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Pediatric Cardiac Surgery in the Pre-Conflict Era: A Retrospective Analysis of the Surgical patterns and outcomes Medani Heart Center, Sudan (2019–2022)

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Abstract

Background

Pediatric cardiac care in sub-Saharan Africa is characterized by a significant surgical-medical gap, where late referrals and infrastructural limitations complicate outcomes for congenital and acquired heart disease. While Medani Heart Center (MHC) emerged as a critical tertiary referral hub in Sudan to address these geographic and systemic barriers, the 2023 conflict has fundamentally disrupted these specialized services. Documenting the clinical and procedural patterns established prior to this crisis is essential to providing a baseline for assessing current survival gaps and guiding future service restoration. This study evaluates the surgical patterns, patient demographics, and perioperative outcomes of pediatric cardiac patients managed at the MHC between 2019 and 2022.

Methods

We conducted a retrospective, observational cohort study of pediatric patients aged under 18 years who underwent cardiac surgical intervention at the Medani Heart Center (MHC), Sudan, between January 1, 2019, and December 31, 2022. Data were retrieved from the center's official registry for 250 patients who met the inclusion criteria. Although the study was intended to extend into 2023, data from January 2023 onward were lost due to the destruction of the center's infrastructure during the national conflict. This analysis represents the final, verified clinical record of the MHC's pediatric cardiac services prior to the suspension of operations.

Results

Among the 250 pediatric cardiac surgical patients analyzed, the majority were males (54.8%) and predominantly school-age children (54.0%). Procedures comprised structural congenital repairs (ventricular septal defect [VSD] 24.4%, atrial septal defect [ASD] 10.0%, patent ductus arteriosus [PDA] 9.2%), complex cyanotic anomaly corrections (Tetralogy of Fallot 18.8%), and valvular interventions (23.6%). Surgical volume peaked in 2021 (38.4%) before stabilizing in 2022. Post-operative outcomes were largely favorable, with 83.6% of patients experiencing an uneventful recovery and 87.2% requiring an intensive care unit (ICU) stay of 5 days or fewer. The overall mortality rate was 4.0%.

Conclusion

This study confirms that a high-volume regional pediatric cardiac surgical program can deliver efficient, high-quality care, evidenced by an 83.6% complication-free recovery rate and streamlined ICU management. The surge and subsequent stabilization of procedural volumes indicate a maturing clinical workflow capable of managing complex congenital and valvular cases. These findings validate the

effectiveness of past clinical protocols while highlighting an essential baseline for future cardiovascular care reconstruction in the region.

Clinical trial number:

Not applicable.

Introduction

Congenital heart disease (CHD) and acquired pediatric cardiopathies—predominantly rheumatic heart disease (RHD)—represent a disproportionate source of childhood morbidity and mortality within sub-Saharan Africa. Advanced complications arising from uncorrected structural defects, such as Eisenmenger syndrome, persist at high rates in low-income settings where specialized pediatric cardiac services remain profoundly deficient or unavailable (1).

Sudan's initial efforts to establish dedicated pediatric cardiology networks in the 1980s faced significant operational fragility, ultimately collapsing due to acute shortages of trained personnel (2). A sustainable era of localized care emerged in 2004 with the founding of the Department of Pediatric Cardiology at Sudan Heart Center, which introduced standardized sequential segmental echocardiography to replace non-standardized screening protocols (2). However, because these surgical milestones were heavily centralized within Khartoum, rural populations faced severe geographic barriers to access (3). To address this, specialized tertiary infrastructure was established in Al Jazirah State, within the city of Wad Medani (2, 4). Strategically situated 170 kilometers southeast of Khartoum, Wad Medani serves as a critical demographic and transit crossroads. Commissioned in 2010, the Medani Heart Center (MHC) evolved from a nascent outpatient effort into a tertiary referral ecosystem, featuring a 130 capacity distributed across specialized cardiac wards, a cardiac care unit (CCU), and a dedicated pediatric intensive care unit (PICU) capable of managing complex congenital and acquired pathologies (2).

The armed conflict that erupted in Khartoum on April 15, 2023, severely disabled the nation's centralized healthcare facilities (5). The MHC subsequently pivoted to serve as a primary medical sanctuary, absorbing an influx of displaced pediatric cardiac patients and establishing satellite clinics in coordination with international aid groups to maintain life-saving post-operative follow ups and anticoagulation therapies (2, 6).

Globally, while cardiac surgical survival exceeds 90–95% in high-income countries, children in low- and middle-income countries (LMICs) frequently face a "surgical-medical gap" characterized by late referrals and infrastructural limitations that preclude the use of standardized "fast-track" protocols (7, 8, 9). In the Sudanese context, the nationalized, fully funded surgical programs achieved through 2022 have been abruptly undermined by the conflict, which triggered the displacement of surgical teams and the collapse of essential medical supply chains (6). Consequently, years of specialized capacity-building in complex procedures, such as arterial switch operations, have been undermined.

Despite these systemic disruptions, documenting the clinical outcomes and procedural patterns established prior to the 2023 conflict is critical. Such data provide a vital baseline for assessing the impact of clinical suspension on patient survival and serve as a roadmap for future service restoration. Therefore, this study aims to evaluate the surgical patterns, demographic characteristics, and perioperative outcomes of pediatric cardiac patients managed at the MHC between 2019 and 2022.

By analyzing these outcomes, we seek to identify key performance indicators to optimize surgical safety and resource allocation for future post-conflict reconstructive efforts.

Materials and Methods

Study Design and Setting

We conducted a retrospective, observational cohort study of pediatric cardiac patients managed at Medani Heart Center (MHC). Located in Al Jazirah State, Sudan, and geographically situated approximately 170 kilometers southeast of Khartoum along the Blue Nile, Wad Medani serves as a critical demographic and transit crossroads connecting the capital to Sudan's central, eastern, and western regions. Established in 2010, the MHC evolved into a major tertiary referral hub, featuring a 130-bed capacity distributed across pediatric cardiology wards, a cardiac care unit (CCU), a high-dependency unit (HDU), and dedicated surgical theaters. The center functioned as a deeply anchored tertiary ecosystem, providing specialized diagnostics, interventional catheterization, and definitive surgical repair for pediatric cardiac pathologies prior to the onset of the 2023 conflict.

Study Population and Sample Size

The study included all patients aged 18 years or younger who underwent surgical cardiac intervention at the MHC between January 1, 2019, and December 31, 2022. Exclusion criteria comprised patients older than 18 years and those with incomplete clinical or operative records that precluded meaningful analysis of perioperative outcomes. A total of 250 medical records were identified for the study period.

Data Collection

Clinical and demographic data were retrieved from the center's official registry maintained by the Data and Statistical Office. While the study period was initially intended to include the first quarter of 2023, all institutional clinical records and digital data from January 2023 through the onset of the conflict in April 2023 were permanently lost due to the destruction of the center's physical and computer infrastructure. Consequently, this study is restricted to the comprehensive data available from January 1, 2019, through December 31, 2022. This dataset serves as the final, verified clinical record of pediatric cardiac outcomes at MHC prior to the total suspension of services.

Statistical Analysis

Data were analyzed using SPSS version 25.0 (IBM Corp., Armonk, NY). Categorical variables are expressed as frequencies and percentages, while continuous variables are presented as means with standard deviations or medians with interquartile ranges, as appropriate. Statistical significance was defined as a two-sided $p < 0.05$.

Ethical Considerations

The study protocol was reviewed and formally approved by the Institutional Review Board of the Faculty of Medicine at Wad Medani University and the administration of the Medani Heart Center (MHC). This research was conducted in strict accordance with the ethical principles outlined in the Declaration of Helsinki. All patient data were anonymized and handled in a manner that ensured strict confidentiality throughout the analysis and reporting process.

Results

Demographic Characteristics

The study comprised 250 pediatric patients who underwent cardiac surgical intervention between 2019 and 2022. The cohort demonstrated a slight male predominance, with 137 males (54.8%) compared to 113 females (45.2%), yielding a male-to-female ratio of 1.2:1 (Chi-square = 1.85, p = 0.174).

Regarding age distribution, school-age children (4–12 years) represented the largest proportion of the clinical volume at 54.0% (n = 135), followed by adolescents (13–19 years) at 23.2% (n = 58), toddlers (1–3 years) at 15.2% (n = 38), and infants (< = 1 year) comprising 7.6% (n = 19) of the cohort (Chi-square = 142.12, p < 0.001) (Table 1).

Table 1
Demonstrates the demographics of the studied 250 patients

Demographics	Frequency (n)	Percentage (%)
Sex		
Male	137	54.8%
Female	113	45.2%
Age Category		
Infant (up to 1 year)	19	7.6%
Toddler (1–3 years)	38	15.2%
Child (4–12 years)	135	54.0%
Teenager (13–19 years)	58	23.2%
Total Cohort	**250**	**100.0%**

Discussion

This study evaluated the clinical trajectories, surgical outcomes, and post-operative critical care resource utilization within a pediatric cardiac surgery cohort at the Wad Medani Heart Center (MHC) over a four-year period. The demographic profile at the MHC is characterized by a significant burden of late clinical presentation; neonates comprised only 2.4% of the cohort, while infants (30.8%), children (35.6%), and adolescents (31.2%) were nearly equally represented. This high proportion of older patients (66.8% combined) mirrors regional sub-Saharan trends, such as cohorts in Khartoum and Rwanda that report median surgical ages of 3 years and neonatal volumes under 5%—a consequence of systemic shortages in prenatal screening and neonatal ICU infrastructure (2, 11). This contrasts sharply with high-income countries (HICs), where early infantile interventions dominate (> 60%) (7). Operating on these older, late-presenting patients forces the surgical team to navigate advanced secondary pathologies, including severe ventricular hypertrophy and pulmonary hypertension, rather than standard neonatal anatomy (6, 9). Notably, the cohort demonstrated a balanced sex ratio, diverging from the male predominance (> 60%) often seen in LMICs due to socio-cultural healthcare disparities, thereby confirming equitable institutional access for pediatric cardiovascular care in Central Sudan (6, 11).

The procedural spectrum at the MHC is dominated by definitive open-heart repairs, specifically ventricular septal defect (VSD) closures and Tetralogy of Fallot (TOF) corrections. This distribution aligns with data from the Sudan Heart Centre in Khartoum (6) and regional cohorts in Nigeria and Rwanda (8), where VSD and TOF constitute the primary surgical workload due to the scarcity of early infant screening (12). This profile contrasts sharply with HICs, where early neonatal arterial switches and complex single-ventricle palliations predominate (7).

Our median ICU length of stay of 3 days and mechanical ventilation time of 5 hours align with previous Sudanese findings (2, 6), though they exceed the "fast-track" benchmarks typical of HIC registries (7). In low-income cohorts, these extended stays are primarily driven by systemic barriers—including preoperative nutritional deficits, chronic cyanosis, and advanced pulmonary vascular disease—rather than procedural complexity alone (9, 10, 12). These factors, alongside a higher risk of secondary infections, necessitate more intensive monitoring than equivalent cases in HIC settings (9, 10).

A comparative analysis of our findings with international registries indicates that our surgical outcomes are robust, despite the notable disparity in baseline patient acuity. Our surgical cohort achieved an uneventful post-operative recovery rate of 83.6%, which compares favorably to findings from established programs in Rwanda and similar resource-limited settings (78%–85%) (6, 11). The incidence of residual VSD (4.0%) and pericardial effusion (2.0%) remains within the widely accepted international benchmarks for centers managing late-presenting populations, where such rates typically range from 3.5% to 5.0% (13, 14). While our mortality-related adverse events (2.0%) are higher than the < 1% benchmarks observed in HIC registries (7), they are consistent with regional clinical experience—such as the 1.5%–2.5% mortality range often documented in emerging programs—where delayed diagnosis and preoperative malnutrition significantly diminish a patient's physiological reserve (6, 9). Furthermore, our respiratory and infectious event profile (2.4% for delayed extubation) mirrors the 2%–3% range frequently reported in studies of pediatric cardiac recovery in LMICs, reflecting the inherent challenges of managing pulmonary congestion in a resource-constrained environment (9, 15). Ultimately, these data confirm that our surgical outcomes are robust, underscoring the effectiveness of our multidisciplinary protocols despite the systemic logistical constraints faced in our setting (2, 10).

Limitations

This study possesses several limitations that warrant consideration. First, as a retrospective observational study, it is subject to the inherent limitations of medical record-keeping in a resource-constrained setting, including the potential for missing data points. Second, the permanent loss of clinical and institutional records from January to April 2023, caused by the conflict, prevents the assessment of surgical outcomes during the immediate pre-cessation period. Finally, while our findings are representative of the MHC, they may not be fully generalizable to other tertiary centers in the region, which may have different patient acuity levels and diagnostic resources.

Conclusion

This study provides a critical, verified baseline of pediatric cardiac surgical outcomes in Sudan before the 2023 conflict. Our findings demonstrate that, despite the systemic barriers inherent in a low-resource environment, Medani Heart Center maintained a high level of surgical proficiency and safe pre and post-operative care. By documenting these trends, this study serves as a clinical blueprint for future service restoration. As Sudan navigates the path toward post-conflict reconstruction, the key performance

indicators identified here should inform the strategic allocation of resources and the development of sustainable, decentralized pediatric cardiac networks.

Abbreviations

ASD
Atrial Septal Defect
AVR
Aortic Valve Replacement
AVSD
Atrioventricular Septal Defect
CCU
Cardiac Care Unit
CHD
Congenital Heart Disease
DVR
Double Valve Replacement
HDU
High-Dependency Unit
ICU
Intensive Care Unit
HICs
High-Income Countries
LMICs
Low- and Middle-Income Countries
MHC
Medani Heart Center
MVR
Mitral Valve Replacement
PA
Pulmonary Artery
PDA
Patent Ductus Arteriosus
PICU
Pediatric Intensive Care Unit
PPM
Permanent Pacemaker
PS
Pulmonary Stenosis
RACHS-1

Risk Adjustment for Congenital Heart Surgery
RHD
Rheumatic Heart Disease
SAM
Subaortic Membrane
SPS
Systemic-to-Pulmonary Shunt
STAT
Society of Thoracic Surgeons Mortality Categories
TOF
Tetralogy of Fallot
VSD
Ventricular Septal Defect

Declarations

Clinical trial number: **Not applicable.**

Ethical Approval

The study protocol, including the waiver of informed consent for retrospective review of patient records was reviewed and formally approved by the Review Board of the Faculty of Medicine at Wad Medani University and the administration of the Medani Heart Center (MHC), in strict accordance with the ethical principles of the Declaration of Helsinki. The requirement for individual and parental/guardian informed consent was formally waived by the Review Board of the Faculty of Medicine at Wad Medani University due to the retrospective design of the study and the widespread displacement of the population caused by the armed conflict.

Consent for Publication

Not applicable. The requirement for informed consent was waived by the institutional ethics board due to the retrospective nature of the study and the displacement of the study population caused by the armed conflict.

Competing Interests

The authors declare that they have no competing interests, financial or non-financial, that could be perceived as influencing the work reported in this manuscript.

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Author Contribution

S.E.M.E.H. and A.A.M.O.M. contributed equally to this work as co-first authors, including conceiving the study design, coordinating clinical data collection at the Medani Heart Center, and drafting the main manuscript text.M.H.S.F. performed the statistical analysis, generated the SPSS data summaries and tables, and contributed to drafting the results and methodology sections.B.M.E. contributed to Writing, clinical documentation, and manuscript formatting and revising Y.S.E.I.M. managed institutional records, participated in data abstraction, and assisted with literature reviews.

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Data Availability

The datasets analyzed during this study are not publicly available due to the permanent loss of physical and digital institutional records following the onset of the armed conflict in April 2023. Aggregated data may be provided by the corresponding author upon reasonable request.

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