the International Children's Heart Foundation (ICHF) require the local hospitals to have a fully functioning blood bank, access to medical subspecialties, or not operating on those weighing less than 10 kg until local capacity has been developed (19). This dropped their mortality from 1.2% to 0%, 1.8% to 0%, 0% to 0%, and 5.6% to 5.1% for atrial septal defect (ASD) repair, ventricular septal defect (VSD) repair, patent ductus arteriosus (PDA) ligation, and repair of tetralogy of Fallot, respectively. The reoperation rate fell from 11% to 3% and reoperation for a bleeding indication fell from 6% to 2%.

A significant 52% of the CHD burden could be addressed by surgical care (20); yet most LMICs and some HICs lack sufficient access to pediatric cardiac surgical care. Some countries even lack any local care whatsoever. Educating government and community leaders about prevention and treatment of paediatric heart disease is imperative because building sustainable cardiovascular services is complex and expensive. Building high-quality cardiovascular services in LMICs require intensive coordinated efforts, infrastructure development, identification of key stakeholders, and building collegial relationships for ongoing consultation and mentorship. Infrastructure development requires a significant amount of capital, building new or renovating old facilities, purchasing equipment, support services such as pharmacy, blood bank, operating rooms, and intensive care resources, and, most importantly, human resources (21). The demanding nature of the formation of a cardiovascular service as described is intimidating, especially for financially constrained LMICs, but will prove to be essential to make a lasting impact on decreasing mortality from CHD and also for the long-term health of their populations. This challenge is no small task: a paradox of the paediatric cardiac literature is that the majority is written in 10% of the world that has the full range of services, and not in the 90% that is still underdeveloped (14).

It is important to note that this study only focused on the availability of congenital cardiac surgeons, which only represents one component of the broader multidisciplinary team involved in the care of patients with CHD. The availability of other crucial team members including cardiac nurses, anesthetists, pediatric cardiologists, perfusionists, remain an equally vital aspect that warrants examination. Further research should aim to encompass a more holistic analysis of the entire healthcare ecosystem to gain a comprehensive understanding of the challenges and disparities in providing specialized care to patients with CHD worldwide.

Finally, a major limitation of CTSNet is the lack of up-to-date verified surgeon's data. Multiple surgeons on the list were found to be not currently practicing, and many surgeons based in LMICs were not included in the last. For example, the data suggests there are 131 surgeons working in the UK, however, there are only 40. This is further misrepresented in the surgeon to population ratio where Monaco has a ratio of 212.86 surgeons per million children under the age of 15 simply because the private hospital is offering a handful of cases each year by numerous visiting surgeons. Additionally, many surgeons especially in LMICs are trained as general surgeons or trauma surgeons but routinely perform cardiac surgery. This population is not captured in the CTSNet data. Multiple countries including those in HICs (e.g., Austria) and those in LMICs (e.g., Ethiopia) are not included in CTSNet data. However, the CTSNet data provides a general scope of the current landscape of the congenital cardiac workforce globally. The CTSNet partially overcomes this by allowing 25 independent societies, including EACTS, STS, and AATS to oversee and revise the registry as required. Additionally, individual surgeons have the opportunity to contribute and update their own information on CTSNet.

With the globalization of the pediatric cardiac surgical workforce, globally coordinated training programmes

including those in LMICs will enable the next generation of global surgeons to understand the disease process in a broad spectrum of patients and support research development. In light recent technological advancements, virtual MDTs, simulation training, and online mentorship will allow for a global training curriculum. Future research should address the quantification of global pediatric cardiac surgical trainees to plan long-term sustainability and prevent further serious healthcare shortages. A truly global paediatric cardiac surgical workforce will allow us to bridge the gap in service provision between HICs and LICs.

Conclusions

The disparity between HICs and LMICs present in congenital cardiac surgery facilities is a global health issue that will take serious thought and planning to resolve. The high proportion of preventable deaths from CHD cases is a regrettable figure that governments and medical organisations should further strive to decrease. The 66% of preventable deaths that stem from CHD in LMICs could be alleviated by further investment in cardiac services that are accessible for the population (7). Lack of resources and personnel are among the biggest and most prominent barriers in delivering satisfactory care to all patients. The stark contrast in surgeries performed and surgeons available between HICs and LMICs attests to this (9). Furthermore, the medical network required to successfully maintain a cardiac centre is extensive and complex; and requires logistical planning. In LMICs, such convenience is not a readily available commodity, and patients find that they cannot access the care available to them, and that the care they receive may not be adequate for survival. Improving upon this scenario represents a significant challenge for cardiac medicine, but also one that will prevent numerous deaths. However, the global number of deaths from CHD has decreased and can continue to decrease if resources are focused on where they will be of most use (1). With over 70% of CHD cases requiring medical or surgical treatment within their first year of life, we can see the value of early screening and proactive medical practice. Above all, education, and proactive investment in LMICs will allow for infrastructure to be built, quality of life improved, and for lives to be saved.

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