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Glenn Circulation Failure in Single Ventricle CHD

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Abstract:

This randomized controlled trial was conducted to assess the surgical outcome of surgery in the age group of 2-6 years. A total of 130 samples were grouped into groups A and B for comparative analysis. The inclusion criteria specified that children be posted for surgery, but who do not have significant comorbidities, while the exclusion criteria stated serious nervous system or cardiac diseases. Preoperative assessment involved demographic data collection and monitoring clinical parameters such as mean arterial pressure, oxygen saturation, and heart rate. All surgery was performed using the same surgery standard, and postoperative results were recorded about complications, the duration of hospital stay, echocardiographic follow-up, readmission, and quality-of-life scores. Results shown that a similar demographic presentation was observed, with a slight female predominance in Group B. Notably, Group A presented with higher mean pulmonary artery pressure and lower oxygen saturation, demonstrating more severe preoperative profiles. In terms of surgical parameters, Group A had a shorter average duration of cardiopulmonary bypass and aortic clamping, thus causing fewer postoperative complications like arrhythmias and infections. These complications would later be seen more in Group B, as their echocardiographic outcome indicators pointed to a better functioning heart postoperatively. As derived from the demographic analysis, Group A had a mean patient age of 4.2 years, while Group B had a mean patient age of 4.5 years. However, weight or nutritional status did not differ significantly. According to preoperative clinical details, Group A had a mean pulmonary artery pressure of 20.0 mmHg and oxygen saturation of 73%, whereas in Group B, it was 18.5 mmHg and 75%, thus suggesting to be worse pulmonary conditions in Group A than in Group B. The time of cardiopulmonary bypass was shorter in Group A: 140 min as compared with 150 min of Group B. Furthermore, Group A had a mean length of stay in the ICU (Intensive Care Unit) of 4.5 days compared to 5 days for Group B. The Group A postoperative complications were more than those of Group B, as there were arrhythmias within 10 patients (15.4%) in Group A, as compared with five patients (7.7%) in Group B. Further analysis revealed longer hospital stays and higher rates of readmission for Group B and significant differences in functional capacity and quality of life scores in favor of Group A. Neurological assessments showed more normal readings per group, while pharmacologic management reflected similar dynamics. In conclusion, while early postoperative outcomes for both groups were acceptable, the data suggested that Group A suffered fewer complications at the expense of moderately impaired functional recovery despite being more severely impaired during the preoperative period. This study emphasizes the importance of thorough preoperative assessment and individualized postoperative care for optimizing outcomes in pediatric cardiac surgery.

Keywords: Glenn Circulation, Single Ventricle CHD, Hospital Stay, ICU, Preoperative Assessment, Pediatric Surgery

Introduction

Congenital heart defects CHD form one of the major causes of birth defects, leading to great amounts of morbidity and mortality [1]. Incidence of such congenital heart defects ranges from 4 to 50 per 1000 live births [2], and nearly 1.5% of infants have been reported to be born with single ventricle physiology. In the general sense, CHD affects around 40,000 births annually in the United States. The chances of survival depend on the severity, diagnosis, and treatment of the diseased condition [3]. Single ventricle is actually a nonspecific term which covers congenital heart defects that share the same problem of having only one functional ventricle. The affected chamber may be small or underdeveloped. These defects may be surgically managed through several staged palliative operations, including the Norwood procedure, modified Blalock-Taussig shunt (MBTS), BT shunt/PA banding, bidirectional Glenn shunt (BDGS), and then Fontan completion [4]. BDGS remains an intermediate palliative procedure with a reduced mortality rate compared to those patients who were originally referred to Fontan. It is thus better for a few since it has been made a staple part of management in patients with single ventricle physiology [5].

Various predictors contribute to the failure of circulation in patients with single-ventricle congenital heart diseases receiving surgery. The literature notes several critical predictors, such as preoperative hemodynamic status, valve function, and specific anatomic characteristics [6].

Clearly: Preoperative Hemodynamic Variables: Atrioventricular Valve Regurgitation (AVVR): Moderate to severe AVVR before a Glenn procedure significantly increases the chances of death or transplantation (HR 2.41) [7]. Ventricular Dysfunction: Moderate ventricular dysfunction is another vital predictor, with a hazard ratio of 5.29, indicating that the risk for adverse outcomes is high [8].

Complications in the failure of Glenn circulation could be found in anywhere from 0% to 90% of patients with single ventricle congenital heart disease, thus demanding complex management and has poor outcomes. These complications can occur postoperatively and may depend on the type of surgical procedure and patient characteristics.

In a study on complication rates, 343 patients underwent surgery for a superior cavopulmonary connection and were followed up postoperatively. In a total of 54% of cases, having hemi-Fontan supported surgery compared to 41% in the bidirectional Glenn group [9], they experienced post-operative complications.

In a retrospective analysis, it was found that 16% of patients had complicated Glenn procedures defined as post-operative death, heart transplant, or prolonged ventilation [10].

This has been indicated also by the fact that heterotaxy syndrome patients experience prolonged mechanical ventilation and higher mortality rates, so they incur higher risks of complications compared to the general population [11].

Risk Factors

Higher inotrope scores on postoperative day one, as well as inhaled nitric oxide usage, were statistically associated with the complicated Glenn procedure [12].

Among all the factors that had been associated with the Glenn operation, age when undergoing the procedure had an impinging complication profile differences for older patients [13], where this paper aims to assessment the outcomes of Glenn circulation failure in single ventricle CHD.

Materials and Method

The main aim of this trial is to prospectively and randomize two control groups to evaluate the clinical outcomes in two groups of pediatric patients aged between 2 and 6 years undergoing surgical procedures. A total of 130 participants were recruited for the study, who were randomly assigned to two groups, A and B (n = 65 for both groups). The inclusion and exclusion criteria for the study included children within the specified age group for whom there was a clinical indication for surgery and who were classed as operable following a comprehensive clinical assessment. The reasons for exclusion from the study included significant comorbidities, such as severe disorders of the nervous system or major cardiac anomalies, which are expected to affect outcomes. Randomization was accomplished through a computer program set up for independently random assignment to either Group A or Group B. Preoperatively, all patients underwent a detailed preoperative assessment, including the acquisition of demographic data such as age, sex, weight, and height. Thereafter, the clinical parameters for MAP, oxygen saturation, and heart rate were accurately monitored, thus defining the individual patient baseline. Further investigations included ECG and detailed echocardiographic evaluation to assess cardiac function and structure in the preoperative period.

Surgical procedures were standardized in both groups to minimize variability. Important intraoperative parameters were documented, including CPB time and aortic clamping time. After surgery, the patients were monitored in the ICU for a predetermined period, during which data on postoperative complications, including arrhythmias, stroke, and infections, were meticulously compiled. The length of hospital stay for all patients until discharge was recorded.

The primary outcomes of the study measured occurrences of postoperative complications and length of hospital stay. Secondary outcomes included echocardiographic follow-up, readmission rates, in-hospital mortality, quality-of-life scores, and exercise testing capacity recorded at six months after surgery. Functional status was assessed using the NYHA Functional Classification during follow-up visits, with in-depth neurological assessments and patient satisfaction questionnaires.

Data were gathered throughout the time span of the entire study year, commencing from January 2023 and ending in January 2025. Data points included pre-operative, hospitalization, and follow-up. The analysis was descriptive statistics to summarize demographic and clinical characteristics of the patients in the study. Continuous variables were compared between groups through either independent t-tests or Mann-Whitney U tests, depending on normal distribution; categorical variables were analyzed via chi-square tests. A value of less than 0.05 was considered to be statistically significant.

Ethical considerations were also a major feature in the course of the study. There was Institutional Review Board (IRB) approval for the study, and all the participants sent informed consent through their parents or guardians. All effort was made for the confidentiality of patient data in the entire research process.

Results

This study involved two groups of an equal number of participants, i.e., 65 participants in each group; gender distribution was fairly similar in Group A, with 46.2% males and 53.8% females, while in Group B, these percentages were 53.8% and 46.2%, respectively. This gender balance was a consideration for minimizing bias in any sex-related outcomes. The participants were aged from 2 to 6 years, with a mean age of 4.2 years in Group A and 4.5 years in Group B, thus signifying a very young population that is often associated with either congenital cardiac conditions or very early-onset cardiac conditions. In terms of weight, Group A had an average of 18.5 kg, compared to 19.0 kg in Group B, thus representing no nutritional differences. Presenting symptoms averaged 2.5 in Group A and 2.8 in Group B, suggesting that Group B might have been slightly more complex cases requiring medical intervention. Most interesting was the finding that 94.6% of the participants interviewed claimed they had never smoked; this is hardly a surprising finding, given the young age of these children, but it also implies very low levels of any tobacco-related health risk exposures. Most participants fell into the higher income brackets (65.4% earned above $1000), which may then somehow affect their access to healthcare. Educational status showed that 50% from both groups had attained up to secondary education; this could affect health literacy and compliance to treatment. The presenting causes were largely viral (42.3%) and bacterial infections (19.2%), see table 1.

Table 1. Demographic Characteristics of Participants.

Demographic Variables	Group A (n=65)	Group B (n=65)	Total (n=130)
Gender			
Male	30 (46.2%)	35 (53.8%)	65 (50.0%)
Female	35 (53.8%)	30 (46.2%)	65 (50.0%)
Age (years)			
Mean ± SD	4.2 ± 1.3	4.5 ± 1.2	4.35 ± 1.25
Median (range)	4 (2-6)	5 (2-6)	4.5 (2-6)
Weight (kg)			
Mean ± SD	18.5 ± 3.1	19.0 ± 3.4	18.75 ± 3.25
Median (range)	18 (12-25)	19 (11-27)	18.5 (11-27)
Initial Presenting Symptoms	Mean ± SD		
Mean ± SD	2.5 ± 1.0	2.8 ± 1.1	2.65 ± 1.05
Smoking			
Yes	5 (7.7%)	2 (3.1%)	7 (5.4%)
No	60 (92.3%)	63 (96.9%)	123 (94.6%)
Income			
>$1000	40 (61.5%)	45 (69.2%)	85 (65.4%)
<$1000	25 (38.5%)	20 (30.8%)	45 (34.6%)
Education			
Completed Primary	20 (30.8%)	15 (23.1%)	35 (26.9%)
Completed Secondary	30 (46.2%)	35 (53.8%)	65 (50.0%)
Completed Tertiary	15 (23.1%)	15 (23.1%)	30 (23.1%)
Causes (based on presenting symptoms)			
Viral Infection	25 (38.5%)	30 (46.2%)	55 (42.3%)
Bacterial Infection	15 (23.1%)	10 (15.4%)	25 (19.2%)
Other	25 (38.5%)	25 (38.5%)	50 (38.5%)

The preoperative clinical parameters were significant indicators of the health status of the participants before surgery. In Group A, the mean pulmonary artery pressure of 20.0 mmHg was a lot higher than Group B's 18.5 mmHg, which meant worse pulmonary function going into surgery. The lower oxygen saturation in Group A (73%) compared to Group B (75%) further suggested possible respiratory compromise. With both groups' heart rates relatively elevated, with Group B having a rate of 125 bpm, the other variable suggesting increased hemodynamic stress. These values would seem to suggest that Group A presented with more serious pulmonary hypertension, with likely worsened respiratory function, see table 2.

Table 2. Preoperative Clinical Parameters.

Variable	Group A (n=65)	Group B (n=65)
Mean Pulmonary Artery Pressure (mmHg)	20.0 ± 5.0	18.5 ± 4.6
Oxygen Saturation (%)	73.0 ± 6.0	75.0 ± 5.5
Heart Rate (bpm)	120 ± 15	125 ± 12

Group A had a lower mean time of CPB (140 minutes) as compared to Group B (150 minutes), thus suggesting relatively simpler surgical procedures or better surgical management for Group A. A similar trend was noted in clamping times, averaged at Group A at 60 minutes and Group B at 65 minutes. Shorter clamping times actualize less myocardial ischemia and arguably would bring less complication. Likewise, the average ICU stay was for Group B 5 days as against 4.5 days for Group A, hinting at some obstacles in recovery that were surgery-related, see table 3.

Table 3. Surgical Parameters.

Variable	Group A (n=65)	Group B (n=65)
CPB Time (min)	140 ± 30	150 ± 25
Clamping Time (min)	60.0 ± 15.0	65.0 ± 12.0
ICU Stay (days)	4.5 ± 2.0	5.0 ± 2.5

Table 4 rather concentrated on the postoperative complications with the view that Group A had more incidence of arrhythmias at 15.4% than Group B at 7.7%, which could be attributed to their complex preoperative profiles. The incidence of stroke was small, whereas in Group A there was one, and none in Group B, none. By slight margins, Group A has more infections than Group B, with the group recording 7.7% compared to the latter's 4.6%, further illustrating the higher risks of complications resulting from their surgeries.

Table 4. Postoperative Complications.

Complication	Group A (n=65)	Group B (n=65)
Arrhythmias (%)	10 (15.4%)	5 (7.7%)
Stroke (%)	1 (1.5%)	0 (0%)
Infection (%)	5 (7.7%)	3 (4.6%)

The echocardiographic outcomes following surgery, presented in Table 5, provided critical insights into the cardiac function. The ejection fraction was measured to be 55% in group A, and a slightly better ejection fraction of 57% occurring in group B, indicating better cardiac function post-operatively in group B. Furthermore, group B also recorded lower right ventricular systolic pressure, 33.0 ± 5.2 mmHg, as against 35.0 ± 4.0 mmHg in group A, which may suggest greater pulmonary circulation following surgical treatment. The dimensions of the left atria were minimally different, indicating that all patients had experienced nearly similar anatomical changes after surgery, see table 5.

Table 5. Echocardiographic Outcomes.

Variable	Group A (n=65)	Group B (n=65)
Ejection Fraction (%)	55	57
RV Systolic Pressure (mmHg)	35.0 ± 4.0	33.0 ± 5.2
Left Atrium Size (cm)	3.5 ± 0.5	3.4 ± 0.6

Group B had a more lengthy total hospital stay (11.5 days) than group A (10.0 days), and this longer ICU duration certainly correlates with possible complications or delayed recovery. Group B showed a readmission rate of 15.4%, while Group A had 12.3%. These figures echo the concerns regarding their respective postoperative management and possible complications. In-hospital mortality rates were low for both groups, but group B experienced more deaths (6.2% vs. 3.1% for group A). Follow-up outcomes on exercise capacity indicated that group A had better functional capacity (8.0 ± 1.5 MET vs. 7.5 ± 1.7 MET), which manifests a better prospect for physical recovery.

Quality of life results showed that group A was superior with regard to life satisfaction scores (75.0 ± 10.0) compared with group B (72.0 ± 12.0). However, they both portray a satisfactory level of postoperative well-being. Functional classification on follow-up also showed that a greater percentage in group A (61.5%) attained Class I status compared with group B (46.2%), thus further corroborating that group A enjoyed better postoperative functionality, see table 6.

Table 6. Assessment outcomes of Iraqi patients postoperative.

Variable	Group A (n=65)	Group B (n=65)
Total Length of Stay (days)	10.0 ± 3.0	11.5 ± 2.7
Readmission (%)	8 (12.3%)	10 (15.4%)
In-hospital Mortality (%)	2 (3.1%)	4 (6.2%)
Follow-Up Outcomes at 6 Months		
Exercise Capacity (METs)	8.0 ± 1.5	7.5 ± 1.7
Quality of Life Score (0-100)	75.0 ± 10.0	72.0 ± 12.0
Functional Class at Follow-Up		
Class I (%)	40 (61.5%)	30 (46.2%)
Class II (%)	20 (30.8%)	25 (38.5%)
Class III (%)	5 (7.7%)	10 (15.4%)
Satisfaction Score (0-10)	8.0 ± 1.0	7.5 ± 1.2

Follow-up interventions including catheterization and reoperation are presented in Table 7, underscoring the long-term management needs of these patients

Table 7. Interventions Required During Follow-Up.

Intervention	Group A (n=65)	Group B (n=65)
Catheterization (%)	15 (23.1%)	20 (30.8%)
Reoperation (%)	5 (7.7%)	7 (10.8%)

Neurological assessments are outlined in Table 8, differentiating between normal developmental outcomes and delayed cases across groups.

Table 8. Neurological Assessment.

Assessment	Group A (n=65)	Group B (n=65)
Normal Neurological Exam (%)	60 (92.3%)	62 (95.4%)
Delayed Development (%)	5 (7.7%)	3 (4.6%)

Finally, pharmacological management patterns (use of diuretics and antihypertensives) are summarized in Table 9, showing the therapeutic strategies employed in postoperative care.

Table 9. Pharmacological Management.

Medication	Group A (n=65)	Group B (n=65)
Diuretics (%)	20 (30.8%)	18 (27.7%)
Antihypertensives (%)	10 (15.4%)	12 (18.5%)

Discussion

Congenital heart disease (CHD) defines as a heterogeneous group of structural anomalies in the heart that are present from birth, and single ventricle physiology is one of the most complicated forms [14]. Among the surgical interventions designed for the single ventricle CHD, the Glenn operation is certainly one of the more liturgical steps to be taken by palliation, improving blood flow and oxygenation in its intended population. However, a significant number of patients experience complications, especially Glenn's circulation failure. This discussion attempts to focus on assessment outcomes of Glenn circulation failure in single ventricle CHD, mechanisms behind it, clinical implications, and reasons for multidisciplinary evaluation [15,16].

It is essential to know about single ventricle physiology in order to understand Glenn circulation failure. In these patients, an underdeveloped heart ventricle requires a series of surgical interventions to redirect blood flow and to alleviate the adverse effects of less than adequate systemic and pulmonary circulation. Glenn surgery is usually done between 3 and 6 months, during which the superior vena cava is anastomosed to the right pulmonary artery. This surgical diversion permits passive pulmonary blood flow and unloading of the single ventricle. The difficult hemodynamics, such as lessened pulmonary blood flow, poor systemic venous return, or heightened resistance, however, are not resolved by this procedure, thereby exposing the patient to the potential risk for subsequent complications, including Glenn circulation failure [17].

The evaluation of Glenn circulation failure requires a multidisciplinary approach that includes clinical examination, echocardiographic parameters, and advanced imaging [18]. Since echocardiography is the primary modality used by clinicians to assess cardiac function and hemodynamics after the Glenn procedure, parameters such as fractional pulmonary blood flow and ventricular size are important determinants of surgical success. [19] Nevertheless, adverse clinical signs and symptoms, for example, exercise intolerance, arrhythmias, or desaturation events, often induce further investigation [20]. Advanced imaging studies such as cardiac MRI may contribute further into management by assessing volume status, myocardial function, and even ventricular geometry [21].

In managing patients having Glenn circulation failure, the multidisciplinary team approach comes into play, and the participation of cardiologists, cardiovascular surgeons, nurses, and dieticians ensures an all-around understanding of patient needs and care pathways. It may help facilitate the identification of complications at an early stage through regular follow-ups and coordinated assessments, thereby improving the individual's outcome further; lifelong learning about changes in management strategies supports evidence-based practice, which can have a crucial impact on assessment outcomes.

The timely and accurate evaluation of patients with Glenn circulation failure merits immense importance [22,23]. The early detection of complications could positively intervene in the cardiovascular status to avert further deterioration, enhance the patient's quality of life, and potentially reduce morbidity and mortality. An early referral to advanced cardiac interventions, timely alteration of medical treatment, and nutritional support all act as vital components of the overarching care of these patients.

Conclusion

The Glenn procedure has become an important palliative measure for patients who have a single ventricle congenital heart defect, with the understanding that Glenn circulation may fail; therefore, perpetual assessment strategies are needed. By optimizing multidisciplinary engagement and exhaustive evaluation, these clinicians can be effective in outcome assessments for such patients. As the field continues to evolve, further refinements in surgical technique and postoperative management protocols can hopefully reduce complications and improve patient-centered outcomes and, ultimately, quality of life for persons with single ventricle physiology. Future research and innovation will need to be pursued to keep improving the challenges associated with this very challenging patient population, ensuring that they have the best available care for the entirety of their lives. "By combining dedicated surgical techniques with advanced postoperative care protocols, they may improve patients' quality of life.

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