

## Supplemental Text

### Supplemental Methodology

#### Search strategy

A thorough literature review was conducted using the search engines PubMed and Scopus. We used the search terms “congenital heart disease”, “low-and-middle-income countries”, “rheumatic heart disease”, “global pediatric cardiac care”, “pediatric cardiac surgery” and “congenital heart surgery”. No time restrictions or other filters were applied to our search results. We used the resulting articles to assimilate information on the burden of Pediatric and Congenital Heart Disease (PCHD) as well as advancements, gaps, and disparities in care. We then examined existing guidelines related to global PCHD care, keeping in mind the resources, capabilities, and challenges faced by low-and-middle-income countries (LMICs).

### Supplemental Tables and Figures

**Table S1: Health Facility Classification according to DCP3 (World Bank) and World Health Organization (WHO) Classifications. Adapted from GICS Optimal Resources For Children’s Surgical Care.(1)**

Facility Classifications			Description	Examples
DCP3 (2017)	WHO (2003)	PCCSL		
Health center	Level 1: Small hospital/health center	PCCSL-1	<ul style="list-style-type: none"> <li>Healthcare facility usually located within a rural community.</li> <li>Provides basic healthcare services of very general nature.</li> <li>Proper triage is a key expectation.</li> </ul>	<ul style="list-style-type: none"> <li>Community health center</li> <li>Primary health center</li> <li>Comprehensive health center</li> </ul>
First-level hospital	Level 2: District/provincial hospital	PCCSL-2	<ul style="list-style-type: none"> <li>Services available are of a general nature and not specialized.</li> <li>First level at which general anesthesia can be available but should be avoided in patients with cardiac diseases given the</li> </ul>	<ul style="list-style-type: none"> <li>General hospital</li> <li>District hospital</li> <li>Cottage hospital</li> </ul>

			<p>complexity of their physiology.</p> <ul style="list-style-type: none"> <li>• Proper triage is a key expectation.</li> </ul>		
<b>Second-level hospital</b>	<b>Level 2: District/provincial hospital</b>	PCCSL-3	<ul style="list-style-type: none"> <li>• Clinical services are specialized by function, but not all specialties and limited specialized technical equipment are available.</li> </ul>	<ul style="list-style-type: none"> <li>• Regional hospital</li> <li>• Provincial hospital</li> <li>• General mission hospital</li> </ul>	
<b>Referral Hospital</b>	<b>Third-level hospital</b>	<b>Level 3: Referral hospital</b>	PCCSL-4	<ul style="list-style-type: none"> <li>• Highly specialized hospital, with specialized staff and technical equipment to support level of care provided.</li> <li>• Clinical services are highly differentiated by function.</li> <li>• Training is provided.</li> </ul>	<ul style="list-style-type: none"> <li>• Academic/teaching/university hospital</li> <li>• National hospital</li> <li>• Central hospital</li> <li>• Specialized mission hospital</li> </ul>
	<b>National Children Hospital.</b>	<b>Level 3: Referral hospital</b>	PCCSL-5	<ul style="list-style-type: none"> <li>• Highly specialized hospital, dedicated to the care of children.</li> <li>• Highly specialized staff and technical equipment in all children's specialties available.</li> <li>• Complex multidisciplinary and chronic care.</li> <li>• Specialized teaching and research in all children's specialties provided.</li> </ul>	<ul style="list-style-type: none"> <li>• Children's hospital</li> <li>• National Heart Institute/Center</li> </ul>

**Table S2a: Care provided at PCCSL-1: Health Center**

PCCSL-1: Health Center		
Scope of Practice		
Function	Basic screening for cardiac disease in children. Preventive cardiology. Training of community healthcare workers. Triage & referral to higher levels of care. Community health education i.e., healthy diet and exercise to modify acquired heart disease.	
Age of Patients	All	
Anesthesia	No anesthesia required at this level for cardiac patients.	
Examples of care provided	<b>Screening</b>	Screening for cardiac disease via pulse oximetry, cardiac specific clinical history and examination and blood pressure measurement.
Optimal Resources		
Training & Staffing	<b>Human Resources</b>	Community health workers, midwife, nurses and staff with basic pediatric training. Physicians with basic pediatric training (optional).
	<b>Required Skills</b>	Pulse oximetry screening. Ability to take a cardiac specific history (syncope, repeated chest infections, family history of sudden death, family history of early heart attacks etc.). Perform a general physical exam (e.g., respiratory rate, status assessment, palpation of pulses, ability to perform cardiac auscultation). Ability to obtain blood pressure. Penicillin administration for Rheumatic Heart Disease (RHD), basic life support (BLS).
Physical Resources	<b>Infrastructure</b>	Basic outpatient infrastructure. Transportation and referral system. Investing in a low-cost tele-medicine platform for timely consultation from higher level centers.
	<b>Equipment &amp; Supplies</b>	See Appendix 2
Quality & Safety (table 3, figure 5)	CME and CPD of healthcare providers around use of pulse oximetry and cardiac specific history taking, examination and blood pressure measurement. Quality audits of transport and referral mechanism.	

	BLS Recertification
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Table S2b: Care provided at PCCSL-2: First-level hospital

First-level hospital		
Scope of Practice		
Function	Basic non-invasive diagnostic cardiology. Wound care and treatment of simple superficial skin wound infections for postoperative patients. Management of duct dependent critical CHD with intravenous prostaglandin E2. Training of community healthcare workers. Triage & Referral to higher levels of care. Community Health Education.	
Age of Patients	All	
Anesthesia	Local anesthesia for minor procedures or conscious sedation using oral agents.	
Examples care provided	<b>Diagnostic Cardiology</b>	Echocardiography
	<b>Outpatient Cardiology</b>	At least once a month outpatient cardiology clinic done by visiting cardiologist.
Optimal Resources		
Training & Staffing	<b>Human Resources</b>	Cardiac imager (preferably with some experience of performing CHD echocardiograms). Nurses with experience in handling pediatric patients. Pediatricians. Visiting pediatric cardiologist.
	<b>Required Skills</b>	Diagnosis & imaging: congenital and acquired structural cardiac defects. Resuscitation and stabilization: BLS, Neonatal resuscitation program (NRP). Medical management: basic pediatric management. Care of postoperative wounds: cleaning, dressing, removal of stitches. Pain management and conscious sedation: use of non-opioid analgesics, oral sedative agents. Management of anticoagulation in patients with RHD and mechanical valves. Blood pressure and lipid management.

Physical Resources	<b>Infrastructure</b>	Basic inpatient and outpatient infrastructure. Low-cost telemedicine platform for diagnostic cardiology. Transportation and referral system.
	<b>Equipment &amp; Supplies</b>	See Appendix 2
Quality & Safety (table 3, figure 5)	In addition to above, QI framework for diagnostic echocardiography. Recertification for NRP.	

**Table S2c: Care provided at PCCSL-3: Second-level hospital**

Referral hospital: Second-level hospital		
Scope of Practice		
Function	Non-invasive screening & diagnostic cardiology. Outpatient & Inpatient cardiology. 24/7 Emergency cardiac care. Emergent cardiac catheterization. Training of healthcare workers. Referral to higher levels of care. Community Health Education.	
Age of Patients	All	
Anesthesia	A trained individual in general anesthesia must be onsite to deal with the ever-changing conditions of the anesthetized patient and prepared to deal with any changes that occur. Oxygenation must be monitored through inhaled measures and pulse oximetry. Ventilation is also monitored first if by trained healthcare clinician who observes chest rise, auscultates breath sounds, and when applicable, monitors the reservoir bag for signs of adequate ventilation. End tidal CO <sub>2</sub> should also be observed. Circulation must also be monitored. This is done by measuring blood pressure through whatever form is deemed appropriate and this must be checked at least every 5 minutes. Heart Rate and EKG must also be used during any anesthetic procedure. Ensure checks of heart sounds, peripheral pulses, or oximetry used during the procedure. Temperature should be monitored when changes in patient body temperature are expected through the duration of the case.	
Examples care provided (See Appendix for a more detailed list)	<b>Diagnostic Cardiology</b>	Echocardiography, Electrocardiogram, X-ray, Holter Monitoring, Ambulatory BP monitoring.
	<b>Outpatient Cardiology</b>	Diagnostics, referral, long-term follow-up.
	<b>Inpatient Cardiology</b>	General inpatient ward equipped to stabilize pre-operative patients and manage stable patients including postoperative care. Emergency cardiac care.
	<b>Emergency Cardiac</b>	Emergent lifesaving procedures: balloon atrial septostomy (bedside ECHO or fluoroscopy guided), pericardiocentesis for cardiac tamponade (bedside ECHO or fluoroscopy guided),

	<b>Catheterization</b>	temporary pacemaker placement.
<b>Optimal Resources</b>		
Training & Staffing	<b>Human Resources</b>	Pediatric cardiologist, congenital cardiac sonographers (preferable), general practice nurses with experience in handling pediatric patients, adult or congenital cardiac surgery backup Anesthetist preferably with some experience in managing cardiac patients.
	<b>Required Skills</b>	Diagnosis & imaging: congenital and acquired structural cardiac defects, rhythm abnormalities Resuscitation and stabilization: BLS, NRP, Pediatric Advanced Life Support (PALS), Advanced Cardiac Life Support (ACLS), Neonatal Intensive Care Unit (NICU), Pediatric Intensive Care Unit (PICU). Medical management: use and monitoring of cardiac medication. Catheterization: basic cardiac catheterization for emergent lifesaving procedures as described above.
Physical Resources	<b>Infrastructure</b>	Basic inpatient, outpatient, and emergency infrastructure. Infrastructure for cardiac catheterization shared with adult cardiac services. Transportation and referral system.
	<b>Equipment &amp; Supplies</b>	See Appendix 2 and 3.
Quality & Safety (table 3, figure 5)	In addition to those in previous levels, shared resources with the general hospital quality improvement & safety representative. Assessment of emergent cardiac catheterization outcomes.	



**Table S2d: Care provided at PCCSL-4: Third-level hospital**

<b>PCCSL-4: Referral hospital: Third-level hospital</b>		
<b>Scope of Practice</b>		
Function	Screening & diagnostic cardiology, including fetal cardiology. Outpatient & Inpatient cardiology. 24/7 Emergency cardiac care. Emergent & elective cardiac catheterization. Cardiac surgery. Training of healthcare workers. Referral to higher levels of care. Community Health Education.	
Age of Patients	All	
Anesthesia	A trained individual in General anesthesia must be onsite to deal with the ever-changing conditions of the anesthetized patient and prepared to deal with any changes that occur. Oxygenation must be monitored through inhaled measures and pulse oximetry. Ventilation is also monitored first if by trained healthcare clinician who observes chest rise, auscultates breath sounds, and when applicable, monitors the reservoir bag for signs of adequate ventilation. End tidal CO <sub>2</sub> should also be observed. Circulation must also be monitored. This is done by measuring blood pressure through whatever form is deemed appropriate and this must be checked at least every 5 minutes. Heart Rate and EKG must also be used during any anesthetic procedure. Ensure checks of heart sounds, peripheral pulses, or oximetry used during the procedure. Temperature should be monitored when changes in patient body temperature are expected through the duration of the case.	
Examples care provided (See Appendix for a more detailed list)	<b>Diagnostic Cardiology</b>	Echocardiography, Electrocardiogram, X-ray, Holter Monitoring, Cardiac Catheterization, CT (can be shared with adult).
	<b>Outpatient Cardiology</b>	Diagnostics, referral, long-term follow-up including lifelong care, rehabilitation, and transition to adult care.
	<b>Inpatient Cardiology</b>	General inpatient ward, special care, emergency cardiac care, congenital cardiac intensive Care (preferable).
	<b>Cardiac Catheterization</b>	Emergent & elective cardiac catheterization (PREDIC3T categories 0-4).

	<b>Cardiac Surgery</b>	RACHS 1 & 2 procedures. STAT 1 & 2 procedures. ABC 1 & 2 procedures. PRAIS2 10 - 15 procedures.
<b>Optimal Resources</b>		
Training & Staffing	<b>Human Resources</b>	Pediatric cardiologists, pediatric intensivists with some training in CICU, congenital cardiac sonographers (preferable), CICU nurses, congenital cardiac surgeons (or adult cardiac surgeons with pediatric experience), congenital cardiac perfusionists. Anesthetist with significant experience in pediatric cardiac cases.
	<b>Required Skills</b>	Diagnosis & imaging: congenital and acquired structural cardiac defects, rhythm abnormalities. Resuscitation and stabilization: BLS, NRP, PALS, ACLS, ATLS, NICU, PICU, CICU. Medical management: use and monitoring of cardiac medication. Care of postoperative wounds: cleaning, dressing, removal of stitches. Pain management: use of opioid & non-opioid analgesics. Cardiac catheterization (see above procedures). Cardiac surgery (see above procedures).
Physical Resources	<b>Infrastructure</b>	Basic inpatient, outpatient, and emergency infrastructure. Functionally and physically separate pediatric echocardiography lab. Infrastructure for CICU. Infrastructure for cardiac catheterization shared with adult cardiac services. Infrastructure for cardiac surgery. Transportation and referral system.
	<b>Equipment &amp; Supplies</b>	See Appendix 1, 2, 3
Quality & Safety (table 3, figure 5)	<p>QI &amp; safety representative (certification, CME, CPD). Sonographers, technicians, anesthesia, and nurses are involved in designing QI projects, research, managing databases and publications.</p>	
	<p>QI framework for diagnostics, cardiac catheterization, and cardiac surgery.</p>	

**Table S2e: Care provided at PCCSL-5: National Children's Hospital**

PCCSL 5: Referral hospital: National Children's Hospital		
Scope of Practice		
Function	Screening & diagnostic cardiology, including fetal cardiology. Outpatient cardiology. Inpatient cardiology. 24/7 Emergency cardiac care. Emergent & elective cardiac catheterization. Cardiac surgery. Training of healthcare workers. Community Health Education.	
Age of Patients	All	
Anesthesia	A trained individual in General anesthesia should be onsite to deal with the ever-changing conditions of the anesthetized patient and prepared to deal with any changes that occur. Oxygenation must be monitored through inhaled measures and pulse oximetry. Ventilation is also monitored first if by trained healthcare clinician who observes chest rise, auscultates breath sounds, and when applicable, monitors the reservoir bag for signs of adequate ventilation. End tidal CO <sub>2</sub> should also be observed. Circulation must also be monitored. This is done by measuring blood pressure through whatever form is deemed appropriate and this must be checked at least every 5 minutes. Heart Rate and EKG must also be used during any anesthetic procedure. Ensure checks of heart sounds, peripheral pulses, or oximetry used during the procedure.	
Examples care provided (See Appendix for a more detailed list)	<b>Diagnostic Cardiology</b>	Echocardiography, Electrocardiogram, X-ray, Holter Monitoring, Cardiac Catheterization, cardiac CT scanner (minimum 64 slice) and cardiac MRI (preferable).
	<b>Outpatient Cardiology</b>	Diagnostics and long-term follow-up including lifelong care, rehabilitation, and transition to adult care.
	<b>Inpatient Cardiology</b>	General inpatient ward, special care, emergency cardiac care, CICU.
	<b>Cardiac Catheterization</b>	All procedures.
	<b>Cardiac Surgery</b>	All procedures.

Optimal Resources		
Training & Staffing	<b>Human Resources</b>	Pediatric cardiologists, dedicated congenital cardiac intensivists, congenital cardiac sonographers, dedicated specially trained congenital cardiac intensive care nurses, congenital cardiac surgeons, pediatric cardiac anesthesiologists.
	<b>Required Skills</b>	Diagnosis & imaging: congenital and acquired structural cardiac defects, rhythm abnormalities. Resuscitation and stabilization: BLS, NRP, PALS, ACLS, ATLS. Medical management: use and monitoring of cardiac medication. Care of postoperative wounds: cleaning, dressing, removal of stitches. Pain management: use of opioid & non-opioid analgesics. Cardiac Catheterization (see above procedures). Cardiac surgery (see above procedures).
Physical Resources	<b>Infrastructure</b>	Full spectrum of inpatient, outpatient, and emergency infrastructure. Functionally and physically separate infrastructure for cardiac intensive care including ECMO (preferable). Functionally and preferably physically separate cardiac catheterization services. Pediatric electrophysiology expertise. Infrastructure for cardiac surgery.
	<b>Equipment &amp; Supplies</b>	See Appendix 1, 2, 3.
Quality & Safety (table 3, figure 5)		QI & safety representative.
		QI framework for diagnostics, cardiac catheterization, cardiac anesthesia and cardiac surgery.

**Table S3: Screening and management at PCCSL-1**

Classification	Clinical Assessment	Pulse Oximetry	Management
No evidence of cardiac disease	No history of cyanosis, shortness of breath, syncope, palpitations, feeding difficulty, failure to thrive.	Refer to Figure S1	Reassurance and appropriate counseling.
	No family history or risk factors of congenital/acquired heart disease or sudden cardiac death.		
	No physical signs of cardiac disease (respiratory distress, cyanosis, clubbing, failure to thrive).		
	No murmur or abnormal heart sounds on auscultation, pulses palpable and equal.		
Possibility of cardiac disease	History of cyanosis, shortness of breath, syncope, palpitations, feeding difficulty or failure to thrive but currently stable.	Refer to Figure S1	Recheck oxygen saturation in one hour. Counsel regarding possibility/risk of cardiac disease. Refer for evaluation to a higher-level center.
	Family history or risk factors of congenital/acquired heart disease or sudden cardiac death.		
	Otherwise healthy and stable patient with abnormal auscultatory findings or physical signs of cardiac disease.		
Likely cardiac disease	History of cyanosis, shortness of breath, syncope, palpitations, feeding difficulty or failure to thrive and/or <b>currently unstable</b> .	Refer to Figure S1	Counsel regarding likely cardiac disease. Basic resuscitation and stabilization measures. Urgent referral and transport to a higher-level center.
	Family history or risk factors of congenital/acquired heart disease or sudden cardiac death.		
	Unstable patient with abnormal auscultatory findings and/or physical signs of cardiac disease.		

**Table S4: Procedural Risk in Congenital Cardiac Catheterization (PREDIC3T) categories. (Adapted from Procedural Risk in Congenital Cardiac Catheterization (PREDIC3T) (2))**

Risk level	Examples	Applicable facility level
PREDIC3T Risk Category 0	Endomyocardial biopsy Endomyocardial biopsy with coronary angiography	PCCSL- 4 and PCCSL-5
PREDIC3T Risk Category 1	Diagnostic $\geq 1$ y Pulmonary valvuloplasty $>30$ d Fontan fenestration or baffle leak device closure	
PREDIC3T Risk Category 2	Diagnostic 1 mo to $<1$ y Pulmonary valvuloplasty + procedure $>30$ d ASD or PFO closure Venous collateral occlusion PDA closure	
PREDIC3T Risk Category 3	Diagnostic $\leq 30$ d Pulmonary valvuloplasty +/- procedure $\leq 30$ d Fontan fenestration or baffle leak device closure + procedure Systemic pulmonary collateral closure +/- procedure Pulmonary artery (1 vessel) Pulmonary artery (1 vessel) + RVOT conduit dilation/stent Aorta (coarctation) dilation and/or stent Atrial septostomy	
PREDIC3T Risk Category 4	ASD or PFO closure + procedure Pulmonary artery (1 vessel) + procedure Pulmonary artery ( $\geq 2$ vessels) Pulmonary vein dilation and/or stent RVOT conduit dilation and/or stent PDA dilation and/or stent	

<p>PREDIC3T Risk Category 5</p>	<p>Aortic valvuloplasty +/- procedure, <math>\leq 30</math> d  Aortic valvuloplasty +/- procedure, <math>&gt; 30</math> d  Mitral valvuloplasty  Atrietic valve perforation with or without valvuloplasty  VSD closure  Pulmonary artery (<math>\geq 2</math> vessels) +RVOT +/- procedure  Aorta (coarctation) dilation and/or stent + procedure  Atrial septostomy + procedure  TPV implantation +/- procedure  Atrial septum static dilation and/or stent placement</p>	<p>PCCSL-5 only</p>
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*ASD: atrial septal defect; PDA: patent ductus arteriosus; PFO: patent foramen ovale; PREDIC3T: procedural risk in congenital cardiac catheterization; RVOT: right ventricular outflow tract; TPV: transcatheter pulmonary valve; VSD: ventricular septal defect*

**Figure S1: Critical Congenital Heart Disease (CCHD) Screening Table (Adapted from Wisconsin SHINE Screening Hearts in Newborns Project) (3)**

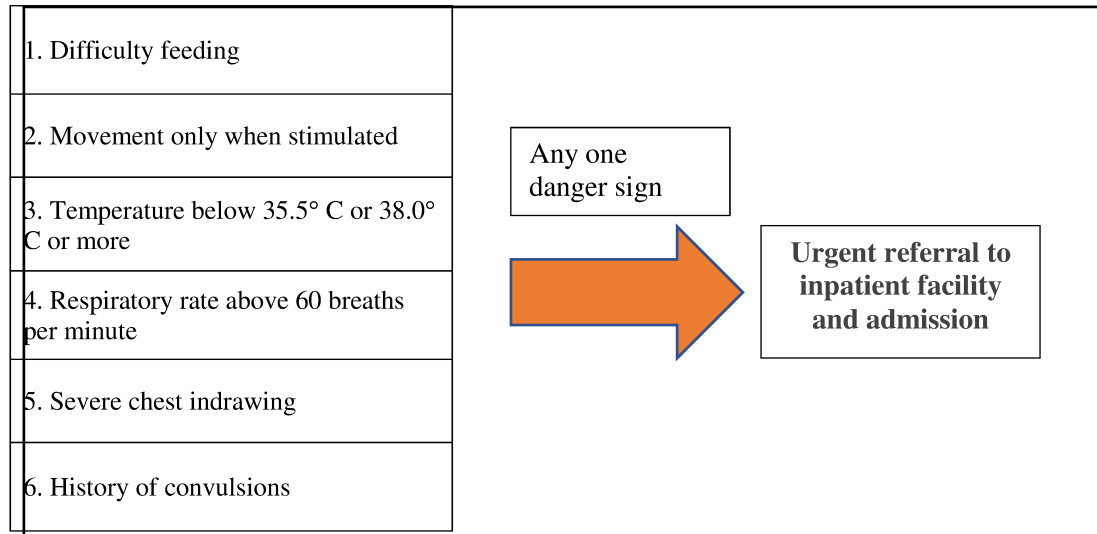
Right Hand	Either Foot											
100	100	99	98	97	96	95	94	93	92	91	90	<90
99	100	99	98	97	96	95	94	93	92	91	90	<90
98	100	99	98	97	96	95	94	93	92	91	90	<90
97	100	99	98	97	96	95	94	93	92	91	90	<90
96	100	99	98	97	96	95	94	93	92	91	90	<90
95	100	99	98	97	96	95	94	93	92	91	90	<90
94	100	99	98	97	96	95	94	93	92	91	90	<90
93	100	99	98	97	96	95	94	93	92	91	90	<90
92	100	99	98	97	96	95	94	93	92	91	90	<90
91	100	99	98	97	96	95	94	93	92	91	90	<90
90	100	99	98	97	96	95	94	93	92	91	90	<90
<90	100	99	98	97	96	95	94	93	92	91	90	<90

**PASS:** 95% or higher in right hand or either foot AND differences of 3% or less between right hand and either foot. Once a measurement in the green range is obtained, no further screening is necessary.

**RESCREEN:** 90-94% in right hand and either foot OR difference of >3% between right hand and either foot. The screening should be repeated in one hour and can be repeated a third time if the results are still in the yellow range. If the third screening is still in the yellow range, the baby has failed the screening.



FAIL: <90% at any time OR if the criteria to PASS are not met despite three attempts.

**Figure S2: Clinical danger signs that predict severe illness in children under 2 years (Adapted from Group YICSS) (4)**

1. Surgery GIfCs. OPTIMAL RESOURCES FOR CHILDREN'S SURGICAL CARE. Guidelines for Different Levels of Care Version 2. 2019.
2. Quinn BP, Yeh M, Gauvreau K, Ali F, Balzer D, Barry O, et al. Procedural Risk in Congenital Cardiac Catheterization (PREDIC. J Am Heart Assoc. 2022;11(1):e022832.
3. McClain MR, Hokanson JS, Grazel R, Van Naarden Braun K, Garg LF, Morris MR, et al. Critical Congenital Heart Disease Newborn Screening Implementation: Lessons Learned. Matern Child Health J. 2017;21(6):1240-9.
4. Group YICSS. Clinical signs that predict severe illness in children under age 2 months: a multicentre study. Lancet. 2008;371(9607):135-42.