Exercise performance after univentricular palliation

Sachin Talwar, Manikala Vinod Kumar[1], Vishnubhatla Sreenivas[2], Vishwa Prakash Gupta[1], Shiv Kumary Choudhary[1], Balram Airan[1]

Department of Cardiothoracic and Vascular Surgery, Cardiothoracic Centre, All India Institute of Medical Sciences, [1]Cardiothoracic Centre, All India Institute of Medical Sciences, [2]Department of Biostatistics, All India Institute of Medical Sciences, New Delhi, India

ABSTRACT

Background : **The optimal timing, need for primary/staged procedure in patients undergoing univentricular palliation, is debatable.**

Aims : **We performed this study to assess the exercise performance of patients undergoing various forms of univentricular palliation.**

Setting and Design : **This was a retrospective, prospective comparative study conducted at a multispecialty tertiary referral center.**

Patients and Methods : **Between January 2012 and June 2015, 117 patients undergoing either bidirectional Glenn (BDG) (n = 43) or Fontan (total cavopulmonary connection [TCPC]) (n = 74) underwent exercise testing.**

Statistical Analysis : **Comparisons between subgroups for continuous data were made with Student's *t*-test if normally distributed and Wilcoxon rank-sum test otherwise. Tests between subgroups for qualitative data were made with Pearson's Chi-square test.**

Results : **Patients who underwent BDG with open antegrade pulmonary blood flow (APBF) had higher saturations (oxygen saturation [SpO_2]) compared to those without it (87.5 ± 5.0% vs. 81.1 ± 4.8%; P = 0.0001). However, we found no differences in exercise parameters of patients undergoing BDG with or without APBF. Extracardiac TCPC (n = 42) patients demonstrated better exercise capacity (15.0 ± 7.7 vs. 11.2 ± 6.2 min; P = 0.02) and increased SpO_2 on exercise (87.0 ± 8.0% vs. 83.4 ± 7.6%; $P \leq 0.05$) compared to lateral tunnel TCPC (n = 32). Fenestrated TCPC (n = 30) patients had higher exercise capacity reflected by higher metabolic equivalents (METs) consumption (6.4 ± 2.3 vs. 5.2 ± 2.0 METs, P = 0.02), fewer pleural effusions (7.0 ± 3.2 vs. 9.2 ± 6.2 days, $P \leq 0.05$), and lower hospital stay (9.5 ± 4.0 vs. 12.7 ± 7.7 days, P = 0.04) compared to nonfenestrated TCPC (n = 44) patients.**

Conclusions : **We observed no differences in exercise parameters of patients undergoing BDG with or without APBF. Extracardiac TCPC patients had better exercise capacity but longer postoperative hospital stay and pleural effusions than patients with lateral tunnel Fontan. Fenestrated TCPC patients seemed to fare better than nonfenestrated ones. Patients undergoing TCPC had better exercise capacity than patients undergoing BDG alone.**

Keywords : Bidirectional Glenn, exercise performance, fontan operation, single ventricle

Access this article online

Quick Response Code:

Website: www.annalspc.com

DOI: 10.4103/apc.APC_43_17

How to cite this article: Talwar S, Kumar MV, Sreenivas V, Gupta VP, Choudhary SK, Airan B. Exercise performance after univentricular palliation. Ann Pediatr Card 2018;11:40-7.

Address for correspondence: Dr. Sachin Talwar, Department of Cardiothoracic and Vascular Surgery, Cardiothoracic Centre, All India Institute of Medical Sciences, New Delhi - 110 029, India. E-mail: sachintalwar@hotmail.com

INTRODUCTION

For patients with single ventricle physiology, the management algorithm aims to achieve a Fontan circulation in a primary or staged fashion. As most of these patients now undergo surgery at a younger age, it is essential to document its long-term outcome, cardiopulmonary functional status, and the variables that determine its outcome.

A number of previous studies have evaluated the exercise performance in Fontan patients,[1-5] but few studies compare patients undergoing different methods of palliation, and still fewer studies[6] compare exercise performance among Fontan patients at early and mid-term follow-up. The aim of this study was therefore (a) to evaluate the influence of having open antegrade pulmonary blood flow (APBF) among patients undergoing bidirectional Glenn (BDG) on the exercise capacity, (b) to compare the exercise performance between primary and staged Fontan patients, (c) to compare the exercise performance between extracardiac Fontan and lateral tunnel Fontan and between fenestrated and nonfenestrated Fontan, (d) to compare the exercise performance between BDG and Fontan patients, and (e) to evaluate the influence of interval between surgery and exercise capacity among Fontan patients.

PATIENTS AND METHODS

We performed exercise stress testing on 117 patients who had undergone either BDG or total cavopulmonary connection (TCPC) at the All India Institute of Medical Sciences, New Delhi, India. Patients who presented to the outpatient department for routine follow-up between January 2012 and June 2015 and had undergone univentricular palliation at least 6 months before this visit were included. Patients with significant rhythm abnormalities, with pacemakers, with poor ventricular function, and in New York Heart Association III/IV were excluded. The study protocol was duly approved by the ethics committee of the institute, and informed consent was obtained from the patients or their parents. Comparisons were performed between those children who underwent primary TCPC and staged TCPC, BDG with interrupted APBF and open APBF, fenestrated and nonfenestrated TCPC, extracardiac and lateral tunnel TCPC, total BDG (with or without APBF) and total TCPC.

Conduct of exercise performance test

Exercise testing was performed on a motor-driven treadmill (LANDICE, Model: 777, USA). Rather than standard Bruce protocol which is comparably faster for small children, alternative protocols were necessary.[7] One practice session was performed before the test to familiarize patients with the equipment and the test to minimize anxiety. Resting heart rate (HR) was measured over a 5-min period in the morning the day before the test and was defined as the lowest value of any 1-min average during the 5-min resting period. Maximal HR was defined as the highest 5-s average during the treadmill test. Before conducting the test, basal HR, blood pressure, and oxygen saturation (SpO_2) were noted. During the test, continuous monitoring of the electrocardiogram, HR, and SpO_2 was performed.

At testing, an initial warm up session for 5 min was conducted at a preset recommended speed and selected grade according to the weight and height of the patient, and they were instructed to walk on a customized treadmill at a brisk and steady pace with an initial constant speed of 2.0 miles/h and slowly increased by 0.5 miles/h after completion of every quarter mile distance. The test was stopped whenever the child felt exhausted or achieved 85% of maximal HR (target HR) or if there was more than 20% fall from the baseline SpO_2 or if there was arrhythmia. After the test, postexhaustion HR, SpO_2, and blood pressure were recorded immediately and after 1, 3, and 5 min intervals.

Exercise parameters

Estimation of VO_2 max

Direct measurements of VO_2 max, though accurate, require expensive laboratory equipment and skill. Therefore, alternative procedures have been developed in which VO_2 max is estimated by HR ratio method described by Uth *et al.*[8-10] and is calculated by the formula:

VO_2 max = Predicted maximal HR/resting HR × 15.

Estimation of predicted maximum heart rate

Predicted maximum HR was estimated according to the Astrand formula (220 – age in years).[11] For healthy adults, HR maximum was calculated using the equation 208 – 0.7 × age (in years).[12]

Estimation of heart rate reserve and heart rate recovery

HR reserve is the difference between peak and resting HRs. HR was also recorded 1, 3, and 5 min after cessation of exercise, and HR recovery was calculated as the difference between peak HR and the HR recovered at 1st min interval in our study. An abnormal value for recovery of HR was defined as a reduction of 12 beats/min or less from HR at peak exercise.

Estimation of chronotropic index

Wilkoff *et al.*[13] introduced the concept of chronotropic metabolic relationship and chronotropic index that is derived by (peak HR – resting HR)/(predicted HR – resting HR). Chronotropic incompetence is defined as a failure to achieve a chronotropic index of 0.8.

Estimation of O_2 pulse

O_2 pulse is calculated by dividing VO_2 max (ml/min) with resting HR. O_2 pulse = stroke volume × (arterial-venous

O_2 content). At peak exercise, arterial-venous O_2 content difference varies little; hence, O_2 pulse might be used as a surrogate for stroke volume at peak exercise.[6] Higher O_2 pulse is associated with better exercise performance.

Statistical analysis

Statistical analysis was performed using STATA (standard error) 12.1 software. Values are presented as mean ± standard deviation for quantitative variables and *n* (%) for qualitative variables. Comparisons between subgroups for continuous data were made with Student's *t*-test if normally distributed and Wilcoxon rank-sum test otherwise. Tests between subgroups for qualitative data were made with Pearson's Chi-square test. Two tailed $P < 0.05$ was considered statistically significant.

RESULTS

The detailed results are summarized in Tables 1-8, and the salient features are presented below.

Patient characteristics

Of the total 117 patients, majority ($n = 74$) belonged to the TCPC group and the rest ($n = 43$) belonged to the BDG group. Males predominated with 3:1 ratio. Tricuspid atresia was the most common diagnosis. As expected, TCPC patients were taller and weighed more than BDG patients. Fatigue was the major reason for termination of exercise in 99 (85%) patients, whereas the effort was insufficient in 18 (15%) patients.

Early postoperative parameters

Duration of pleural effusions and hospital stay was significantly higher in extracardiac TCPC group as compared to the lateral tunnel group (9.3 ± 6.3 days vs. 6.8 ± 3.1 days; $P = 0.04$ and 12.9 ± 7.8 days vs. 9.4 ± 3.8 days; $P = 0.02$, respectively). Nonfenestrated TCPC group had longer duration of pleural effusions and hospital stay (9.2 ± 6.2 days vs. 7.0 ± 3.2 days; $P = 0.05$ and 12.7 ± 7.7 days vs. 9.5 ± 4.0 days; $P = 0.04$, respectively) than the fenestrated group.

Exercise parameters

VO_2 max (ml/kg/min) and O_2 pulse (ml/min/beat)

VO_2 max (33.0 ± 6.1 ml/kg/min vs. 30.5 ± 5.0 ml/kg/min; $P = 0.03$) and O_2 pulse (10.4 ± 6.1 vs. 6.7 ml/min/beat ± 3.3 ml/min/beat; $P = 0.004$) were both higher in the TCPC patients ($n = 74$) than in BDG patients [Table 2]. However, the patients in the BDG group were younger as compared to the TCPC group.

Peak O_2 consumption (VO_2 max) was not different between primary and staged TCPC [Table 3]; hence, an attempt was made to make it more accurate by categorizing and analyzing them according to the interval between surgery and exercise (i.e., 1–5 years and 6–13 years). The interesting finding was that VO_2 max was significantly higher in patients undergoing staged TCPC (32.7 ± 2.6 ml/kg/min vs. 29.0 ± 5.1 ml/kg/min; $P < 0.05$) compared to primary TCPC in the 6–13-year interval between surgery and exercise. This signifies better preservation of exercise capacity among patients undergoing staged TCPC with time [Tables 3 and 4].

Duration of exercise and metabolic equivalents

Duration of exercise was significantly higher in extracardiac TCPC group compared to lateral tunnel group (15.0 ± 7.7 min vs. 11.2 ± 6.2 min; $P = 0.02$) and in total TCPC group compared to total BDG group (13.3 ± 7.3 min vs. 11.0 ± 4.5 min; $P = 0.05$) [Tables 1 and 5].

Metabolic equivalents (METs) were higher in total TCPC group compared to total BDG group (5.7 ± 2.2 METs vs. 3.0 ± 0.6 METs; $P < 0.0001$) and fenestrated TCPC group compared to nonfenestrated TCPC group (6.4 ± 2.3 METs vs. 5.2 ± 2.0 METs; $P = 0.02$) [Tables 1 and 7].

Heart rate reserve and chronotropic index

Primary TCPC patients had better HR reserve and chronotropic index than staged TCPC patients (42.2 ± 18.5 bpm vs. 34.0 ± 19.3 bpm; $P < 0.05$ and 0.43 ± 0.2 vs. 0.33 ± 0.2; $P = 0.03$, respectively) within 5 years from surgery [Table 3]. However, this significant difference in HR reserve and chronotropic index did not hold true for patients in the 6–13-year follow-up group [Tables 4 and 5].

HR recovery was relatively slower among total TCPC patients (21.0 ± 12.0 bpm vs. 28.5 ± 15.2 bpm, $P = 0.03$) than total BDG patients [Table 2].

Arterial oxygen saturation

SpO_2 at rest was significantly higher in BDG patients with open APBF (87.5 ± 5.0% vs. 81.1 ± 5.0%; $P < 0.0002$) compared to BDG with interrupted APBF [Table 8].

SpO_2 at exercise was significantly higher among nonfenestrated TCPC group (87.0% ± 8.0 vs. 83.2 ± 7.7%; $P = 0.04$) compared to the fenestrated TCPC group [Table 7].

SpO_2 both at rest and exercise was higher among total TCPC group than total BDG group (95.0 ± 4.0% vs. 85.1 ± 6.0%; $P = 0.001$ and 85.4 ± 8.0% vs. 73.5 ± 12.0%; $P = 0.001$, respectively) [Table 2].

Comment

This study addresses many comparisons among single ventricle physiology patients. It was a unique opportunity to compare the exercise performance among varied combinations such as within the BDG group (open vs. interrupted APBF) and within the TCPC group (primary vs. staged; extracardiac vs. lateral tunnel; fenestrated vs. nonfenestrated; and prior BDG with open APBF vs.

Table 1: Patient demographic details

Parameters	BDG	TCPC	Total
n	43	74	117
Age at surgery (years)			
Mean±SD	3.5±2.0	8.6±4.1	6.7±4.4
Median	3	8	6
Mode	1-12	3-20	1-20
Age at exercise (years)			
Mean±SD	7.0±3.0	13.0±4.2	10.7±4.7
Median	7	13	10
Mode	3-15	7-25	3-25
Interval between surgery and exercise			
Mean±SD	3.5±2.0	4.3±3.0	4.0±2.6
Median	3	3	3
Mode	1-10	1-13	1-13
Diagnosis			
TA/VSD/PS	14	25	39
DORV/VSD/PS	9	23	32
TGA/VSD/PS	12	16	28
AVSD (unbalanced)	1	6	7
Others	7	4	11
Sex ratio (male:female)	32:11 (2.9:1.0)	56:18 (3.1:1.0)	88:29 (3.0:1.0)
Weight age at study (kg)			
Mean±SD	18.3±5.4	33.2±13.5	28±13
Median	18	30	25
Mode	8.5-35	15-71	9-71
Height age at study (cm)			
Mean±SD	112±15.5	139±19.1	129±22
Median	111	138	130
Mode	83-150	100-173	83-173
BDG-APBF			
Open	27	-	43
Interrupted	16		
TCPC			
Primary	-	37	74
Staged		37	
Extracardiac	-	42	74
Lateral tunnel		32	
Fenestrated	-	30	74
Nonfenestrated		44	
TCPC with prior BDG			
Open APBF	-	25	37
Interrupted APBF		12	

Values as mean±SD. TA: Tricuspid atresia, VSD: Ventricular septal defect, PS: Pulmonary stenosis, DORV: Double outlet right ventricle, TGA: Transposition of great arteries, AVSD: Atrioventricular septal defect, BDG: Bidirectional Glenn, APBF: Antegrade pulmonary blood flow, TCPC: Total cavopulmonary connection, SD: Standard deviation

prior BDG with persistent APBF). Another comparison was made among primary TCPC versus staged TCPC after categorizing them according to the interval between surgery and exercise to evaluate the impact of time on the exercise performance. However, this analysis is complicated by the varying anatomic diagnoses and the differences in ages of the patients in this study group. These differences in the study population could partly account for varying exercise capacity of patients in these subgroups.

Exercise testing in children is challenging. Motivation to exercise might be a major reason for exercise limitation in those children (15%) who failed to complete at least quarter a mile. This suggests that the aerobic capacity in younger children may often be underestimated due to submaximal effort. Although a number of factors might influence exercise performance, it is superior O2 pulse at peak exercise that seems to be the most important factor that distinguishes the Fontan patients who are doing well on follow-up. Contributions of chronotropic incompetence and arterial desaturation to the exercise dysfunction seen in Fontan patients seem to be relatively small.[6]

Bidirectional Glenn versus Fontan procedure

BDG is typically performed as one step of the staging procedure in preparation for a Fontan[14] or as a definitive procedure for patients with univentricular physiology.[15-17] Yamada *et al.* studied 34 patients who underwent BDG and found that even after a 5-year follow-up, only seven patients needed complete TCPC. Despite acceptable saturation and exercise tolerance, this study could not demonstrate a clear superiority of long-term BDG over the Fontan procedure.[15]

In our study, no patient in BDG group has SpO_2 at rest below 80%. Even after a mean of 5 years after surgery,

Table 2: Comparison of exercise stress testing and postoperative parameters between total bidirectional Glenn and total totalcavopulmonary connection patients

Parameters	Total TCPC	Total BDG	*P*
n	74	43	
Age at exercise (years)	13.0±4.1	7.0±3.0	0.001
VO_2 max (ml/min)	1020.0±475.3	614.2±241	0.0001
VO_2 max (ml/kg/min)	33.0±6.1	30.5±5.0	0.03
VO_2 percentage predicted	80±13	87±16	0.05
O_2 pulse (ml/min/beat)	10.4±6.1	6.7±3.3	0.004
Heart rate at rest	104.1±19.2	97.3±15.2	0.05
Heart rate at peak exercise	142.1±22.2	138.0±21.1	0.30
Heart rate reserve	38.0±19.3	40.3±18.4	0.53
Heart rate recovery	21.0±12.0	28.5±15.2	0.003
Chronotropic index	0.40±0.20	0.40±0.23	0.71
SpO_2 at rest (%)	95.0±4.0	85.1±6.0	0.001
SpO_2 at exercise (%)	85.4±8.0	73.5±12.0	0.001
Metabolic equivalents	5.7±2.2	3.0±0.6	0.0001
Termination time (min)	13.3±7.3	11.0±4.5	0.05
ICD duration (days)	8.2±5.3	3.1±2.2	0.001
Hospital stay (days)	11.4±6.6	6.5±2.6	0.01

Values as mean±SD. ICD: Intercostal chest tube, SD: Standard deviation, BDG: Bidirectional Glenn, TCPC: Total cavopulmonary connection

Table 3: Comparison of exercise stress testing and postoperative parameters in patients with primary total cavopulmonary connection versus staged total cavopulmonary connection

Parameters	Primary TCPC	Staged TCPC	*P*
n	37	37	
Age at exercise (years)	13.7±4.0	12.1±4.2	0.10
VO_2 max (ml/min)	1014.0±538.4	1014.0±410.1	0.93
VO_2 max (ml/kg/min)	31.1±5.1	31.1±5.0	0.30
VO_2 percentage predicted	78±13	81±13	0.22
O_2 pulse (ml/min/beat)	10.0±5.2	11.0±7.0	0.60
Heart rate at rest	106.0±17.4	102.2±21.0	0.41
Heart rate at peak exercise	148.2±23.0	136.0±20.0	0.01
Heart rate reserve	42.2±18.5	34.0±19.3	0.05
Heart rate recovery	21.3±12.0	20.4±12.1	0.75
Chronotropic index	0.43±0.2	0.33±0.2	0.03
SpO_2 at rest (%)	94.6±4.6	95.0±3.4	0.80
SpO_2 at exercise (%)	84.1±9.4	87.0±6.0	0.14
Metabolic equivalents	5.1±2.2	5.2±2.0	0.20
Termination time (min)	12.5±6.5	14.2±8.0	0.32
ICD duration (days)	7.8±5.6	8.6±5.0	0.51
Hospital stay (days)	11.0±7.0	12.0±6.2	0.44

Values as mean±SD. ICD: Intercostal chest tube, TCPC: Total cavopulmonary connection, SD: Standard deviation

VO_2% predicted in BDG patients was 87 ± 16% with reasonable exercise capacity. However, the exercise capacity parameters were superior in TCPC patients rather than those undergoing BDG.

Increased HR during exercise is due to reduced vagal tone, and immediate HR recovery after exercise is due to vagal reactivation function. Because a generalized decrease in vagal activity is known to be a risk factor for death, delayed HR recovery after exercise might be an important prognostic marker.[18] TCPC patients in our study had relatively delayed HR recovery when compared to BDG patients ($P = 0.03$).

Table 4: Comparison of exercise parameters between primary and staged total cavopulmonary connection when the interval between surgery and exercise is between 1 and 5 years

Parameters	Primary TCPC	Staged TCPC	*P*
n	20	29	
VO_2 max (ml/min)	1072.0±386.6	942.3±487.8	0.15
VO_2 max (ml/kg/min)	30.7±4.6	30.7±5.5	0.98
VO_2 percentage predicted	80±13	81±14	0.84
O_2 pulse (ml/min/beat)	10.6±4.2	10.0±6.6	0.63
Heart rate at rest	103±15.1	104.3±23.0	0.82
Heart rate at peak exercise	147.1±21.0	135.6±21.1	0.05
Heart rate reserve	44.1±18.7	31.3±19.6	0.02
Chronotropic index	0.42±0.18	0.32±0.21	0.05
SpO_2 at rest (%)	93.15±5.65	94.7±3.6	0.22
SpO_2 at exercise (%)	83.0±12.3	87.6±6.2	0.09
Metabolic equivalents	5.1±2.2	5.1±2.0	0.94
Termination time (min)	14.3±5.2	15.0±7.8	0.74

Values as mean±SD. TCPC: Total cavopulmonary connection, SD: Standard deviation

Table 5: Comparison of exercise parameters between primary and staged total cavopulmonary connection when the interval between surgery and exercise is between 6 and 13 years

Parameters	Primary TCPC	Staged TCPC	*P*
n	17	8	
VO_2 max (ml/min)	945.0±438.0	1313.2±645	0.05
VO_2 max (ml/kg/min)	29.0±5.1	32.7±2.6	0.05
VO_2 percentage predicted	75±13	83±0.6	0.10
O_2 pulse (ml/min/beat)	9.4±6.3	14.2±8.0	0.11
Heart rate at rest	109.4±19.6	95.0±9.0	0.05
Heart rate at peak exercise	150.5±25.6	138.0±15.3	0.24
Heart rate reserve	40.1±18.7	43.0±15.8	0.72
Chronotropic index	0.44±0.22	0.40±0.14	0.52
SpO_2 at rest (%)	96.3±2.42	95.1±2.4	0.24
SpO_2 at exercise (%)	85.3±4.4	84.1±5.0	0.53
Metabolic equivalents	7.0±2.4	7.3±2.2	0.61
Termination time (min)	10.4±7.3	11.5±8.8	0.75

Values as mean±SD. TCPC: Total cavopulmonary connection, SD: Standard deviation

Bidirectional Glenn with or without antegrade pulmonary blood flow

Chen *et al.*[19] performed a retrospective, longitudinal, nonrandomized study on 111 patients who underwent BDG (57 with APBF and 54 without APBF) and observed that leaving APBF following a BDG improves only arterial SpO_2 without differences in ventilation duration, Intensive Care Unit stay, hospital stay, and chest tube drainage. Our results are similar as there was no significant difference observed in any exercise parameters, except for higher SpO_2 at rest in BDG with APBF.

Apart from increase in SpO_2 in patients of BDG with APBF, the other possible advantages of pulsatile antegrade flow may be that it maintains the pulmonary vasculature in optimal state, preventing the development of pulmonary arteriovenous malformations and promoting pulmonary artery growth.[20]

Table 6: Comparison of exercise stress testing and postoperative parameters in patients with extra cardiac total cavopulmonary connection and lateral tunnel total cavopulmonary connection

Parameters	Extra cardiac TCPC	Lateral tunnel TCPC	*P*
n	42	32	
Age at exercise (years)	13.3±4.7	12.3±3.3	0.33
VO_2 max (ml/min)	1044.4±527.0	983.4±404	0.60
VO_2 max (ml/kg/min)	31.0±6.0	30.2±3.4	0.62
VO_2 percentage predicted	80±15	79±10	0.90
O_2 pulse (ml/min/beat)	11.0±7.2	9.6±4.4	0.33
Heart rate at rest	104.0±23.1	104.3±13	0.91
Heart rate at peak exercise	140.1±22.0	145.0±22.4	0.40
Heart rate reserve	36.3±18.2	40.3±20.7	0.40
Heart rate recovery	22.0±12.0	20.0±12.4	0.40
Chronotropic index	0.37±0.2	0.40±0.2	0.67
SpO_2 at rest (%)	95.1±3.5	94.1±4.7	0.30
SpO_2 at exercise (%)	87.0±8.0	83.4±7.6	0.05
Metabolic equivalents	6.1±2.4	5.5±2.0	0.25
Termination time (min)	15.0±7.7	11.2±6.2	0.02
ICD duration (days)	9.3±6.3	6.8±3.1	0.04
Hospital stay (days)	12.9±7.8	9.4±3.8	0.02

Values as mean±SD. ICD: Intercostal chest tube, TCPC: Total cavopulmonary connection, SD: Standard deviation

Table 7: Comparison of exercise stress testing in patients with fenestrated and nonfenestrated total cavopulmonary connection

Parameters	Fenestrated TCPC	Nonfenestrated TCPC	*P*
n	30	44	
Age at exercise (years)	12.2±3.1	13.4±4.7	0.22
VO_2 max (ml/min)	978.3±412.5	1045.2±517.0	0.55
VO_2 max (ml/kg/min)	30.3±3.7	31.0±6.0	0.73
VO_2 percentage predicted	80±10	80±15	0.92
O_2 pulse (ml/min/beat)	9.6±4.5	11.0±7.0	0.34
Heart rate at rest	104.3±13.4	104.0±22.5	0.92
Heart rate at peak exercise	146.1±23.0	140.0±22.0	0.21
Heart rate reserve	42.0±20.1	35.5±18.5	0.17
Heart rate recovery	20.4±12.2	21.1±12.0	0.80
Chronotropic index	0.40±0.20	0.36±0.2	0.37
SpO_2 at rest (%)	94.0±5.0	95.2±3.4	0.24
SpO_2 at exercise (%)	83.2±7.7	87.0±8.0	0.04
Metabolic equivalents	6.4±2.3	5.2±2.0	0.02
Termination time (min)	12.0±6.0	14.3±8.0	0.14
ICD duration (days)	7.0±3.2	9.2±6.2	0.05
Hospital stay (days)	9.5±4.0	12.7±7.7	0.04

Values as mean±SD. ICD: Intercostal chest tube, TCPC: Total cavopulmonary connection, SD: Standard deviation

Primary versus staged total cavopulmonary connection

Atz *et al*. performed a multicenter cohort study on 516 patients to explore the impact of exercise performance and ventricular function between primary and staged TCPC and concluded that exercise capacity was similar between the groups and long-term outcomes did not differ.[21]

In our study, primary TCPC patients demonstrated better chronotropic index than staged TCPC patients ($P = 0.03$). This seemed to hold true for patients, in whom the exercise testing was performed within 5 years of TCPC. However, if the testing was performed after this period, then the patients with staged TCPC seemed to be doing better. The significance of this finding is unclear. Ideally, the same patient undergoing the exercise test at two different time-points would provide the best answer to this problem.

Extracardiac total cavopulmonary connection versus lateral tunnel total cavopulmonary connection

Bossers *et al*.[22] in a multicenter cross-sectional exercise performance study on 101 TCPC patients found that the only parameter that was significantly lower in lateral tunnel TCPC was % predicted VO_2 max and observed favorable exercise outcome at medium term follow-up. Studies by others[23,24] did not describe any differences between the two techniques. However, in our study, SpO_2 at exercise and duration of exercise were significantly higher in extracardiac TCPC than lateral tunnel TCPC group.

Fenestrated total cavopulmonary connection versus nonfenestrated total cavopulmonary connection

In a study of 226 patients, Salazar *et al*.[25] found that early postoperative outcomes were similar in both the groups, except for increased duration of intubation in the fenestrated group. They concluded that fenestration should be reserved for high-risk Fontan procedure and not for routine use. However, in our study, we observed that the duration of pleural effusions and hospital stay was higher in the nonfenestrated group although fenestration was more frequently performed in the lateral TCPC group. This can be attributed to younger patient population, need for concomitant cardiac procedure, unfavorable anatomy, and high-risk procedures. As our experience progressed, staging followed by extracardiac TCPC was the more common approach. No significant difference in exercise capacity was observed between fenestrated and nonfenestrated TCPC, except for decreased SpO_2 at exercise among fenestrated TCPC.

Limitations

This study is limited to those children who could perform the exercise test and agreed to participate in the study and does not reflect all children who underwent the procedure. It includes patients across all age groups with a wide range of anatomic diagnoses and operative procedures that are known to affect the outcomes and the exercising capacity, thus making the analysis difficult. Further, small numbers of individual subgroups make the analysis complex and limit meaningful conclusions. Since it is not a longitudinal study and does not reflect a particular cohort, the difference in the results might be due to change in management strategies over a period. In addition, patients who underwent exercise testing do not reflect the entire spectrum of univentricular physiology. Since the study is primarily focused on exercise capacity, echocardiographic variables were not assessed. Ideally, a study with clinical examination, echocardiographic follow-up, and serial exercise testing would be needed

Table 8: Comparison of exercise stress testing and postoperative parameters in patients with bidirectional Glenn (interrupted antegrade pulmonary flow versus open antegrade pulmonary flow)

Parameters	BDG (interrupted APBF)	BDG (open APBF)	*P*
n	16	27	
VO_2 max (ml/min)	615.0±231	613.0±250	0.97
VO_2 max (ml/kg/min)	33.5±5.8	32.3±6.3	0.55
VO_2 max percentage predicted	89±16	86±16	0.51
O_2 pulse (ml/min/beat)	6.7±3.7	6.7±3.4	0.96
Heart rate reserve	40±19	40.5±18.5	0.47
Heart rate recovery	28.6±13.4	28.4±18.4	0.96
Chronotropic index	0.37±0.1	0.41±0.2	0.60
SpO_2 at rest (%)	81.1±4.9	87.5±5.0	0.0002
SpO_2 at peak exercise (%)	70.0±12.0	75.6±11.5	0.13
Metabolic equivalents	2.8±0.3	3.0±0.3	0.55
Termination time (min)	9.7±5.0	11.8±4.1	0.15
ICD duration (days)	3.8±3.0	2.7±1.6	0.12
Hospital stay	7.3±3.5	6.0±1.7	0.09

Values as mean±SD. ICD: Intercostal chest tube, BDG: Bidirectional Glenn, APBF: Antegrade pulmonary blood flow, SD: Standard deviation

to answer all the questions related to this field in a much-more appropriate manner.

CONCLUSIONS

We observed no differences in exercise parameters of patients undergoing BDG with or without APBF. Extracardiac TCPC patients had better exercise capacity but longer postoperative hospital stay and pleural effusions compared to lateral tunnel TCPC patients. Fenestrated TCPC patients fared better when compared to nonfenestrated TCPC patients. Overall, patients who underwent TCPC had better exercise capacity than patients who underwent BDG alone.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Nir A, Driscoll DJ, Mottram CD, Offord KP, Puga FJ, Schaff HV, *et al.* Cardiorespiratory response to exercise after the Fontan operation: A serial study. J Am Coll Cardiol 1993;22:216-20.
2. Harrison DA, Liu P, Walters JE, Goodman JM, Siu SC, Webb GD, *et al.* Cardiopulmonary function in adult patients late after Fontan repair. J Am Coll Cardiol 1995;26:1016-21.
3. Durongpisitkul K, Driscoll DJ, Mahoney DW, Wollan PC, Mottram CD, Puga FJ, *et al.* Cardiorespiratory response to exercise after modified Fontan operation: Determinants of performance. J Am Coll Cardiol 1997;29:785-90.
4. Troutman WB, Barstow TJ, Galindo AJ, Cooper DM. Abnormal dynamic cardiorespiratory responses to exercise in pediatric patients after Fontan procedure. J Am Coll Cardiol 1998;31:668-73.
5. Mahle WT, Wernovsky G, Bridges ND, Linton AB, Paridon SM. Impact of early ventricular unloading on exercise performance in preadolescents with single ventricle Fontan physiology. J Am Coll Cardiol 1999;34:1637-43.
6. Paridon SM, Mitchell PD, Colan SD, Williams RV, Blaufox A, Li JS, *et al.* A cross-sectional study of exercise performance during the first 2 decades of life after the Fontan operation. J Am Coll Cardiol 2008;52:99-107.
7. Rhodes J, Ubeda Tikkanen A, Jenkins KJ. Exercise testing and training in children with congenital heart disease. Circulation 2010;122:1957-67.
8. Uth N, Sørensen H, Overgaard K, Pedersen PK. Estimation of VO2max from the ratio between HRmax and HRrest – The Heart Rate Ratio method. Eur J Appl Physiol 2004;91:111-5.
9. Fahey T, Insel P, Roth W. The three VO2max calculators requiring physical exertion are adapted. Fit & Well: Core Concepts and Labs in Physical Fitness and Wellness. 7th ed.Mishawaka, IN, USA: McGraw-Hill; 2007.
10. Kline GM, Porcari JP, Hintermeister R, Freedson PS, Ward A, McCarron RF, *et al.* Estimation of VO2max from a one-mile track walk, gender, age, and body weight. Med Sci Sports Exerc 1987;19:253-9.
11. Astrand I. Aerobic work capacity in men and women with special reference to age. Acta Physiol Scand Suppl 1960;49:1-92.
12. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol 2001;37:153-6.
13. Wilkoff BL, Corey J, Blackburn G. A mathematical model of cardiac chronotropic response to exercise. J Electrophysiol 1989;3:176-80.
14. Pridjian AK, Mendelsohn AM, Lupinetti FM, Beekman RH 3rd, Dick M 2nd, Serwer G, *et al.* Usefulness of the bidirectional Glenn procedure as staged reconstruction for the functional single ventricle. Am J Cardiol 1993;71:959-62.
15. Yamada K, Roques X, Elia N, Laborde MN, Jimenez M, Choussat A, *et al.* The short-and mid-term results of bidirectional cavopulmonary shunt with additional source of pulmonary blood flow as definitive palliation for the functional single ventricular heart. Eur J Cardiothorac Surg 2000;18:683-9.
16. Mazzera E, Corno A, Picardo S, Di Donato R, Marino B, Costa D, *et al.* Bidirectional cavopulmonary shunts: Clinical applications as staged or definitive palliation. Ann Thorac Surg 1989;47:415-20.
17. Calvaruso DF, Rubino A, Ocello S, Salviato N, Guardì D, Petruccelli DF, *et al.* Bidirectional Glenn and antegrade pulmonary blood flow: Temporary or definitive palliation? Ann Thorac Surg 2008;85:1389-95.
18. Cole CR, Blackstone EH, Pashkow FJ, Snader CE, Lauer MS. Heart-rate recovery immediately after exercise as a predictor of mortality. N Engl J Med 1999;341:1351-7.
19. Chen Q, Tulloh R, Caputo M, Stoica S, Kia M, Parry AJ.

Does the persistence of pulsatile antegrade pulmonary blood flow following bidirectional Glenn procedure affect long term outcome? Eur J Cardiothorac Surg 2015;47:154-8.

20. Caspi J, Pettitt TW, Ferguson TB Jr., Stopa AR, Sandhu SK. Effects of controlled antegrade pulmonary blood flow on cardiac function after bidirectional cavopulmonary anastomosis. Ann Thorac Surg 2003;76:1917-21.
21. Atz AM, Travison TG, McCrindle BW, Mahony L, Glatz AC, Kaza AK, *et al.* Cardiac performance and quality of life in patients who have undergone the Fontan procedure with and without prior superior cavopulmonary connection. Cardiol Young 2013;23:335-43.
22. Bossers SS, Kapusta L, Kuipers IM, van Iperen G, Moelker A, Kroft LJ, *et al.* Ventricular function and cardiac reserve in contemporary Fontan patients. Int J Cardiol 2015;196:73-80.
23. Müller J, Christov F, Schreiber C, Hess J, Hager A. Exercise capacity, quality of life, and daily activity in the long-term follow-up of patients with univentricular heart and total cavopulmonary connection. Eur Heart J 2009;30:2915-20.
24. Fernandes SM, McElhinney DB, Khairy P, Graham DA, Landzberg MJ, Rhodes J. Serial cardiopulmonary exercise testing in patients with previous Fontan surgery. Pediatr Cardiol 2010;31:175-80.
25. Salazar JD, Zafar F, Siddiqui K, Coleman RD, Morales DL, Heinle JS, *et al.* Fenestration during Fontan palliation: Now the exception instead of the rule. J Thorac Cardiovasc Surg 2010;140:129-36.