The outcome of surgery for congenital heart disease in India: A systematic review and metanalysis

Lamk Kadiyani[1], Mani Kalaivani[2], Krishna S. Iyer[3], Sivasubramanian Ramakrishnan[1]

[1]Department of Cardiology, All India Institute of Medical Sciences, New Delhi, India, [2]Department of Biostatistics, All India Institute of Medical Sciences, New Delhi, India, [3]Department of Pediatric and Congenital Heart Surgery, Fortis Escorts Heart Institute, New Delhi, India

ABSTRACT

Background : **The mortality risks of children undergoing various cardiac surgeries for congenital heart disease (CHD) in India are not well defined. We conducted a systematic review and meta-analysis to estimate the inhospital mortality of various common CHD surgeries reported in India and compared it to representative data from established Western databases.**

Methods and Results : **We searched four bibliographic databases for studies published in India over the last 25 years. In total, 135 studies met the inclusion criteria and included 30,587 patients aged from 1 day to 65 years. The pooled mortality rate of 43 Indian studies reporting multiple CHD surgical outcomes is 5.63% (95% confidence interval [CI]: 4.26–7.16; I^2 = 93.9%), whereas the Western data showed a pooled mortality rate of 2.65% (*P* value for comparison <0.0001). The pooled mortality risk for ventricular septal defect closure and tetralogy of Fallot repair in Indian studies was 2.87% (95% CI: 0.76–5.91; I^2 = 62.4%) and 4.61% (95% CI: 2.0–8.02; I^2 = 87.4%), respectively. The estimated mortality risk was higher than the Western databases for all subcategories studied except for surgeries in the grown-ups with CHD population and coarctation repair.**

Conclusions : **The estimated mortality risks are higher among Indian patients undergoing cardiac surgery for CHD as compared to Western data. We need prospective multicentric data to document whether the observed excess mortality exists after adjusting for various high-risk features and comorbidities in Indian patients. We need systemic measures to improve the outcomes of CHD surgeries in India.**

Keywords : Operative mortality, low- and middle-income countries, pooled mortality risk, congenital heart surgery

INTRODUCTION

Across the globe, around 130 million children are born annually, and 4 million are estimated to die during the neonatal period.[1] Seven percent of these deaths are due to congenital abnormalities,[2] with cardiac illness being the most common.[3,4] It is estimated that 90% of children are born in low- and middle-income countries (LMIC). However, <20% of cardiac surgeries happen in these countries.[5,6] A vast majority of children with correctable congenital heart disease (CHD) are not operated on time in the LMIC countries. India's high birth

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Address for correspondence: Prof. Sivasubramanian Ramakrishnan, Department of Cardiology, All India Institute of Medical Sciences, New Delhi, India. E-mail: ramaaiims@gmail.com

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rate predicts 150,000–200,000 children are born with CHD each year, with at least 50,000 neonates and infants requiring early intervention.[5,7] Currently, less than one-third to one-fourth of these children are operated on. Children undergoing surgery in LMIC countries are often burdened with comorbidities of heart failure, serious infections, prolonged cyanosis, pulmonary vascular disease, and malnutrition.[8]

In India, lower rates of antenatal diagnosis of CHD, delayed diagnosis of CHD, issues related to accessibility and affordability of pediatric cardiac care, and lack of a formal referral system for CHD may lead to inadequate delivery of care. Hence, CHD surgery-related outcomes may be suboptimal in India as compared to the corresponding Western data. However, the magnitude of differences is unknown and could vary for different surgeries and subgroups. Large-scale prospective data from India studying the outcomes of CHD surgeries are limited. In addition, analyses comparing pediatric cardiac surgery outcomes across countries are limited.[9] No formal analysis specifically compares the outcomes of CHD surgeries observed in India with those of developed countries. Hence, we compiled the published data from India over 25 years on CHD surgical outcomes in this systematic review. We intended to estimate the inhospital mortality of cardiac surgeries for CHD reported from India and compare it to the representative data from established Western registries of the developed world, such as the STS (Society of Thoracic Surgeons) Database.

MATERIALS AND METHODS

Search strategy

We searched the electronic databases PubMed, Embase, Web of Science, and Scopus for studies published in India between January 1998 and March 2023. The search terms included "congenital heart disease" OR "congenital heart defect" OR "congenital heart malformation" AND "outcome" OR "surgery." Our initial searches revealed 46,304 studies, which were narrowed down to 1442 after applying the date range and country filters. We also manually searched the reference lists of relevant articles and review papers.

Study selection

The following steps were taken for study selection: (1) identification of titles of records through database search, (2) removal of duplicates, (3) screening and selection of abstracts, (4) assessment for eligibility through full-text articles, and (5) final inclusion in the study. There were no language restrictions. Two authors (LK and SR) independently screened the titles and abstracts of the identified studies for relevance and then reviewed the full-text articles for inclusion/exclusion. When there was disagreement, a third reviewer (MK) decided to include or exclude the study. Ethical approval did not apply to this study because it consisted of a systematic review with meta-analysis. The study protocol was registered in the PROSPERA database (ID: CRD42023462297).

Inclusion and exclusion criteria

Using the Population, Interventions, Comparison, Outcome, and Study Design strategy, studies were included if the following criteria were fulfilled: (1) Patients who underwent any cardiac surgical procedure for a CHD; (2) Published in the last 25 years (1998–2023), (3) Published from an Indian center, (4) Outcomes studied included hospital mortality, and (5) Studies could be retrospective, prospective, clinical trials, or case series. We excluded studies reporting surgical outcomes of only specific risk-category patients and redo surgery. Case reports and case series with less than five patients were also excluded. We extracted the following data from each included study: total number of patients, age (mean/median and range), gender, type of surgical deaths including operative, inhospital, and 30-day mortality, and preoperative risk scores. Any discrepancies were resolved through discussion. The studies were then divided into overall and lesion-specific groups based on the population studied.

Outcomes

The primary outcome of the meta-analysis is to estimate the inhospital mortality of cardiac surgeries for CHD reported from India and compare it to the representative data from established Western databases. Secondary outcomes included individual surgical mortality of various common lesions reported from India and analysis of the reported Risk Adjustment for Congenital Heart Surgery (RACHS) score-based mortality. We planned to report the outcome of surgery for ventricular septal defect (VSD), aortopulmonary window, and coarctation of the aorta among acyanotic CHD. Tetralogy of Fallot (TOF), transposition of great arteries (TGA), and total anomalous pulmonary venous drainage (TAPVC) outcomes were compared to represent the correctable cyanotic CHD group. Among the palliative surgeries, we compared outcomes of the pulmonary artery banding, Blalock–Taussig–Thomas shunt (BTTS), bidirectional Glenn shunt (BDG), and Fontan surgeries. The outcome of surgeries for grown-ups with congenital heart disease is also compared with the available Western database. We excluded studies reporting other CHD surgery outcomes, including atrial septal defect, atrio-ventricular septal defect, partial venous anomalous venous drainage, double-outlet right ventricle, and congenital valve surgeries.

Data extraction

The method is outlined in the PRISMA flow diagram [Figure 1].

Risk-of-bias (quality) assessment

Risk-of-bias assessment was made using the mixed method appraisal tool (MMAT) version 2018 for systematic reviews of studies, including qualitative, quantitative, and mixed methods studies. Sufficient data for analysis were available for 133 studies. The most common category of the studies was quantitative descriptive (126), followed by randomized controlled trials (6), and the remaining one was a nonrandomized clinical trial. The individual study MMAT scoring table and overall category-wise scores are provided in Supplementary Table 1.

Statistical analysis

A pairwise meta-analysis was performed for overall analysis. We used the DerSimonian and Laird random effects model in our study to determine the 95% confidence interval (CI) and pooled risk ratio for each outcome. We utilized the Higgins I^2 statistic to compute between-study heterogeneity calculations. Low heterogeneity and high heterogeneity are defined by I^2 <25% and >75%, respectively. We also conducted a leave-one-out sensitivity analysis to eliminate the impact of individual studies on our findings. The studies were divided into overall and lesion-specific groups based on the population studied. We used the Chi-square test to compare Indian data with the Western outcome. All tests were 2-tailed with a $P < 0.05$ considered statistically significant.

Reporting

We reported the results of our meta-analysis using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. The estimates of sensitivity and CIs are presented.

RESULTS

Out of the 1442 studies identified, 135 were finally included in the analysis, and the process is summarized in Figure 1. Details of the included Indian studies are presented in Table 1. Most studies were retrospective (73.3%) and single-center (99.3%) studies reporting lesion-specific outcomes. Only one study (Nair *et al.* 2021) was a multicentric study reporting outcomes among 2059 patients with CHD from Kerala.[10] Only 43 studies reported outcomes of multiple CHD surgeries, and 65.2% of studies were published in the last 10 years. The primary analysis excluded studies reporting data from other LMICs (not exclusively in India).[11-13] About 16% of the patients in these analyses were from seven Indian centers. For the comparator, the Western data obtained from reports published in 2021 by the Society of Thoracic Surgery (STS)[14] were multicentric and prospective, while the GUCH data obtained from the European database[15] were retrospective in nature.

We compared the mortality outcomes reported by 135 Indian studies and compared them with the major international multicentric registries. We included 30,587 patients with ages ranging from 1 day to 65 years. The studies were divided based on patient population, either reporting outcomes of lesion-specific studies or varied CHD surgeries. The pooled mortality rate of the 43 studies reporting varied multiple CHD surgical outcomes published in the country from 1998 to 2023 is 5.63% (95% CI: 4.26–7.16; $I^2 = 93.9\%$) [Figure 2], whereas the Western data throughout 2016–2021 reported a mortality rate of 2.65%. When we compared the Indian studies published in the last 10 years (after 2012), the pooled mortality is 5.35% (95% CI: 4.46–6.32). We also performed a supplementary analysis, including studies involving other LMICs that included a significant proportion of patients from India (otherwise excluded in the primary analysis). This analysis involving 49 studies ($n = 86116$) showed a pooled mortality rate of 5.84% (95% CI: 4.93–6.82; $I^2 = 94.4\%$).

Only a few Indian and LMIC studies reported RACHS classification-based outcomes [Table 2a]. However, more

Table 1: Details of the included Indian congenital heart disease surgery outcome studies

Type of outcome reported	Number of studies	Prospective (%)	In the last 10 years (2012–2023), *n* (%)
Overall outcome	43	23 (53.5)	31 (72.1)
GUCH population	13	0	6 (46.2)
Lesion-specific - acyanotic CHD surgeries			
Ventricular septal defect	8	4 (50)	7 (87.5)
Aortopulmonary window	7	0	6 (85.7)
Coarctation of aorta	4	0	3 (75)
PA banding	5	0	2 (40)
Lesion-specific - cyanotic CHD surgeries			
TOF	19	8 (42.1)	16 (84.2)
TGA	10	1 (10)	7 (70)
TAPVC	10	0	5 (50)
BTTS	7	0	1 (14.3)
Bidirectional Glenn shunt	6	0	2 (33.3)
Fontan	3	0	2 (66.7)

CHD: Congenital heart disease, GUCH: Grown-ups with congenital heart disease, PA: Pulmonary artery, TOF: Tetralogy of Fallot, TGA: Transposition of great arteries, TAPVC: Total anomalous pulmonary venous connection, BTTS: Blalock–Taussig–Thomas shunt

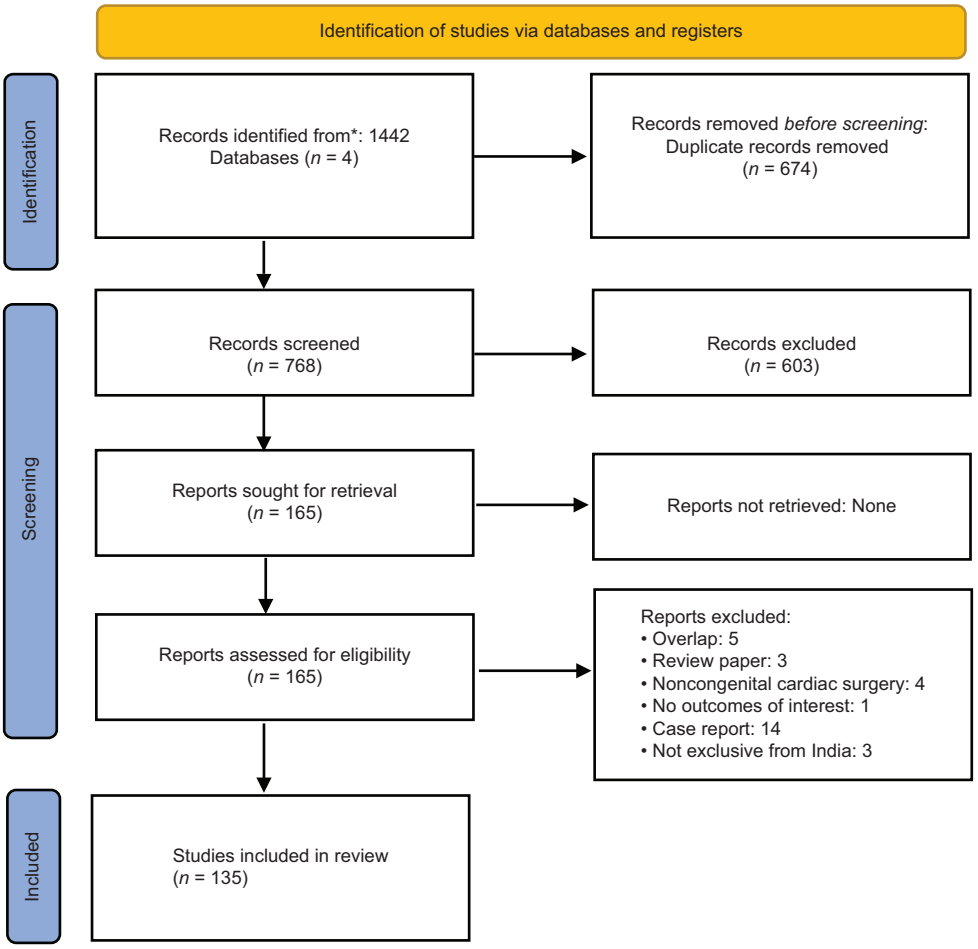

Figure 1: Schematic flow chart showing the selection of studies

studies reported the distribution of patients in various RACHS classes [Table 2b]. Out of 20,511 patients included in these studies, RACHS scoring could be calculated for 19,606 patients [Table 2b]. The chosen Western databases reported STAT categorization only [Table 3].

Western data showed the maximum number of patients in STAT category 1. Nearly two-thirds of patients were in categories 1–3, with <4% of patients in category 4 and none in category 5. In contrast, most Indian patients belonged to RACHS category 2, with 6.5% belonging to categories 4–6. Numerically, the observed mortality seems higher in Indian studies across the various classes. However, head-to-head comparison of Indian, other LMICs and Western data were impossible due to significant heterogeneity in reporting preoperative risk classification and outcomes. Similarly, the age and gender distribution of patients also could not be meaningfully analyzed due to significant heterogeneity in reporting.

The pooled inhospital mortality of surgery reported by Indian studies for VSD (n = 1400; 8 studies) was 2.87% (95% CI: 0.76–5.91; I^2 = 62.4%), coarctation of the aorta (n = 151; 4 studies) was 2.25% (95% CI: 0.18–5.75; I^2 = 0%), and APW (n = 368; 7 studies) was 4.43% (95% CI: 0.44–10.96; I^2 = 75.29%) [Figure 3].

Table 2a: Risk adjustment for congenital heart surgery category-wise mortality reported from the pooled Indian and low- and middle-income countries studies[11,43,44]

RACHS-1 category	Alam S *et al.* (2018)	Joshi S *et al.* (2014)	Jenkins KJ *et al.* (2014)	Total	Mortality (%)
1	163	224	2724	3111	1.51
2	613	797	7254	8664	4.07
3	72	111	3347	3530	10.67
4	72	5	750	827	17.62
5+6	0	0	87	87	51.10

RACHS: Risk adjustment for congenital heart surgery

Among surgeries for cyanotic CHD, the pooled inhospital mortality of surgery reported by Indian studies for TGA (n = 1069; 10 studies) was 9.2% (95% CI: 4.86–14.6; I^2 = 83.19%), TAPVC (n = 1157; 10 studies) was 7.96% (95% CI: 2.54–15.65; I^2 = 93%), and TOF (n = 2053; 19 studies) was 4.53% (95% CI: 2.09–7.67; I^2 = 86.64%) [Figure 4].

The pooled inhospital mortality of palliative surgeries reported by Indian studies were: PA banding (n = 284;

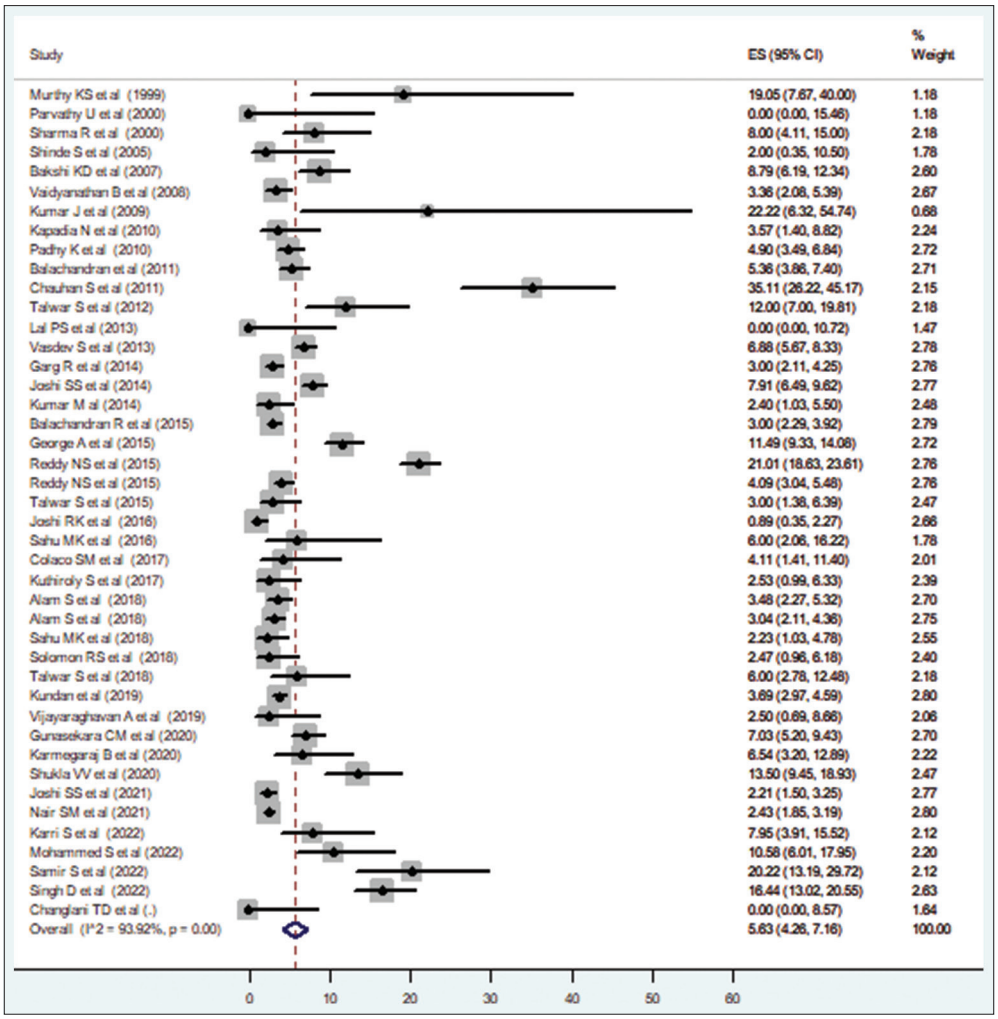

Figure 2: Pooled analysis of in-hospital mortality reported by pediatric cardiac surgery studies from India[10,16-54]

Table 2b: The Indian and low- and middle-income countries studies that are reporting the risk adjustment for congenital heart surgery score[11,28,43,44,46,55,56]

Author (year)	Total (*n*)	Mortality (%)	RACHS 1, *n* (%)	RACHS 2, *n* (%)	RACHS 3, *n* (%)	RACHS 4, *n* (%)	RACHS 5, *n* (%)	RACHS 6, *n* (%)
Joshi SS *et al.* (2014)	1150	7.9	224 (19.5)	797 (69.3)	111 (9.7)	5 (0.4)	0	0
Jenkins KJ *et al.* (2014)	15,049	6.3	2724 (18.1)	7254 (48.2)	3347 (22.2)	750 (5.0)	9 (0.1)	78 (0.5)
Reddy *et al.* (2015)	1028	4.1	50 (4.9)	544 (52.9)	303 (29.5)	120 (11.7)	0	11 (1.1)
Balachandran R *et al.* (2015)	1702	3.0	230 (13.5)	815 (47.9)	510 (30.0)	129 (7.6)	2 (0.1)	11 (0.7)
Alam S *et al.* (2018)	574	3.5	51 (8.9)	407 (70.9)	62 (10.8)	54 (9.4)	0	0
Alam S *et al.* (2018)	920	3.0	163 (17.7)	613 (66.6)	72 (7.8)	72 (7.8)	0	0
Karri S *et al.* (2022)	88	8.0	0	48 (54.6)	9 (10.2)	28 (31.8)	3 (3.4)	0
Overall	19,606	5.8	3442 (17.6)	10,478 (53.4)	4414 (22.5)	1158 (5.9)	14 (0.1)	100 (0.5)

RACHS: Risk adjustment for congenital heart surgery

5 studies) 5.82% (95% CI: 0.3–15.87; I^2 = 85.69%), blalock-taussig-thomas (BTT) shunt (*n* = 371; 7 studies) 5.61% (95% CI: 2.31–9.96; I^2 = 49.65%), BDG (*n* = 1116; 6 studies) 4.04% (95% CI: 1.56–7.45; I^2 = 81.22%), and Fontan (*n* = 242; 3 studies) 5.89% (95% CI: 2.19–11.01; I^2 = 0%) [Figure 5].

Analysis of cardiac surgery among the GUCH population included 13 Indian studies involving 2467 patients. The pooled mortality was 2.61% (95% CI: 0.81–5.07; I^2 = 74.8%) [Figure 6].

We compared the pooled mortality from Indian studies with that from representative Western databases [Table 4].

For studies reporting the outcome of multiple varied CHD surgeries, the pooled mortality of Indian studies was 5.63% compared to 2.65% reported by the STS

database (P < 0.00001 for comparison). For surgery among the GUCH population, the mortality reported was 2.61% by Indian studies compared to 3.02% by the European database (P = 0.22). Indian pooled mortality was higher for all the lesion-specific outcomes analyzed except for surgery for coarctation of the aorta (P = 0.06).

DISCUSSION

Our analysis shows that Indian patients have a pooled mortality rate of 5.84% (4.93–6.82) for cardiac surgery for CHD, which is comparable to that reported from other LMIC countries (5.65% [5.0%–6.8%]).[11-13] However, it is much higher than the mortality rates reported by Western databases. This remains the only study that cumulatively included representative data from across India, comprising over 30000 surgeries outlined in 135 studies. The mortality ranged widely from 0% to 35%, denoting a heterogeneous pool of studies, as seen from the distribution of I^2 values except for VSD closure and BT shunt (I^2 values >25–<75). Our lesion-specific mortalities were also significantly higher than the Western data, except for the GUCH population and coarctation of the aorta.

Table 3: Society of Thoracic Surgeons - European Association for Cardio-Thoracic Surgery category-wise mortality reported from the Society of Thoracic Surgeons database[14]

Database	STAT category	*n* (%)	Mortality rate (%)
STS (2021)	1	27,163 (28.1)	0.40
	2	33,244 (34.4)	1.38
	3	11,272 (11.7)	2.02
	4	21,150 (21.9)	6.15
	5	3765 (3.9)	12.23
	Overall	96,594 (100)	2.65

STS: Society of Thoracic Surgeons, STAT: The STS - European Association for Cardio-Thoracic Surgery

The estimated all-age mortality for CHD in 2019 is 2.80 (2.29–3.38) per 100,000 population, with a 60.4% (41.4–71.9) decrease from 1990, and the estimated age-standardized mortality for CHD is 3.23 (2.64–3.92) per 100,000 population, with a 45.5% (19.5–61.1) decrease from 1990. India remains the most significant contributor, with 38,000 deaths (25,000-56,000).[144] Most of the excess CHD-related mortality in India is due to lack of timely surgery. However, some excess could be related to suboptimal cardiac surgery outcomes.

Among the studies included in this meta-analysis, 14 studies[19,23,26,32,34,35,41,45,79,85,92,120,121,145] reported data

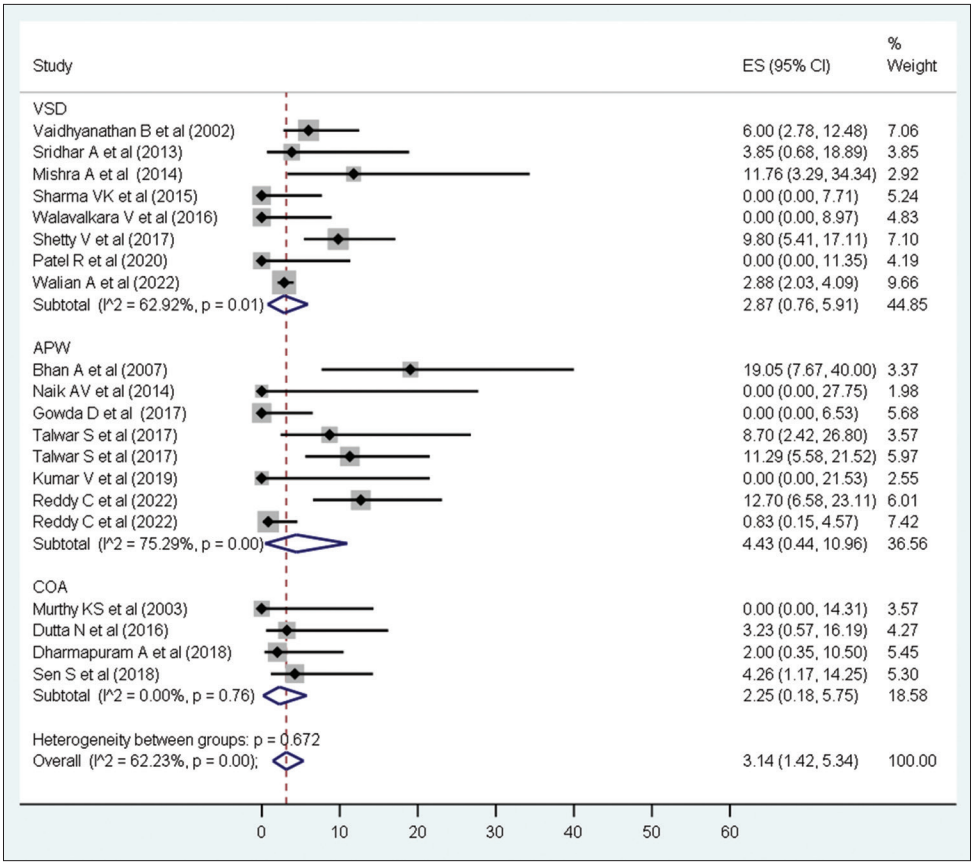

Figure 3: Pooled analysis of in-hospital mortality reported by Indian studies – Selected surgeries for acyanotic congenital heart diseases (VSD,[57-64] APW,[65-71] COA[72-75]). VSD: Ventricular septal defect, APW: Aortopulmonary window, COA: Coarctation of the aorta. (Reddy C, *et al.* (2022) Single comparative study of APW simple versus complex groups[69])

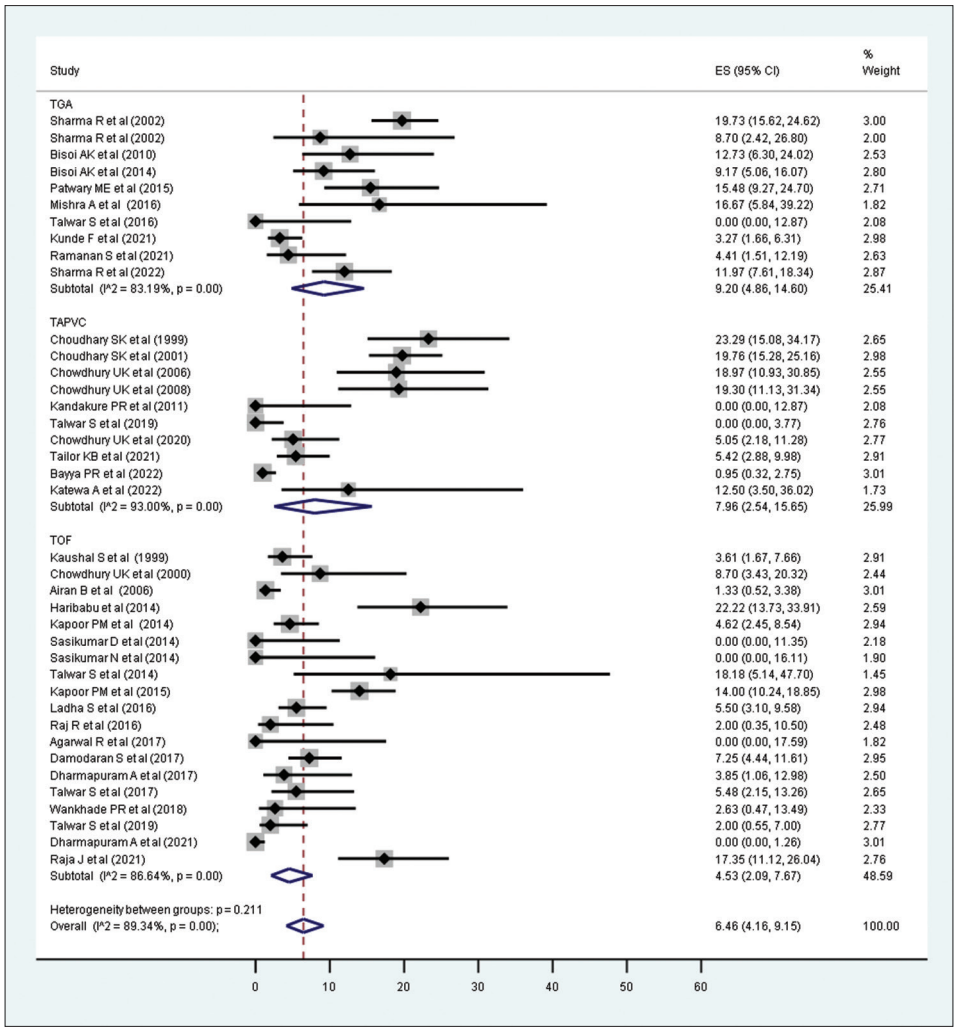

Figure 4: Pooled analysis of in-hospital mortality reported by Indian studies – Selected surgeries for cyanotic congenital heart diseases. (TGA,[76-84,148] TAPVC,[85-94] TOF[95-112]). TGA: Transposition of great arteries, TAPVC: Total anomalous pulmonary venous connection, TOF: Tetralogy of Fallot

exclusively from 2199 neonatal surgeries and reported 155 deaths, with mortality rates ranging from zero to 10.4 percent. Exclusive infant cardiac surgeries were reported by 21[19,23,24,28,32,34,35,37,41,44-46,78,80,83,89,120-122,145] studies with 4791 patients and 413 deaths, with mortality rates ranging up to 21%. The mortality from CHD surgery in infancy diagnosed either prenatally or through newborn screening from a single center in California, US, is 10.4%.

The developed nations have established databases for prospective recording of CHD surgical outcomes. The IQIC collaborative is another worldwide initiative with over 70 sites in 25 developing countries. The STS database[14] reported outcomes of 96,594 operations in 2021, while data from LMIC countries (including India) reported by the IQIC network in 2019 comprised 54521 operations.[11-13] Currently, 17 centers in India are partner centers that share data with the framework.[13] However, some of India's most populated states with the highest birth rates and lowest GDP (gross domestic product) are not part of the framework. Some of these states do not even have one center capable of providing optimal treatment for neonates and children born with CHD.[7]

Indian children undergoing surgery frequently have advanced heart failure, severe cyanosis, pulmonary vascular disease, and malnutrition.[8] The median weight for age standard score (Z score) of patients undergoing congenital heart surgery reported by George *et al.* was −3.2.[50] A few studies established a worsening mortality trend with undernutrition severity. Indian population-based studies have shown that the median z score of healthy Indian children is -0.59, with 8% of urban and 42% of rural children being underweight.[146,147] This leaves Indian children of the same age at risk of higher mortality due to lower weight as compared to their Western counterparts.

The surgical mortality for VSDs ranged from zero to 11.8%; however, the eldest patient was 22 years,[64] with the mean age of the studies ranging from 3 months to

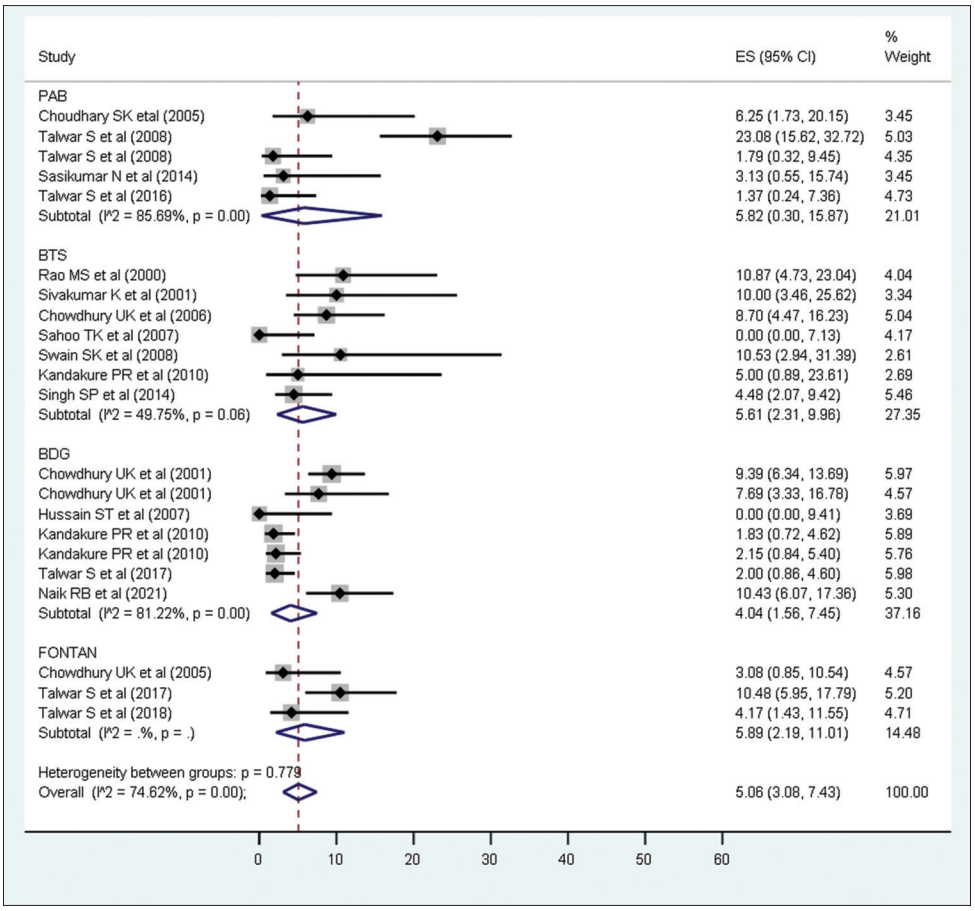

Figure 5: Pooled analysis of in-hospital mortality reported by Indian studies – Selected palliative surgeries (PAB,[113-116] BTS,[117-122,145] BDG,[123-128] Fontan[129-131]). PAB: Pulmonary artery banding, BTTS: Blalock-Taussig-Thomas shunt, BDG: Bidirectional Glenn. (Chowdhury *et al*. (2001)[125] single comparative study of outcomes of BDG based on two groups before and after 2 years of age)

3 years. Apart from undernutrition and infection, delayed presentation and advanced pulmonary vascular disease could have contributed to the excess mortality of Indian children with VSD undergoing surgical closure. Of the eight studies assessing VSD surgical outcomes, three studied the role of perioperative intravenous sildenafil.[58,60,62] Two studies specifically looked at outcomes of apical and multiple muscular defects, a rather complicated subset to tackle among various subtypes.[57,64] One study reported outcomes from all children >2 years of age, with two-thirds of patients being nonresponders on preoperative vasoreactivity testing during catheterization.[59] A delayed age at surgery and advanced cyanosis may be the most critical factors contributing to excess mortality in patients with cyanotic CHD undergoing either palliative or corrective surgery in India. The RACHS score, which is widely used for risk stratification, unfortunately, does not consider non-cardiac factors such as malnutrition, preexisting sepsis, and late presentation which have a significant impact on the outcomes of surgery in India and other LMICs.

Our surgical mortality for TGA ranged from none, as reported in atrial switch operations, to nearly 20% in the earliest reported arterial switch series from 2002. Notably, the age of the patients in the study ranged up to adolescence,[148] which remains a rare occurrence in developed nations. Two of these studies specifically report outcomes in late presenters of TGA-IVS beyond 6 weeks,[80,82] while one study reports outcomes in a subset with intramural coronaries.[84] These subgroups are well-established factors for increased mortality following an arterial switch operation. The higher mortality in TGA studies from India is primarily due to late presentation and multiple comorbidities like severe infection and a sicker state at presentation. On the other hand, a survey by Kunde *et al*. reports the lowest mortality rates of TGA in patients with prenatal detection and planned peripartum care in India.[81]

Ten studies report outcomes of TAPVC repair in 1157 patients, with 107 deaths. A recent study of TAPVC from South India reported outcomes matching those reported from Western countries. In addition, one of the studies reported outcomes beyond infancy,[90] while another reported outcomes beyond 10 years of age.[91] Surprisingly, both these groups have reported no mortality. Among the studies reporting

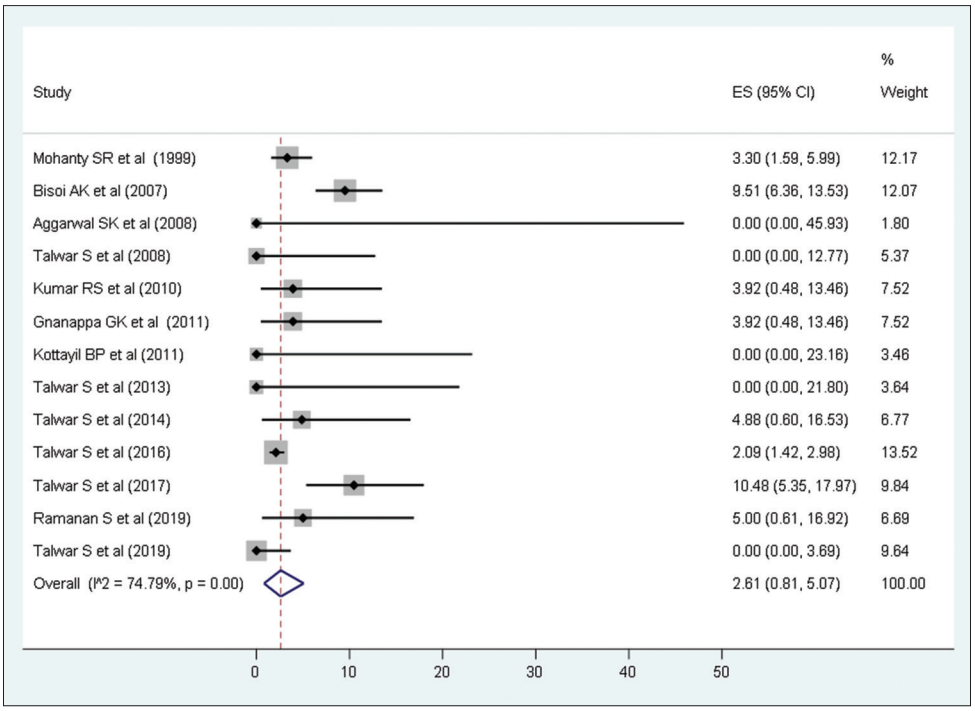

Figure 6: Pooled analysis of in-hospital mortality reported by Indian studies involving the GUCH population[91,130,132-143]

Table 4: Comparative outcomes of lesions as reported in Western databases and Indian studies[14,15]

Category	Western data			Pooled Indian studies		*P*
	Database	Patients (*n*)	Mortality (%)	Patients (*n*)	Pooled mortality (95% CI)	
Overall	STS database	96,594	2.65	19,723	5.63 (4.26–7.16)	<0.00001
GUCH population	Vida VL *et al.* (European database)	20,602	3.02	2467	2.61 (0.81–5.07)	0.22
TGA	STS database (ASO)	1876	1.90	1069	9.20 (4.86–14.60)	<0.00001
TGA-VSD	STS database (ASO + VSD)	849	5.30			
TOF	STS database	4569	1.20	2053	4.51 (2.0–8.02)	<0.00001
BDG	STS database	4027	2.00	1116	4.04 (1.56–7.45)	<0.00001
FONTAN	STS database	3791	1.10	242	5.89 (2.19–11.01)	<0.00001
VSD	STS database	7161	0.43	1400	2.87 (0.76–5.91)	<0.00001
COA	STS database	3460	1.01	151	2.25 (0.18–5.75)	0.06

CI: Confidence interval, STS: Society of Thoracic Surgeons, GUCH: Grown-ups with congenital heart disease, ASO: Arterial switch operation, TGA: Transposition of great arteries, VSD: Ventricular septal defect, TOF: Tetralogy of Fallot, BDG: Bidirectional Glenn shunt, COA: Coarctation of aorta, CI: Confidence interval

outcomes following surgical repair of TOF, two report outcomes in the absence of a pulmonary valve. At the same time, one mentions outcomes specifically in the anomalous pulmonary branch from the aorta subset. These studies have been excluded from sensitivity analyses.

Lack of organized systems of care, transport systems, trained workforce, referral mechanisms, insurance, and other support systems are some of the significant limitations of Indian pediatric cardiac care systems that contribute to this excess mortality.[149-151] In many hospitals, surgeons deal with a huge patient load and often lack the support systems to deliver high-quality care. Despite all these challenges, surgery for CHD in India costs less than a fraction of what it costs in the developing world.[152]

Efforts to improve outcomes– Islands of excellence

Among the studies reporting the overall surgical CHD mortality, 13 studies[10,16,17,21,25,41,42,44,48] have mortality rates equal to or lesser than the STS data. The IQIC analysis from 2019 showed that India, despite having a low GDP per capita income, showed a standardized mortality ratio of <1.[13] According to the GBD (global burden of disease) data in 2017, India has shown a modest reduction in CHD mortality of –1.36% [–1.75 to –0.98] from 1990 to 2019.[144] Hridyam, Kerala state health department's scheme to check mortality due to CHD has performed over 7000 surgeries. The scheme employs screening of children for CHD at birth, anganwadis, schools, and home visits. A referral system is outlined for further confirmation of diagnosis and management. Various government and private hospitals

are empanelled under the scheme for financial support. The Ayushman Bharat Pradhan Mantri Jan Arogya Yojana (PM-JAY) and the various state-sponsored financing schemes are beginning to impact the care of children with CHD in India.[152] Under the West Bengal government-sponsored scheme, 11,483 surgical interventions have been done over 10 years, with an inhospital mortality rate of 5.2%.[153] Three studies identifying the impact of the intrauterine diagnosis of CHD on neonatal surgery have reported mortality rates of 0%, 2%, and 3%, respectively, showcasing the ability of Indian health-care providers to do optimum management when the challenges are preplanned.[35,41,45] In India, maintaining and improving surgical standards and attracting fresh talent to pediatric cardiac surgery are significant challenges in the future.[149-151]

Limitations of the study

Most of the studies included in the analysis were retrospective in nature and, hence, are marred by shortcomings. Significant heterogeneity was observed in the studies, so the overall effect may be skewed. The analysis is subject to publication bias, and the actual mortality may be greater than reported numbers. The studies are from a handful of significant centers, which would affect results both ways. Most publications are from academic institutions, whereas most congenital heart surgery in India is done in nonacademic and private institutions, with less compulsion to publish data. The derived results may, therefore, not reflect the situation in the public or private sectors.

We compared our data with the STS 2021 data, which comprises data from July 2016 to June 2022. A comparison with STS data from the corresponding period of Indian studies would have been more accurate. The STS 2016 data,[154] comprising data from 1998 to 2014, reported a mortality rate of 3.4%. The mortality of STS 2016 was significantly higher than the 2021 data (2.65%; $P < 0.05$ for comparison). However, the cumulative mortality from the Indian studies (mortality-5.63%) is still higher than even the STS 2016 data ($P < 0.05$). The GUCH data from the Western population included patients with residual lesions and redo sternotomies, whereas corresponding Indian data included predominately unoperated late presenters, making direct comparisons erroneous.

Even though we tried to be meticulous in our search for Indian studies, we could have inadvertently missed a few studies. Furthermore, we could not include the more recent (2024) large series involving over 11,000 Indian children undergoing cardiac surgery.[153] However, the reported mortality in that series (5.2%) was close to our estimate (5.63%). Comprehensive, uniform surgical training and standardized postoperative management may promote better results; however, catering to the most complex versions of the illness and significant delays in surgery due to long waiting lists would affect the outcomes negatively.

CONCLUSIONS

CHD surgical mortality in India is higher than in the developed nations. The estimated lesion-specific mortalities are significantly higher than the Western data, except for the GUCH population and coarctation of the aorta. Factors inherent to socioeconomic status, demographics, and health-care system accessibility are vital in determining outcomes. We must establish prospective multicentric registries to document the quantum and the causes of the observed excess mortality. We need systemic measures to improve the outcomes of CHD surgeries in India.

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Conflicts of interest

There are no conflicts of interest.

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Supplementary Table 1: Overall percentage score of risk-of-bias assessment by mixed method appraisal tool

Category	Number of studies	Score (%)
Overall	42	89.05
GUCH	13	84.62
TGA	10	89.09
TAPVC	9	77.78
TOF	17	87.65
PAB	6	73.33
BTTS	7	85.71
BDG	7	81.43
Fontan	3	80
VSD	8	83.75
APW	7	88.57
CoA	4	90

MMAT: Mixed method appraisal tool, GUCH: Grown-ups with congenital heart disease, TGA: Transposition of great arteries, TAPVC: Total anomalous pulmonary venous connection, TOF: Tetralogy of Fallot, PAB: Pulmonary artery banding, BTTS: Blalock–Taussig–Thomas shunt, BDG: Bidirectional Glenn shunt, VSD: Ventricular septal defect, APW: Aortopulmonary window, COA: Coarctation of the aorta