Cardiology in the Young

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Screening and diagnostic imaging at centres performing congenital heart surgery in middle-income countries

Amara Majeed[1,2], Kathy Jenkins[1,2], Kimberlee Gauvreau[1,2], Julian F. Forero[3], Fabiola Pérez Juárez[4], Snehal Kulkarni[5], Vu Minh Phuc[6] and David Schidlow[1,2]

[1]Departments of Cardiology, Harvard Medical School, Boston, MA, USA; [2]Boston Children's Hospital, and Pediatrics, Harvard Medical School, Boston, MA, USA; [3]Fundacion Cardioinfantil, Universidad del Rosario, Bogota, Colombia; [4]National Institute of Pediatric, Mexico City, Mexico; [5]Kokilaben Dhirubhai Ambani Hospital, Andheri West, Mumbai, India and [6]Children's Hospital, Ho Chi Minh City, Vietnam

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Address for correspondence:
Amara Majeed, Department of Cardiology, Boston Children's Hospital, Boston, MA, USA. Tel: 617-355-7186; Fax: 617-730-0710. E-mail: amara.majeed@cardio.chboston.org

Abstract

Background: Surgical care for CHD is increasingly available in low- and middle-income countries, and efforts to optimise outcomes are growing. This study characterises cardiac imaging and prenatal diagnosis infrastructure in this setting. *Methods:* An infrastructure survey was administered to sites participating in the International Quality Improvement Collaborative for CHD. Questions regarding transthoracic, transesophageal and epicardial echocardiography, cardiac CT, cardiac magnetic resonance, prenatal screening and fetal echocardiography were included. Associations with in-hospital and 30-day mortality were assessed. *Results:* Thirty-seven sites in 17 countries responded. Programme size and geography varied considerably: < 250 cases (n = 13), 250–500 cases (n = 9), > 500 cases (n = 15); Americas (n = 13), Asia (n = 18), and Eastern Europe (n = 6). All had access to transthoracic echo. Most reported transesophageal and epicardial echocardiography availability (86 and 89%, respectively). Most (81%) had cardiac CT, but only 54% had cardiac magnetic resonance. A third reported impediments to imaging, including lack of portable machines, age/size-appropriate equipment and advanced cardiac imaging access and training. Only 19% of centres reported universal prenatal CHD screening in their catchment area, and only 46% always performed fetal echocardiography if screening raised concern for CHD. No statistically significant associations were identified between imaging modality availability and surgical outcomes. *Conclusions:* Although access to echocardiography is available in most middle-income countries; advanced imaging modalities (cardiac CT and magnetic resonance) are not always accessible. Prenatal screening for CHD is low, and availability of fetal echocardiography is limited. Imaging infrastructure in low- and middle-income countries and associations with outcomes merits additional study.

Medical and surgical care for CHD is increasingly available in low- and middle-income countries. While the rank of death attributable to infectious and other illnesses has decreased in low- and middle-income countries, the rank correctly attributed to CHD has increased.[1] Therefore, delivery of high-quality CHD care in these settings is an increasing priority.[2] The International Quality Improvement Collaborative for CHD, currently comprising 74 centres in 27 low- and middle-income countries, is an international multicentre effort with the goal of reducing morbidity and mortality related to CHD.[3] Identifying potentially important infrastructure gaps is an important part of this effort.[4–7]

High-quality, accurate, and timely cardiovascular imaging forms the foundation of CHD diagnosis and management. The International Quality Improvement Collaborative and others have reported on access to CHD surgery in low- and middle-income countries[8,9], but no reports comprehensively describe access to cardiovascular imaging in this setting. Purposes of this study were to (1) characterise prenatal and postnatal cardiovascular imaging capabilities among low- and middle-income countries participating in International Quality Improvement Collaborative and (2) identify associations between imaging capabilities and outcomes.

Materials and methods

The creation of the International Quality Improvement Collaborative and its data collection and audit methods have been described previously.[3,10] The platform was formed in 2008 to improve outcomes at congenital heart surgery centres in low- and middle-income countries by benchmarking data and providing data collection, analysis and QI resources. As part of an effort to understand infrastructure for CHD care in low- and middle-income countries, a comprehensive 546-question survey was distributed to participating centres. The survey comprised questions

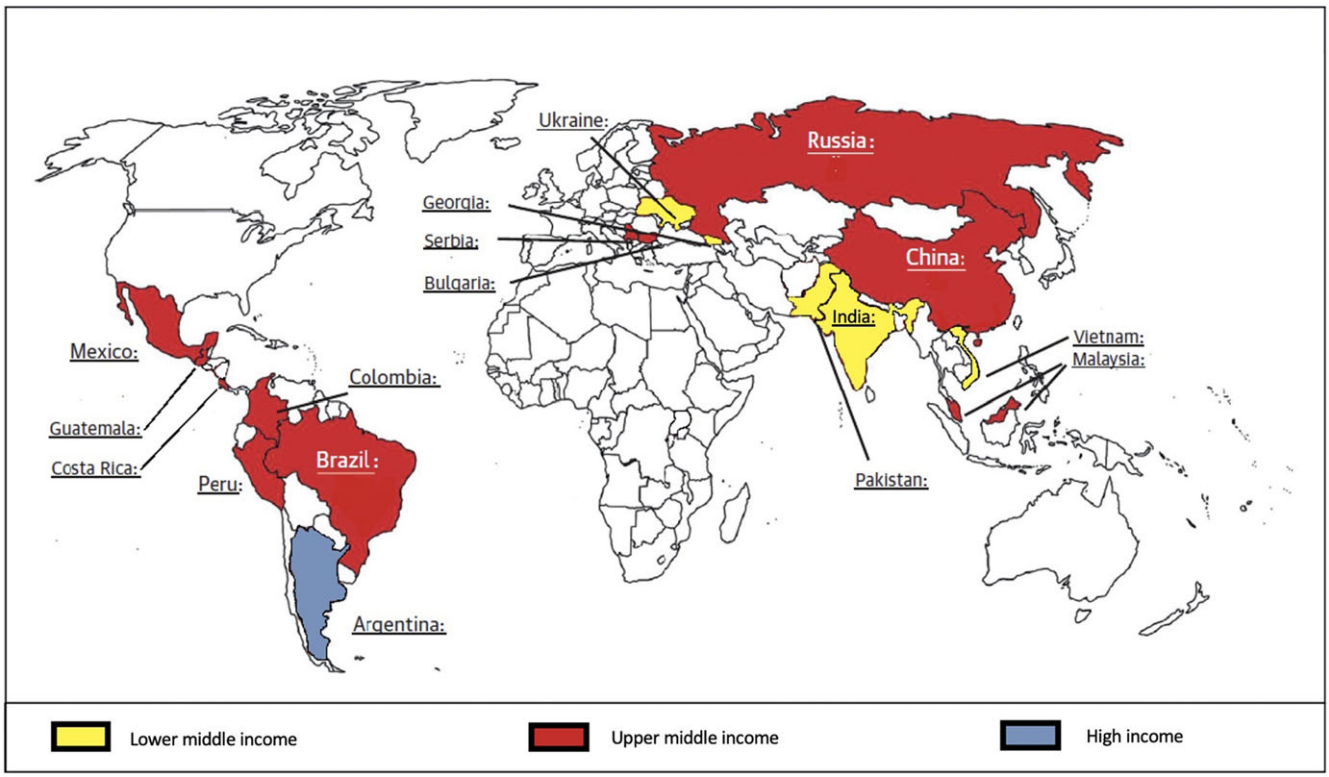

Figure 1. Participating sites (n = 37).

pertaining to numerous aspects of CHD care including: operating room resources, catheterisation capabilities, surgical material and medication availability, inpatient and intensive care availability and staffing, and funding sources. There were 11 questions specifically pertaining to imaging infrastructure (Supplementary material SI), including those related to transthoracic echocardiography, transesophageal echocardiography, epicardial echocardiography, cardiac CT, and cardiac MRI availability, imaging cost and utilisation. Questions about prenatal screening for CHD and formal fetal echocardiography were included. Data were collected and entered into a REDCap database between 2015 and 2016.[11] Data regarding RACHS risk scoring of surgical procedures and CHD surgical outcomes were also captured in a linked database. For analysis, all reported cardiac surgical cases including congenital paediatric, adult congenital, and acquired paediatric were combined. Associations between imaging modality availability and in-hospital and 30-day mortality were assessed.

Responses to frequency questions were subjective and presented on a Likert scale as never, rarely, sometimes, often, and always. Responses were summarised as medians (25th, 75th percentiles) for continuous variables and number (percent) for categorical responses. Data were presented stratified by WHO region location, programme surgical volume, surgical case mix complexity using Risk Adjustment for Congenital Heart Surgery 1 (RACHS-1) risk category[12] and country income level classified using the World Bank classification.[13] Comparisons among groups were made using the Wilcoxon rank sum test or Kruskal–Wallis test for continuous variables and Fisher's exact test for categorical variables. P values < 0.05 were considered significant.

Results

Among the 42 centres participating in the International Quality Improvement Collaborative at the time, the survey was distributed, 37 (88%) in 17 countries completed the survey (Fig 1) (Supplement SII). Programme size, location, income level and surgical complexity are given in Table 1. Programme geography was classified based on WHO regions as follows: Americas (n = 13), Asia (n = 18) and Eastern Europe (n = 6). Of note, although the International Quality Improvement Collaborative includes programmes from low-income countries, only programmes in middle-income countries completed the survey. Programmes were therefore stratified into lower-middle (17 programmes, 46%) and upper-middle (30 programmes, 54%). Per the world bank classification, lower middle-income economies are those with a gross national income per capita between $1026 and $4035 and upper middle-income economies are those with a gross national income per capita between $4036 and $12,475.[14,15]

The majority of the responding sites reported being a public hospital 23 (62%). The remainder were non-government 6 (16%), private 2 (5%), and other 6 (16%) (see survey supplement SI for definitions). Sites indicated that a median of 80% (30,95) of patients treated in 2015 received funds via public financing mechanisms. Other sources of funding reported were private health insurance, self-pay, and charitable donations which were all reported as < 10% of the population cared for by the sites.

Fifteen sites performed > 500 cases/year (very large); 9 sites performed 250–500 cases/year (large); and 13 sites performed < 250 cases/year (small-medium). The median number of CHD surgeries performed across all International Quality Improvement Collaborative programmes responding to the survey was

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Table 1. Participating programmes characteristics

	Programme location		
	Americas (n = 13)	Asia (n = 18)	Eastern Europe (n = 6)
Programme size			
Small-medium	5 (38%)	3 (17%)	5 (83%)
Large	5 (38%)	3 (17%)	1 (17%)
Very large	3 (23%)	12 (67%)	0 (0%)
Percent of cases in RACHS-1 risk categories 3–6	40 (31, 49)	23 (18, 35)	36 (26, 45)
Percent of congenital heart surgery cases age ≤ 30 days (n = 12,17,6)	11 (7, 14)	3 (0, 6)	17 (12, 21)
Income level			
Lower middle	1 (8%)	14 (78%)	2 (33%)
Upper middle	12 (92%)	4 (22%)	4 (67%)

Values shown are number (column percent) or median (25th, 75th percentile).

317 (200, 600). The median percent of neonatal (age ≤ 30 days) heart surgery was 11% in the Americas, 3% in Asia, and 17% in Eastern Europe (Table 1).

Figure 2 shows the availability of cardiovascular imaging modalities across regions. Availability of modalities based on programme location, size, percent of cases in RACHS-1 risk categories 3–6, and country income level is shown in Table 2. All programmes had access to transthoracic echo with a median of 3 (2, 4) echo machines in programmes with < 250 cases and 10 (4, 15) in programmes with >500 cases. Institutions with more echo machines were more likely to be very large (p = 0.006). The median ratio of number of congenital heart surgeries to number of echo machines were 47 (28,100). The distribution across regions was as follows: Americas = 45 (30, 57), Asia = 60 (27, 135), Eastern Europe = 47 (30, 68). The median ratio seemed to be similar in Europe and Americas while Asia had a higher median number of congenital heart surgeries to number of echo machines. There was no association, of the median ratio of number of congenital heart surgeries to number of echo machines, with in-hospital mortality (rs = 0.01, p = 0.98)

Almost all centres were equipped to conduct sedated echocardiography for infants and young children (97%) and were able to perform emergency echocardiograms within 1 hour (92%). The median cost of one diagnostic echo was US $26 (17, 52), which was less than half of an initial clinic visit $47 (23, 73). The median cost of an echo was similar in the Americas and in Eastern Europe at $53 (17, 137) and $55 (16, 62), respectively. The cost was lower in Asia at $23 per study (17, 47). Costs reported were not adjusted for inflation.

Most centres reported availability of intraoperative transesophageal (86%, 31/36). Among the large and very large surgical programmes, 78% (7/9) and 87% (13/15), respectively, had access to transesophageal echocardiography. There was no statistically significant association between programme size and availability of transesophageal echocardiography. Similarly, most centres reported the availability of epicardial echocardiography (89%, 33/37). One-third of programmes reported limitations that restricted the number and complexity of cardiac imaging studies performed. This commonly included a lack of portable echo machines and age- and size-appropriate echocardiography transducers.

Most (81%, 30/37) programmes had cardiac CT while only 54% (20/37) had cardiac MRI imaging availability. The majority of very large programmes (93%, 14/15) and programmes in Asia (89%, 16/18) had the ability to perform cardiac CT. There was no statistically significant association between programme size and availability of cardiac CT. Cardiac MRI availability was lower than cardiac CT with small-medium and large; and programmes in Europe having the least availability (31%, 33%, and 33%, respectively). Larger programmes were more likely to have access to cardiac MRI (p = 0.005). There was an increased availability of cardiac MRI with high-income level, but this was not statistically significant (p = 0.19). All programmes reported access to X-ray and 95% reported portable X-ray availability.

Both prenatal screening for CHD and the availability of formal fetal echocardiography were also assessed (Table 3). Screening was defined as ultrasound evaluation of the heart during routine obstetric ultrasound in a centre's catchment area. Among respondents, the screening frequency was reported as always in 19% (n = 7), often in 28% (n = 10), sometimes in 36% (n = 13) and never/rarely in 17% (n = 6). Formal fetal echocardiography (performed by a cardiologist or a maternal-fetal-medicine specialist), if the prenatal screen was positive, was always available in 46% (16/35) respondents: Europe (66%, n = 4), Asia (44%, n = 7), and the Americas (38% n = 5). There was no significant relationship between programme size and availability of prenatal screening (p = 0.17)

Access to imaging modalities and prenatal screening frequency and associations with in-hospital mortality and post-surgical 30-day mortality are given in Table 4. There were no significant associations between the availability of imaging modalities and mortality. Trends toward lower mortality were identified among programmes with cardiac CT and cardiac MRI, but these did not reach statistical significance.

Discussion

We present a broad overview of diagnostic imaging infrastructure for CHD assessment among a number of congenital heart surgical programmes in middle-income countries participating in International Quality Improvement Collaborative.[16,17] Despite variation in programme size, location, income and surgical complexity, transthoracic, transesophageal and epicardial echocardiography is nearly universally available, whereas advanced imaging modalities such cardiac MRI and cardiac CT are not. Prenatal screening for CHD is infrequently performed, and when CHD is suspected, formal fetal echocardiography is performed less than 50% of the time. Despite varying availability of imaging modalities and prenatal CHD assessment, there were no statistically significant associations with mortality. Nevertheless, the survey results were informative in gaining a deeper understanding of CHD care in low- and middle-income countries countries.

Single-centre reports in middle-income countries demonstrate a substantial reduction in mortality and morbidity when transesophageal echocardiography is available.[18] Therefore, it is encouraging that the majority of programmes report transesophageal and epicardial echocardiography availability. However, transesophageal echocardiography equipment can be prohibitively expensive

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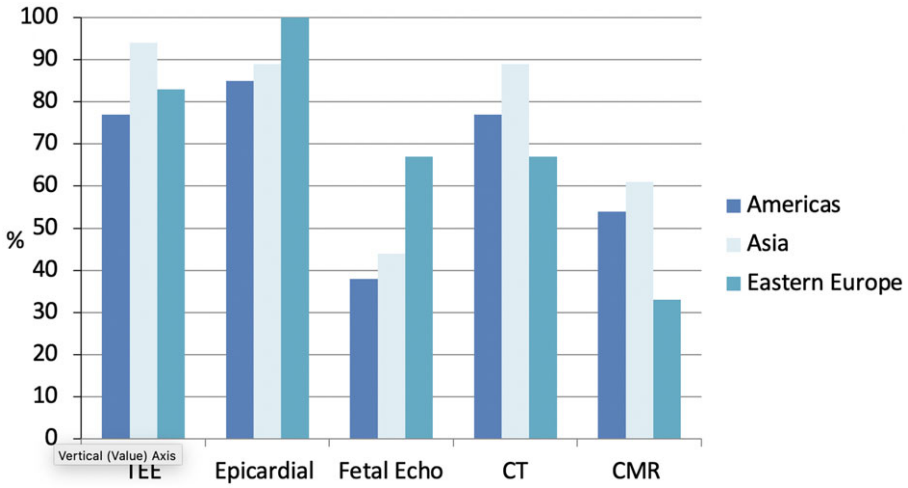

Figure 2. Access to Imaging modalities by region in middle-income countries. Abbreviations: TEE = transesophageal echocardiogram, CT= computed tomography, CMR = cardiac magnetic resonance.

to purchase and maintain, and performance of these examinations requires training and expertise, especially in younger children and infants. Interestingly, some centres note commonly performing intraoperative epicardial echocardiography when transesophageal echocardiography is not available. Moreover, often the cardiologist and not the surgeon perform these studies. This is an interesting contrast to some high-income countries where epicardial echocardiography is less frequently performed and is often completed by the surgeon when utilised.[19]

Transthoracic echocardiography is nearly universally available; however, some centres described specific limitations regarding its implementation, including those related to appropriately sized transducers, portable machines, scanning time, and personnel trained in paediatric echo. Costly maintenance of ultrasound equipment may be another impediment to reliably imaging, and image review may be limited by the lack of an electronic imaging database.

Cardiac MRI and CT play an increasingly important role in comprehensive multimodal anatomic, functional, and physiologic assessment.[20] Many centres have access to cardiac CT, but access to cardiac MRI was less common. It is unknown whether cardiac CTs and cardiac MRIs were performed and interpreted by a cardiologist, a radiologist, or both through collaboration.

There may be numerous reasons for limited cardiac MRI availability. The cost of purchasing and maintaining an MRI scanner may be prohibitive. At some centres, large patient volumes may limit MRI availability. Wait times for insurance approval and long-distance travel to larger cities where advanced imaging modalities are available can also be problematic.

Cardiac MRI is a highly specialised examination requiring detailed knowledge of both CHD and the technical aspects unique to MRI of the moving heart. Advanced imaging training programmes are unlikely to be available in low- and middle-income countries. Physicians frequently must seek training in high-income countries, which may pose logistical and financial challenges.[17]

Prenatal screening and detection of CHD in low- and middle-income countries is a complex matter, with cultural and financial factors both playing an important role. In high-income countries, prenatal screening for CHD is part of routine prenatal obstetric care.[21] Mothers carrying fetuses with CHD are routinely sent to a cardiologist with advanced training and expertise in fetal echocardiography, which is a highly specialised examination. Information gleaned from a high-quality fetal echocardiography permits delivery planning (e.g. prostaglandin for ductus-dependent lesions), prenatal family counselling, and in some instances, termination of pregnancy.[22–24]

This assumes a robust infrastructure capable of providing care during the transition from the prenatal to the postnatal period, and this infrastructure may not be present in some low- and middle-income countries. In addition, prenatal diagnosis may increase the identification of more complex CHD such as single-ventricle defects. One neonate with tenuous single-ventricle CHD may disproportionately require limited resources that could otherwise have been provided to multiple children with relatively more simple CHD (e.g. ventricular septal defects or tetralogy of Fallot), potentially creating an ethical dilemma for providers.

In any case, prenatal diagnosis of CHD infrequently occurs in middle-income countries participating in International Quality Improvement Collaborative. A prenatal detection rate of about 30% or less among low- and middle-income countries is reported in the literature.[25,26] This is not surprising given that only 19% of centres reported always screening for CHD in their catchment area. Interestingly, one centre in this study reports that approximately 70–80% of pregnant patients have fetal anomaly scans but that routine imaging of the heart is not included as part of that scan.

Similarly, fetal echocardiography is infrequently performed. Among those that perform prenatal screening for CHD, only 46% of those go on to perform fetal echocardiography if an abnormality is suspected. Similar to cardiac MRI, fetal echocardiography availability may also be limited by the number of clinicians with training dedicated to this specialised examination. Furthermore, there may be less of an impetus to build prenatal screening or a fetal echocardiography programme if there simply is limited ability to act on the information due to a lack of resources or choice to terminate the pregnancy in light of limited resources and/or personal beliefs in low- and middle-income countries. Nevertheless, there have been some reports suggesting that prenatal screening for CHD and fetal echocardiography in low- and middle-income countries may afford similar benefits to those in high-income countries, and prenatal screening and fetal echocardiography are likely to grow in these settings.[25,27]

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Table 2. Availability of intraoperative echo and advanced cardiac imaging modalities

	Intraoperative TEE			Intraoperative epicardial echo			Cardiac CT			CMR		
	Yes (n = 31)	No (n = 5)	p value	Yes (n = 33)	No (n = 4)	p value	Yes (n = 30)	No (n = 7)	p value	Yes (n = 20)	No (n = 17)	p value
Programme location			*0.36*			*1*						
Americas	10 (77%)	3 (23%)		11 (85%)	2 (15%)		10 (77%)	3 (23%)		7 (54%)	6 (46%)	
Asia	16 (94%)	1 (6%)		16 (89%)	2 (11%)		16 (89%)	2 (11%)	*0.42*	11 (61%)	7 (39%)	*0.50*
Eastern Europe	5 (83%)	1 (17%)		6 (100%)	0 (0%)		4 (67%)	2 (33%)		2 (33%)	4 (67%)	
Programme size			*0.70*			*0.048*						
Small-medium	11 (92%)	1 (8%)		13 (100%)	0 (0%)		10 (77%)	3 (23%)		4 (31%)	9 (69%)	
Large	7 (78%)	2 (22%)		6 (67%)	3 (33%)		6 (67%)	3 (33%)	*0.25*	3 (33%)	6 (67%)	*0.005*
Very large	13 (87%)	2 (13%)		14 (93%)	1 (7%)		14 (93%)	1 (7%)		13 (87%)	2 (13%)	
Percent of cases in RACHS-1 risk categories 3–6	32(23, 42)	26(18, 37)	*0.42*	32(21, 42)	15(7, 34)	*0.15*	31(21, 38)	36(8, 49)	*0.84*	36(21, 43)	28(19, 37)	*0.19*
Income level			*0.64*			*1*						
Lower middle	13 (81%)	3 (19%)		15 (88%)	2 (12%)		12 (71%)	5 (29%)	*0.21*	7 (41%)	10 (59%)	*0.19*
Upper middle	18 (90%)	2 (10%)		18 (90%)	2 (%10)		18 (90%)	2 (10%)		13 (65%)	7 (35%)	

Abbreviations: TEE = transesophageal echocardiogram, CT= computed tomography, CMR = cardiac magnetic resonance
Values shown are number (row percent) or median (25th, 75th percentiles) within columns. Comparisons are made using the Wilcoxon rank sum test for percent of cases in RACHS-1 risk categories 3–6, and Fisher's exact test for all other variables.

Table 3. Prenatal CHD screening via anatomy scan and fetal echo frequency if prenatal screening was positive

	Prenatal screening (n = 36)				Fetal echo (n = 35)			
	Often/always (n = 17)	Sometimes (n = 13)	Never/rarely (n = 6)	p value	Sometimes (n = 7)	Often (n = 12)	Always (n = 16)	p value
Programme location				*0.77*				*0.89*
Americas	5 (38%)	5 (38%)	3 (24%)		3 (24%)	5 (38%)	5 (38%)	
Asia	9 (53%)	5 (29%)	3 (18%)		3 (19%)	6 (37%)	7 (44%)	
Eastern Europe	3 (50%)	3 (50%)	0 (0%)		1 (17%)	1 (17%)	4 (66%)	
Programme size				*0.17*				*0.48*
Small-medium	9 (69%)	4 (31%)	0 (0%)		1 (8%)	4 (31%)	8 (61%)	
Large	3 (33%)	3 (33%)	3 (33%)		3 (38%)	2 (24%)	3 (38%)	
Very large	5 (36%)	6 (43%)	3 (21%)		3 (21%)	6 (43%)	5 (36%)	
Percent of cases in RACHS-1 risk categories 3–6	28	32	29	*0.59*	44	30	30	*0.14*
	(20, 40)	(26, 45)	(7, 45)		(35, 48)	(18, 36)	(22, 44)	
Income level				*1*				*0.9*
Lower middle	7 (44%)	6 (38%)	3 (18%)		3 (20%)	6 (40%)	6 (40%)	
Upper middle	10 (50%)	7 (35%)	3 (15%)		4 (20%)	6 (30%)	10 (50%)	

Values shown are number (row percent) or median (25th, 75th percentile) within columns. Comparisons are made using the Kruskal–Wallis test for percent of cases in RACHS-1 risk categories 3–6 and Fisher's exact test for all other variables.

Table 4. (a), (b) Associations between imaging modalities and prenatal screening and in-hospital mortality

	Intraoperative TEE			Intraoperative epicardial echo			Cardiac CT		
	Yes (n = 31)	No (n = 5)	p value	Yes (n = 33)	No (n = 4)	p value	Yes (n = 30)	No (n = 7)	p value
(a)									
In-hospital mortaity	3.8 (2.5, 9.1)	6.0 (4.7, 13.1)	0.27	4.7 (2.8, 9.2)	2.8 (1.8, 8.5)	0.59	3.9 (2.8, 9.1)	6.6 (1.8, 12.9)	0.63
30-day mortality*	3.8 (2.8, 9.2)	6.2 (4.7, 13.4)	0.33	4.7 (2.9, 9.3)	3.8 (1.8, 13.4)	0.97	4.3 (3.0, 9.2)	6.2 (1.8, 13.1)	0.91

	CMR			Prenatal screening				Fetal echo		
(b)	Yes (n = 20)	No (n = 17)	p value	Often/ Always (n = 17)	Sometimes (n = 13)	Never/ Rarely (n = 6)	p value	Often/ Always (n = 28)	Sometimes (n = 7)	p value
In-hospital mortaity	3.4 (1.8, 9.1)	5.5 (2.7, 13.0)	0.25	4.1 (2.9, 5.5)	7.1 (2.3, 13.2)	3.5 (1.8, 9.5)	0.48	4.7 (1.8, 9.2)	5.5 (3.2, 9.5)	0.47
30-day mortality*	3.7 (3.0, 5.0)	5.6 (2.8, 13.4)	0.19	4.3 (2.9, 5.6)	8.2 (2.8, 13.4)	3.8 (2.8, 8.6)	0.37	4.9 (2.5, 9.3)	3.8 (3.5, 8.7)	0.95

Abbreviations: TEE = transesophageal echocardiogram, CT= computed tomography, CMR = cardiac magnetic resonance.
Values shown are median (25th, 75th percentile) of in-hospital mortality rates. Comparisons are made using the Kruskal–Wallis test or Wilcoxon rank sum test.
*Data available for 32 institutions.

Limitations

There were a number of important limitations to this study. These included the usual limitations of survey research. Respondents were self-selected, and the data reported likely represent an oversimplification of the nuances of imaging infrastructure in low- and middle-income countries. Also of note, no centres from low-income countries responded to the survey. Furthermore, the ability to draw conclusions at the conventional statistical significance level of 0.05 was limited by the relatively small number of centres participating in the survey.

Importantly, the International Quality Improvement Collaborative comprises centre from a number of low- and middle-income countries, but resources specific to a specific country, region, and centre are highly variable and may not be accurately represented by the reported data. It should be noted that many of the observations in the discussion represent the anecdotal experience of the International Quality Improvement Collaborative collaborators that are not necessarily representative of all centres. We did not characterise the relationship of each programme's unique health care and financial structure and their relationships to cardiac imaging availability. With regard to prenatal and screening and fetal echocardiography, the questions were not linked to one another. Therefore, the programmes that reported performing prenatal screening in their catchment/region were not necessarily the same programmes that reported performing fetal echocardiography at their institution. Finally, the associations studied were only limited to early surgical mortality.

Conclusion

Centres from middle-income countries participating in International Quality Improvement Collaborative report abundant access to transthoracic and intraoperative echocardiography. In contrast cardiac CT, and in particular cardiac MRI, were less readily available. Despite these differences, no associations between imaging capabilities and outcomes were identified, raising important questions pertaining to resource utilisation and optimal patient care. Sparse prenatal CHD screening and fetal echocardiography utilisation were also identified, but the complex relationship between fetal cardiac imaging and its role in perinatal care and outcomes in low- and middle-income countrie is highly nuanced, region-specific, and warrants further investigation.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S1047951122001731

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Conflicts of interest. None.

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