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The Glenn Shunt Revisited, A Single Center Registry in Ain Shams University Cardiology Department

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ABSTRACT

Background: Bidirectional Glenn shunts have long been available as palliative procedures for patients with single ventricle physiology that is, patients unsuitable for biventricular repair. In our country they are performed at an older age than that recommended by the literature. So, we aim to assess post bidirectional Glenn shunt patients to detect the presence of any complications and to evaluate their functional capacity. **Methods:** This was a descriptive study that included all patients who underwent a bidirectional Glenn shunt and were referred for follow up in Ain shams university hospitals. History taking including NYHA class and physical activity, clinical examination, six-minutes-walk test, laboratory investigations, full echocardiographic assessment were done for all patients. Some patients needed invasive cardiac catheterization. **Results:** Our registry included 178 patients who underwent bidirectional Glenn procedure referred for follow up in Ain Shams university hospital from January 2019 till July 2020. The mean age of the registry was 18.7 ± 8.26 years (range between 5 and 37 years), 85 males (48%) and 93 females (52%). Regarding the basic anatomy, double outlet right ventricle with hypoplastic left ventricle was the commonest. Furthermore, our descriptive study confirmed many characteristic similarities between our patients and patients in developing countries. Our patients underwent bidirectional Glenn shunt at a median age of 6 years which is considered a relatively old age but similar to other studies that have been made in developing countries like Pakistan, India and Iran. There is a significant delay in the operation in Egyptian patients due to lack of patients' awareness, few numbers of primary health care facilities and high economic burden. **Conclusion:** Although the presence of slight systemic desaturation, our study demonstrated a satisfactory functional capacity among our patients; thus, bidirectional Glenn can be considered an acceptable definite univentricular repair in patients with late presentation.

KEYWORDS

Bidirectional Glenn shunt; single ventricle; univentricular repair

1 Introduction

Among the most frequently encountered causes of fetal mortality and morbidity are congenital heart diseases, with an incidence of 1% in newborns [1,2]. Specially in developing countries, the exact incidence is vague and usually the presentation is delayed; and the reasons include insufficient registries,

asymptomatic nature of disease at early months of life and missed diagnosis. Single ventricular physiology, also known as univentricular heart, requires an experienced heart team including pediatric cardiologist and cardiothoracic surgeons, in order to reach the most suitable management plan for each case. The management plan entails series of palliative operations like Norwood procedure, modified Blalock-Taussig shunt (MBTS), MBTS/Pulmonary artery banding, bidirectional Glenn shunt (BDG), and then Fontan completion.

Staged procedures towards Fontan completion are preferred providing better results and less complications. However, the choice of suitable candidate is crucial and must follow the Ten Commandments for an ideal Fontan operation [3]. These commandments include age younger than 4 years, sinus rhythm, normal venous return, normal right atrial dimension and volume, mean pulmonary artery pressure not exceeding 15 mmHg, pulmonary vascular resistance less than 1 Wood unit/m^2, pulmonary artery–aorta ratio more than 0.75, preserved systemic ventricle function, competent mitral valve and good anatomy of pulmonary arteries.

Most importantly, it remains critical that the resistance across the pulmonary capillary bed remains low. Excessive pulmonary vascular resistance is a clear contraindication to a Fontan completion because pulmonary vascular resistance provides the primary limitation to cardiac output in patients without a pre-pulmonary pump [4].

The BDG is still an essential step in univentricular heart repair; as it offers excellent palliation and increased pulmonary blood flow. In addition, it unloads the heart and allows pulmonary artery growth, hence, it improves survival and quality of life [5].

Although BDG is routinely used as a step towards Fontan procedure or a definite palliation in high-risk candidates for Fontan, little is known about the late results, the duration of palliation, and the frequency with which this procedure allows later successful conversion to a Fontan type of procedure. Therefore, in the current study, we aim to report present-day outcomes following BDG in patients with various single ventricle anomalies and to assess the post BDG patients' functional capacity and desaturation. The ultimate goal is to identify how satisfactory is our patients' quality of life and if BDG could be considered as a standard of care for univentricular repair in late presenter population.

2 Materials and Methods

This was a retrospective study including patients who underwent BDG referred for follow up in Ain Shams University hospitals from January 2019 till July 2020.

Inclusion criteria:

All patients who underwent BDG for follow up in Ain shams university hospital were included. Pediatric and adult patients were both included in the study.

Exclusion criteria:

Critical ill patients (patients with hemodynamic instability or significant neurological deficit) and patients refusing the study.

After the informed consent, all patients were subjected to the following:

2.1 History

Proper history taking by a customized questionnaire including: demographic data (gender, current age, weight, height, body surface area, order of birth), relevant family history (familial congenital heart disease, consanguinity and maternal risk factors), clinical data (age at first presentation, functional capacity, level of physical activity and any reported symptoms), surgical data (age and weight at time of the operation, date of operation, surgical procedures other than BDG such as a previous pulmonary artery banding or

aortopulmonary shunt), history of percutaneous interventions (Pulmonary artery stenting or veno-venous collaterals closure) and current medical treatment.

2.2 Clinical Examination

Including general examination with special emphasis on general appearance, specific features, complexion, vital data, clubbing, weight, height, peripheral pulsations, oedema, hepatomegaly and jugular venous pressure examination.

2.3 Six-Minutes-Walk Test

The test was performed according to American Thoracic Society Standard [6]. The distance, blood oxygen saturation before test (rest SAT) and desaturation at the maximum effort (rest SAT–SAT 6′), initial and maximal heart rate (rest HR, peak HR) and the recovery time were analyzed.

2.4 Routine Investigation

12 lead surface electrocardiogram (ECG) and routine laboratory investigations including (complete blood picture, kidney function, liver function, electrolytes and coagulation profile) were performed for all patients in the study.

2.5 Conventional 2D Echocardiography

Full ECG gated echocardiographic study using echocardiography machine with phased array transducer of suitable frequency to perform sequential segmental analysis (Figs. 1 and 2).
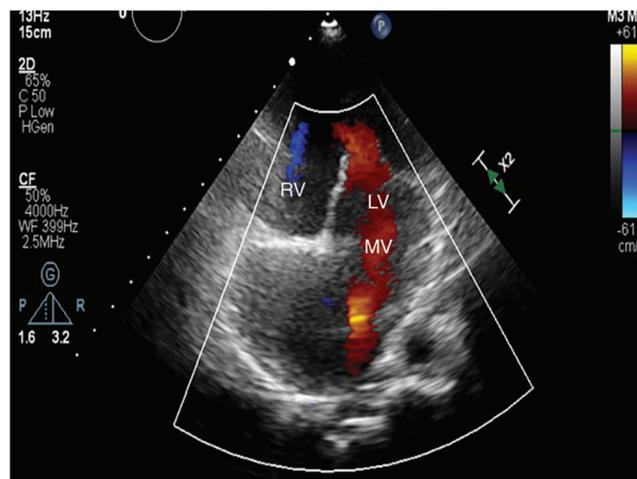

Figure 1: Apical 4 chamber view showing tricuspid atresia in patient number 2 (MV: mitral valve, LV: left ventricle, RV: right ventricle)

The morphology of the dominant ventricle (right, left or indeterminate), the location of the rudimentary ventricles or outlet chambers (anterior or posterior, left or right); the location of the papillary muscles and chordal attachments within the ventricular chambers (straddling and/or overriding) were assessed.

Assessment of dominant ventricular systolic function:

If the dominant ventricular morphology was left, then the ventricular function was assessed by M-mode or 2-dimensional echocardiography [7] and the modified Simpson biplane method [8].
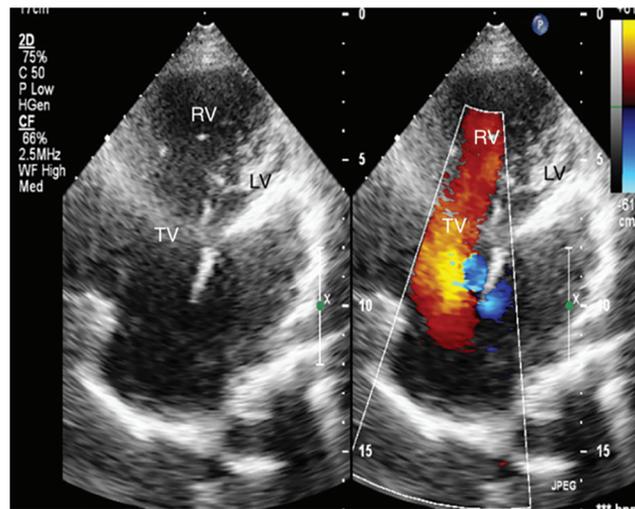
Figure 2: Apical 4 chamber view showing mitral atresia in patient number 15 (TV: Tricuspid valve, LV: left ventricle, RV: right ventricle)

If the dominant ventricular morphology was right, then the ventricular function was assessed by tricuspid annular plane systolic excursion (TAPSE) and the right ventricle fractional area change (FAC). RV FAC < 35% indicates RV systolic dysfunction [7,9].

Assessment of the atrioventricular valves was done as well and the degree of regurgitation was noted.

Evaluation of pulmonary valve morphology, degree of pulmonary stenosis and regurgitation if present. Level of stenosis and gradient across the valve was recorded. In patients with previous banding, gradient across the band and its site were evaluated.

Pulmonary arteries size, flow and the presence of peripheral stenosis were noted.

The BDG was evaluated from the suprasternal notch view, a BDG might be right, left sided or bilateral in patients with bilateral superior vena cava. Patent flow was assessed by the presence of laminar flow on color Doppler and with low phasic velocity flow pattern on pulsed-wave Doppler and respiratory variation was also assessed. A significant obstruction was determined by a measured mean gradient of more than 2 mmHg between the BDG circuit and the pulmonary arteries (Fig. 3) [10].
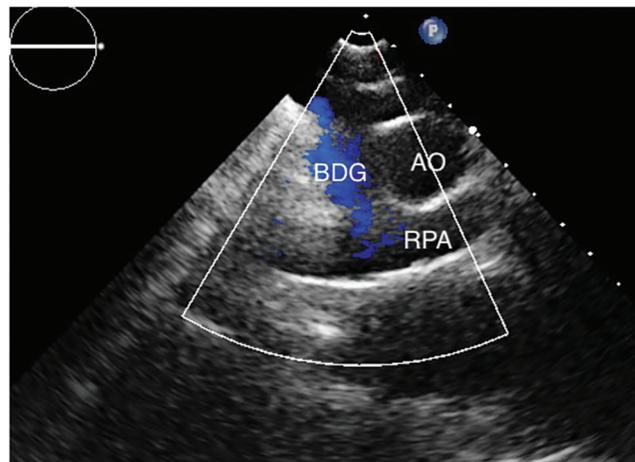

Figure 3: Suprasternal view with color flow showing patent right sided BDG with no reversal of flow in patient number 21 (BDG: bidirectional Glenn, AO: aorta, RPA: right pulmonary artery)

2.6 Cardiac Catheterization

Cardiac catheterization was done to selected patients if Fontan completion was planned, hemodynamic assessment was needed due to desaturation or catheter-based interventions were required.

2.6.1 Hemodynamic Study: Under GA and 100% Oxygen

Various pressures (aorta and pulmonary artery systolic, diastolic and mean pressures and dominant ventricle systolic and diastolic pressures) and saturations (aorta and pulmonary artery saturations) were recorded, veno-venous collaterals and aortopulmonary collaterals were looked for and assessment of peripheral pulmonary arteries for significant peripheral pulmonary stenosis was done.

2.6.2 Percutaneous Interventions

Percutaneous interventions were done to few patients and most commonly indicated for peripheral pulmonary stenting or collaterals closure (Fig. 4).
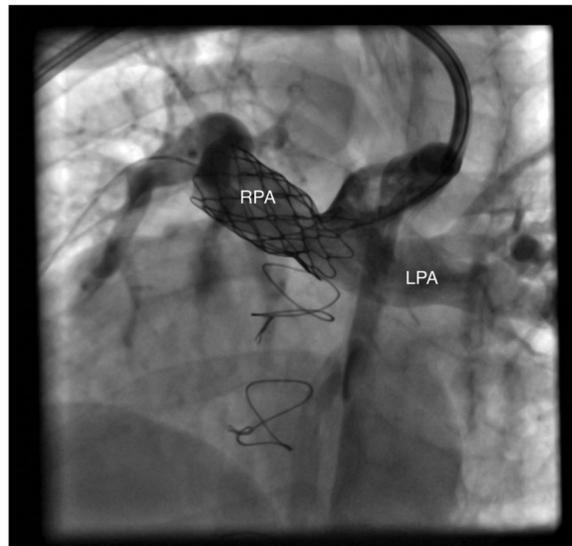

Figure 4: Showing well deployed RPA stent in patient number 10 (RPA: right pulmonary artery, LPA: left pulmonary artery)

3 Statistical Analysis

The collected data was summarized, presented and analyzed using the commercially available software (SPSS 19.0 version, IBM Co., Armonk, NY, USA). Qualitative data was summarized by frequency and percentages and quantitative data was expressed as mean ± standard deviation. Chi square test was used to compare the systemic ventricle morphology with the degree of functional capacity limitation. The correlation between the RDW and the oxygen saturation was assessed by linear regression and Pearson correlation analysis. $P < 0.05$ was considered statistically significant.

4 Results

4.1 Demographic Data

Primarily, our registry included 194 patients; however, 16 patients were excluded (4 were critically ill and 12 had refused the study) with remaining 178 patients. The mean age of the registry was 18.7 ± 8.26 years (range between 5 and 37 years), 85 males (48%) and 93 females (52%).

128 patients (72%) were single, 46 patients (26%) were married and 4 patients (2%) were divorced. 17 females post BDG got pregnant and gave birth to healthy offspring.

In our study, 87 patients (49%) had a systemic ventricle of right ventricular morphology, while, 91 patients (51%) had a systemic ventricle of left ventricular morphology. The primary diagnosis had a wide range among the commonest were double outlet right ventricle with hypoplastic left ventricle and tricuspid atresia (Table 1).

Table 1: Primary diagnosis

		Number	Percentage
Ventricular morphology	Primary diagnosis		
Dominant right ventricular morphology	Double outlet right ventricle with hypoplastic left ventricle	45	25.3%
	Mitral atresia	26	14.6%
	Transposition of great arteries	10	5.6%
	Unbalanced common atrio-ventricular canal	6	3.4%
Dominant left ventricular morphology	Tricuspid atresia	38	21.3%
	Double inlet left ventricle	25	14%
	Unbalanced common atrio-ventricular canal	12	6.7%
	Tetralogy of Fallot	5	2.8%
	Pulmonary atresia	4	2.3%
	Hypoplastic right ventricle	4	2.3%
	Ebstein anomaly	2	1.1%
	Double outlet left ventricle	1	0.6%

105 patients (59%) had undergone only BDG, while 73 patients (41%) had undergone surgeries prior to BDG. In addition to that, 42 patients (23.6%) had undergone percutaneous intervention (Table 2).

Table 2: Surgical and percutaneous interventions

	Number	Percentage
Surgical intervention prior to bidirectional Glenn shunt (BDG)		
None	105	59%
Pulmonary artery banding	47	27%
Modified Blalock-Taussig shunt	24	13%
Pulmonary artery banding and modified Blalock-Taussig shunt	2	1%
Percutaneous intervention		
None	136	76.3%
Rashkind balloon atrial septostomy prior to BDG	19	10.7%
Peripheral pulmonary stenting after BDG	10	5.6%
Veno-venous collateral closure after BDG	8	4.5%
Multiple hemodynamic studies after BDG	3	1.7%
Balloon pulmonary valvuloplasty after BDG	1	0.6%
Accessory pathway ablation after BDG	1	0.6%

Patients underwent BDG at a median age of 6 years (range between 1 and 34 years) (Fig. 5).
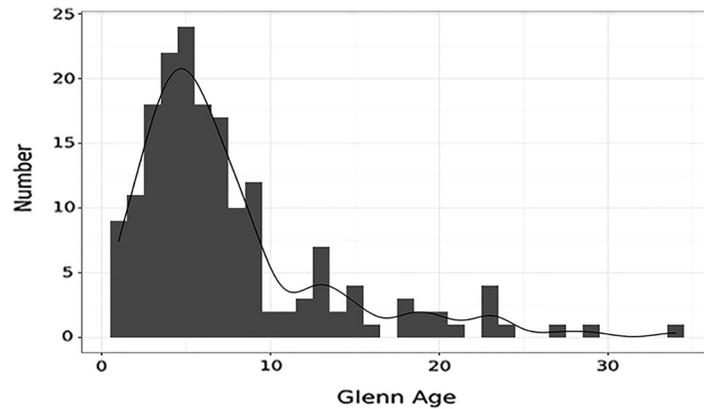

Figure 5: Showing age at which patients underwent BDG

Currently, 27 patients (15%) had no limitations to daily physical activities and 151 patients (85%) suffered from limitation to daily physical activity; among the sufferers, 78 patients (44%) claimed to have mild limitation, 67 patients (38%) complained of having moderate limitation and 6 patients (3%) had severe limitation of daily physical activity (Fig. 6). In order to have a more objective evaluation of the functional capacity of our patients, the six-minutes-walk test was used. The distance walked during the test ranged between 108 and 504 m with a mean of 302 ± 82.7 m with a mean decrease in oxygen saturation pre and post exercise of $7.56 \pm 6.07\%$. However, the mean recovery time required to reach baseline oxygen saturation was 2.45 ± 1.10 min.

Figure 6: Showing the degree of physical activity limitation among patients

66 patients (37%) take no medications at all; on the other hand, 112 patients (63%) are on various medications [53 patients (30%) are on aspirin therapy, 28 patients (16%) are on iron therapy, 15 patients (8%) are on anti-failure treatment, 9 patients (5.1%) are on folic acid therapy, 4 patients (2.2%) are on febuxostat treatment and 3 patients (1.7%) are on warfarin].

4.2 Six-Minutes-Walk Test

The functional capacity of our patients was assessed by using the six-minute-walk test. The distance walked during the test ranged between 108 and 504 m with a mean of 302 ± 82.7 m with a mean decrease in oxygen saturation pre and post exercise of 7.56 ± 6.07%. However, the mean recovery time required to reach baseline oxygen saturation was 2.45 ± 1.10 min.
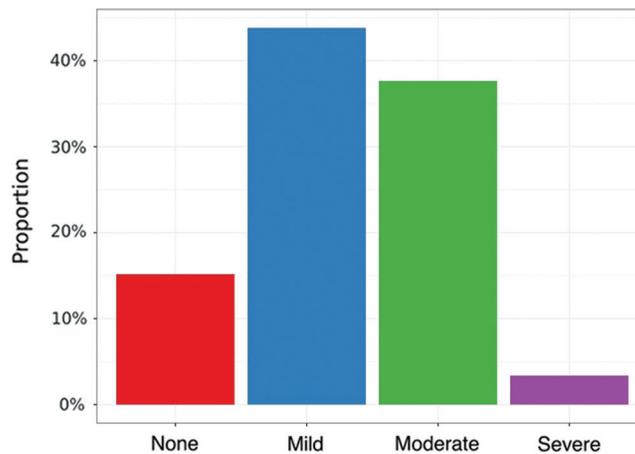
4.3 Laboratory Findings

It was noted that most of our cohort had polycythemia, however, the blood indices showed microcytic hypochromic pattern denoting the presence of iron deficiency anemia. The hemoglobin ranged from 10 to 24 g/dl with a mean of 16.7 ± 2.48 g/dl and the hematocrit value ranged from 22 to 73% with a mean of 60.8 ± 7.27%. The mean RBC count was 7.61 ± 1.45 million/cmm, the mean MCV was 76.8 ± 10.3 fl, the mean MCH was 25.1 ± 3.85 pg, the mean MCHC was 31.7 ± 2.01 g/dl and the RDW ranged from 11.8 to 32.3% with a mean of 21.3 ± 4.20%. Rest of laboratory findings are summarized in Table 3.

Table 3: Laboratory findings

	Mean ± SD	Range
Hemoglobin	16.7 ± 2.48	10–24
Hematocrit value	60.8 ± 7.27	22–73
RBC count	7.61 ± 1.45	4.79–11.3
MCV	76.8 ± 10.3	46.6–99
MCH	25.1 ± 3.85	13.7–33.2
MCHC	31.7 ± 2.01	25.8–36.4
RDW	21.3 ± 4.20	11.8–32.3
TLC	6.81 ± 1.86	3–15.9
PLT	191 ± 48.8	86–329
Urea	30.8 ± 6.95	10–81
Creatinine	0.743 ± 0.172	0.4–1.32
Uric acid	7.26 ± 2.12	3.1–16
Sodium	141 ± 2.76	128–149
Potassium	4.61 ± 0.534	3.4–6.4
AST	19 ± 4.45	10–52
ALT	14.3 ± 4.42	3–29
Total bilirubin	0.788 ± 0.253	0.39–2.1
Direct bilirubin	0.257 ± 0.09	0.03–0.7
INR	1.15 ± 0.233	0.8–2.9

4.4 Echocardiographic Findings

In our 91 patients with left ventricular morphology, the mean LV end diastolic volume was 169 ± 11.4 ml, the mean LV end systolic volume was 79 ± 8.42 ml and the LV ejection fraction ranged between 34.3% and 67.2% with a mean of 53.3 ± 3.29%. In our 87 patients with right ventricular morphology, the mean RV end diastolic area was 37.6 ± 4.62 cm^2, the mean RV end systolic area was 22.1 ± 3.62 cm^2 and the RV fractional area change ranged between 20% and 58.7% with a mean of 41.1 ± 5.47%. The atrio-

ventricular valvular findings together with the pulmonary valve and peripheral pulmonary branches assessment results are shown in Table 4.

Table 4: Atrio-ventricular valves, pulmonary valve and peripheral pulmonary branches assessment

	Number	Percentage
Left atrio-ventricular valve		
Competent	30	17%
Trivial regurgitation	28	16%
Mild regurgitation	66	37%
Moderate regurgitation	24	13%
Severe regurgitation	4	2%
Atretic	26	15%
Right atrio-ventricular valve		
Competent	12	6.7%
Trivial regurgitation	31	17.4%
Mild regurgitation	55	30.9%
Moderate regurgitation	30	16.9%
Severe regurgitation	12	6.7%
Atretic	38	21.4%
Pulmonary valve		
Native stenosis	112	62.9%
Atretic	17	9.6%
Pulmonary artery band	49	27.5%
Peripheral pulmonary branches size		
Good	176	99%
Small	2	1%
Peripheral pulmonary branches stenosis		
Absent	162	91%
Left pulmonary artery stenosis	10	5.6%
Right pulmonary artery stenosis	6	3.4%
	Mean ± SD	Range
Peak pressure gradient across pulmonary valve	78.4 ± 11	50–102 mmHg

During Glenn shunt assessment, 156 patients (88%) were found to have a right sided Glenn, 8 patients (4%) were found to have a left sided Glenn and 14 patients (8%) were found to have bilateral Glenn. Significant flow reversal was present in 24 patients (13%) and mean Glenn shunt mean pressure gradient was 1.07 ± 0.29 mmHg.

4.5 Cardiac Catheterization Findings

In 154 patients who underwent hemodynamic cardiac catheterization, the mean pulmonary artery pressure had a mean of 12 ± 5.29 mmHg and the mean aortic artery pressure had a mean of 82.7 ± 12.4 mmHg. The dominant ventricle mean diastolic pressure was11.2 ± 3.03 mmHg. The mean invasive systemic oxygen saturation was $84.7 \pm 7.57\%$. Added to that, 14 patients (9%) were found to have significant proximal peripheral pulmonary artery branches stenosis [9 patients (5.8%) having left pulmonary artery stenosis and 5 patients (3.2%) having right pulmonary artery stenosis]. Moreover, 90 patients (58%) had significant veno-venous collaterals, 74 patients (48%) had minor aorto-pulmonary collaterals, 23 patients (15%) had major aorto-pulmonary collaterals and 10 patients (6.5%) had significant AV malformations.

4.6 Important Correlation

4.6.1 Effect of Dominant Ventricular Morphology on Degree of Limitation of Daily Physical Activity

In our study, there was no statistically significant difference between dominant ventricle morphology and degree of limitation of daily physical functioning.

In 91 patients with left ventricular morphology, 12 patients (13%) had no limitations on daily physical activity, 40 patients (44%) had mild limitations on daily physical activity, 35 patients (38%) had moderate limitations on daily physical activity and 4 patient (5%) had severe limitations on daily physical activity.

In 87 patients with right ventricular morphology, 15 patients (17%) had no limitations on daily physical activity, 38 patients (43.5%) had mild limitations on daily physical activity, 32 patients (37%) had moderate limitations on daily physical activity and 2 patient (2.5%) had severe limitations on daily physical activity (Table 5).

Table 5: Effect of dominant ventricular morphology on degree of limitation of daily physical activity

Dominant ventricle	Degree of limitation of daily physical functioning				
	None	Mild	Moderate	Severe	
Left	12	40	35	4	91 (51.1%)
	13.2% RT	44.0% RT	38.5% RT	4.4% RT	
	44.4% CT	51.3% CT	52.2% CT	66.7% CT	
	6.7% GT	22.5% GT	19.7% GT	2.2% GT	
Right	15	38	32	2	87 (48.9%)
	17.2% RT	43.7% RT	36.8% RT	2.3% RT	
	55.6% CT	48.7% CT	47.8% CT	33.3% CT	
	8.4% GT	21.3% GT	18.0% GT	1.1% GT	
	27	78	67	6	178
	(15.2%)	(43.8%)	(37.6%)	(3.4%)	
Significance level	$P = 0.7780$				

4.6.2 Effect of Veno-Venous Collaterals Presence and Degree of Desaturation During the Six-Minutes-Walk Test

In our study, there was statistically significant difference between patients with and without veno-venous collateral presence detected by catheterization regarding the degree of desaturation evaluated during the six-minutes-walk test.

The mean oxygen desaturation among the patients having veno-venous collateral was 8.6 ± 6.8%; in contrast to a mean oxygen desaturation of 6.1 ± 4.6% among the patients having no veno-venous collaterals ($P = 0.008$).

4.6.3 Effect of RDW on Oxygen Saturation

In our study, there was statistically significant difference between patients with high oxygen saturation (above 80%) and patients with low oxygen saturation (below 80%) regarding the RDW.

The mean RDW among the patients with high oxygen saturation (above 80%) was 20.7 ± 4.18%; in contrast to a mean RDW of 22.3 ± 4.05% among the patients with low oxygen saturation (below 80%) ($P = 0.012$).

Using ROC curve analysis; a RDW cutoff value was generated to predict lowered oxygen saturation. The area under this ROC curve was 0.624 and *P*-value was 0.004. A RDW cutoff value of 21.8% provided the highest balanced sensitivity (53.85%) and specificity (69.91%) to determine oxygen saturation less than 80% on room air. A cutoff value more than 32.3% had 100% specificity to predict oxygen saturation less than 80% on room air (Fig. 7).
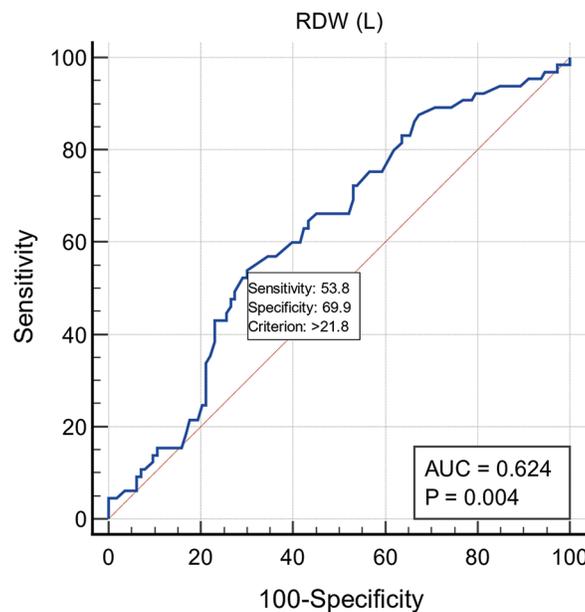

Figure 7: ROC curve showing a RDW cutoff value of 21.8% provided the best balanced sensitivity 53.85% and specificity 69.91% to determine oxygen saturation less than 80%

4.7 Long Term Outcome

A sub-analysis was done in our study demonstrating 87 patients who had BDG aged more than 10 years. In this cohort of patients, 41 males (47%) and 46 females (53%) with a mean age of 23.1 years.

The most common primary diagnosis was tricuspid atresia (28%). Prior to BDG, 23 patients had undergone pulmonary artery band, 16 patients had MBT shunt, 1 patient had PAB + MBT shunt and 12 patients had undergone Rashkind balloon atrial septostomy. While after BDG procedure, 8 patients had undergone veno-venous collaterals closure and 5 patients had peripheral pulmonary artery stenting.

Although their invasive systemic oxygen saturation was 84.2%, those patients had an acceptable functional capacity as only 25 patients (28%) claimed NYHA class III and 3 patients (3.5%) had NYHA class IV. While tested by 6MWT, the mean walked distance was 295 meters.

Their blood indices showed polycythemia with the same pattern of the microcytic hypochromic iron deficiency anemia as our main cohort. The mean hemoglobin was 17.2 gm/dl, hematocrit was 59.6 gm/dl, MCV was 76.2 fl, MCH was 24.7 pg and RDW was 21.8%.

During cardiac catheterization, their mean pulmonary artery pressure had a mean of 12.4 mmHg and the mean dominant ventricle diastolic pressure was 11.4 mmHg. 9 patients (10%) had evidence of peripheral pulmonary artery stenosis, 61 patients (70%) had veno-venous collaterals, 8 patients (9%) had major significant aorto-pulmonary collaterals and only 7 patients (8%) had AV malformations.

5 Discussion

It is well known that Fontan procedure is the final step in single ventricle palliation. However, in our country and due to late presentation and unavailability of heart-lung transplantation, BDG was considered the preferred palliative step. As it carries a lower rate of complications compared to Fontan procedure.

In our study, we tried to demonstrate the actual outcomes following BDG as well as our patients' functional capacity and comorbidities. These data were also highlighted in our sub-analysis of 10 and more years following BDG patients.

In our study, there was no statistically correlation between the basic anatomy nor the dominant ventricular morphology and our patients' functional capacity. Similarly, Sen et al. [11] noted that neither the basic anatomy nor the dominant ventricular morphology could affect the distances walked during the six-minutes-walk test among his patients. He correlated the distances walked during the six-minutes-walk test with the resting heart rate [11]. On the opposite side, Alsoufi et al. [12] studied 227 patients and concluded that the prognosis of single ventricle patients is greatly affected by underlying cardiac anatomy and type of dominant ventricle, as patients with dominant left ventricular morphology can better accommodate to volume and pressure overload and develop late systolic or diastolic disfunction. He also observed that patients with tricuspid atresia and double inlet left ventricle had the best prognosis [12].

In our study, 73 patients (41%) had undergone prior surgeries that included pulmonary artery banding, MBT shunt and combined pulmonary artery banding with MBT shunt. Compared to a study conducted by Yamada et al. [13], 34 patients were included in the study. 6 patients (18%) had undergone BDG only, while 12 patients (35%) had undergone a single MBT shunt, 6 patients (17%) had undergone two MBT shunts and 10 patients (30%) had undergone pulmonary artery banding [13].

Our patients who underwent BDG had a median age of 6 years ranging between 1 and 34 years; similarly in the study of Tariq et al. in Pakistan (a developing country like ours), the mean age at which their 79 patients underwent BDG was 4.5 years [14]. Added to that, Sen et al. [11], who conducted his study in India, demonstrated that the mean age at BDG was 7.5 years ± 5.1 years [11]. This age was higher than the actual minimum age for BDG and it might be due to late presentation and delayed seeking medical advice. Hence, the hypoplastic left heart identity was not represented in either study possibly due to delayed diagnoses and death before Norwood operation. In addition, Al-Dairy et al. [14] who studied 161 patients in Iran, found that the median age at which his patients underwent BDG was 5 ± 4.9 years ranging between 9 months and 24.5 years [15].

The relative older age of children undergoing the operation in developing countries is due to the late presentation, delayed diagnosis and lack of primary health care facilities. Added to that, insufficient awareness regarding congenital heart disease and poor socio-economic status played a huge role in delaying the age at which operation should be done.

Regarding the degree of limitation of daily physical activities of our 178 patients, we had identified 27 patients (15%) with no limitations at all, 78 patients (44%) with mild limitations, 76 patients (38%) with moderate limitations and 6 patients (3%) with severe degree of limitation. Comparatively with the evaluation of the degree of exercise tolerance done by Yamada et al. [13], on 34 patients, 11.1% of the patients had normal exercise tolerance, 40.7% of the patients had mild exercise limitation, 48.2% of the patients had moderate exercise limitation and no patients had severe exercise limitations [13]. This difference could be due to the few numbers of patients studied compared to our registry.

In addition, a six-minutes-walk test was performed to further assess functional capacity of our 178 patients and it was found that the mean distance walked during the test was 302 m ± 82.7 m with mean of degree of desaturation was 7.56% ± 6.07%. However, Sen et al. [11] had evaluated 44 patients post BDG by six-minutes-walk test and it was found that the mean distance walked was 374 m ± 83 m with mean of degree of desaturation was 21.8% ± 19.7% [11].

A probable cause of decreased functional capacity noted in our patients especially the more aged patients with BDG operation performed for 10 or more years was the relative iron deficiency anemia causing a microcystic hypochromic pattern. This pattern was noted in the majority of patients with mean MCV of 76.8 ± 10.3 fl and MCH of 25.1 ± 3.85 pg. However only 28 patients (16%) were on iron therapy. Thus, we believe that prompt iron therapy to our patients could result in better quality of life.

In addition to that, another cause for significant desaturation during six-minutes-walk test was the presence of veno-venous collaterals, 90 patients (58%) were found to have significant veno-venous collaterals, this percentage had risen to 70% in our cohort with 10 or more years BDG. Nevertheless, 8 patients underwent veno-venous collateral closure. Among the group of patients with veno-venous collaterals, we have noted significantly higher degree of oxygen desaturation during the six-minutes-walk test.

This was supported by a study on 54 patients conducted by McElhinney et al. [15], who found that 18 patients (33%) had veno-venous collaterals and 6 patients had undergone coil embolization for veno-venous collateral closure. Those 18 patients had a significantly lower systemic oxygen saturation [16].

Additional reason of systemic oxygen desaturation is the development of arterio-venous malformation. Within our 154 patients who were investigated by cardiac catheterization, 10 patients (6.5%) were found to have arterio-venous malformation. However, Kim et al. [17] had studied 27 patients with BDG and only 4 patients (14%) had typical arterio-venous malformation during pulmonary angiography [17]. The most common theories behind pulmonary arterio-venous malformation development are the lack of hepatic venous effluent directly perfusing the pulmonary arteries or the loss of pulsatile pulmonary blood flow [18].

6 Conclusion

The follow up of our post BDG patients had demonstrated some unique features including an older age while undergoing the procedure and an acceptable function capacity although slight systemic desaturation. This functional capacity can be improved by treatment of the relative iron deficiency anemia and timely catheter-based interventions like collaterals closure and peripheral pulmonary stenting. Thus, in developing country like ours where the rate of complication of Fontan procedure is relatively high and the absence of heart-lung transplant program, BDG can be considered a safe and acceptable palliation for single ventricle patients.

7 Study Limitations

It was a single center study; however, the sample size was relatively larger compared with previous studies on patients follow up after BDG. Another limitation of our study was the lack of a post Fontan cohort that could allow a more comparison between post BDG and post Fontan outcomes; thus, another

comparative study evaluating post BDG and post Fontan patients will be conducted. Due to limited resources, iron profile was unavailable for our patients.

Ethics Approval: The study was approved by Research Ethics Committee at the Faculty of Medicine Ain Shams University (FWA 000017585). Approval No. FMASU M D 65/2019.

Availability of Data and Materials: The data sets used and analyzed during the present study are available upon request.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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