Exercise performance after univentricular palliation

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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 [SpO₂]) 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 SpO₂ on exercise (87.0 ± 8.0% vs. 83.4 ± 7.6%; P ≤ 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 ≤ 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

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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.
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,\textsuperscript{[1-5]} but few studies compare patients undergoing different methods of palliation, and still fewer studies\textsuperscript{[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.\textsuperscript{[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\textsubscript{2}) were noted. During the test, continuous monitoring of the electrocardiogram, HR, and SpO\textsubscript{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\textsubscript{2} or if there was arrhythmia. After the test, postexhaustion HR, SpO\textsubscript{2}, and blood pressure were recorded immediately and after 1, 3, and 5 min intervals.

Exercise parameters

Estimation of VO\textsubscript{2} max

Direct measurements of VO\textsubscript{2} max, though accurate, require expensive laboratory equipment and skill. Therefore, alternative procedures have been developed in which VO\textsubscript{2} max is estimated by HR ratio method described by Uth et al.\textsuperscript{[8-10]} and is calculated by the formula:

\[
\text{VO}_2 \text{ max} = \frac{\text{HR max}}{\text{resting HR}} \times 15. 
\]

Estimation of predicted maximum heart rate

Predicted maximum HR was estimated according to the Astrand formula (220 – age in years).\textsuperscript{[11]} For healthy adults, HR maximum was calculated using the equation 208 – 0.7 x age (in years).\textsuperscript{[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.\textsuperscript{[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\textsubscript{2} pulse

O\textsubscript{2} pulse is calculated by dividing VO\textsubscript{2} max (ml/min) with resting HR. O\textsubscript{2} pulse = stroke volume × (arterial-venous
O₂ content). At peak exercise, arterial-venous O₂ content difference varies little; hence, O₂ pulse might be used as a surrogate for stroke volume at peak exercise.\(^{[60]}\) Higher O₂ 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**

\(V\text{O}_2\) max (ml/kg/min) and \(O\text{~}_2\) pulse (ml/min/beat)

\(V\text{O}_2\) max (33.0 ± 6.1 ml/kg/min vs. 30.5 ± 5.0 ml/kg/min; \(P = 0.03\)) and \(O\text{~}_2\) 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 \(O\text{~}_2\) consumption (\(V\text{O}_2\) 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 \(V\text{O}_2\) 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**

\(Sp\text{O}_2\) 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].

\(Sp\text{O}_2\) 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].

\(Sp\text{O}_2\) 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.
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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 SpO2 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 cavopulmonary 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|
| VO2 max (ml/min)              | 1020.0±475.3 | 614.2±241 | 0.0001|
| VO2 max (ml/kg/min)           | 33.0±6.1   | 30.5±5.0  | 0.03 |
| VO2 percentage predicted      | 80±13      | 87±16     | 0.05 |
| O2 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 |
| SpO2 at rest (%)              | 95.0±4.0   | 85.1±6.0  | 0.001|
| SpO2 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    | 31.2±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 |
| VO2 max (ml/min)              | 1014.0±538.4 | 1014.0±410.1 | 0.93 |
| VO2 max (ml/kg/min)           | 31.1±5.1     | 31.1±5.0    | 0.30 |
| VO2 percentage predicted      | 78.1±13      | 81±13       | 0.22 |
| O2 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 |
| SpO2 at rest (%)              | 94.6±4.6     | 95.0±3.4    | 0.80 |
| SpO2 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

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          |      |
| VO2 max (ml/min)              | 1072.0±386.6 | 942.3±487.8 | 0.15 |
| VO2 max (ml/kg/min)           | 30.7±4.6     | 30.7±5.5    | 0.98 |
| VO2 percentage predicted      | 80±13        | 81±14       | 0.84 |
| O2 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 |
| SpO2 at rest (%)              | 93.15±5.65   | 94.7±3.6    | 0.22 |
| SpO2 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           |      |
| VO2 max (ml/min)              | 945.0±438.0  | 1313.2±645 | 0.05 |
| VO2 max (ml/kg/min)           | 29.0±5.1     | 32.7±2.6    | 0.05 |
| VO2 percentage predicted      | 75±13        | 83±0.6     | 0.10 |
| O2 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 |
| SpO2 at rest (%)              | 96.3±2.42    | 95.1±2.4   | 0.24 |
| SpO2 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 SpO2 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 SpO2 at rest in BDG with APBF.

Apart from increase in SpO2 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 |
| VO₂ max (ml/min)          | 1044.4±527.0 | 983.4±404          | 0.60 |
| VO₂ max (ml/kg/min)       | 31.0±6.0 | 30.2±3.4 | 0.62 |
| VO₂ percentage predicted  | 80±15      | 79±10              | 0.90 |
| _O₂_ 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| 145.1±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 |
| _SpO₂_ at rest (%)         | 95.1±3.5  | 94.1±4.7           | 0.30 |
| _SpO₂_ 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±6.5   | 6.8±3.1            | 0.04 |
| Hospital stay (days)       | 12.9±7.8  | 9.4±3.8            | 0.02 |

Values as means±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 |
| VO₂ max (ml/min)          | 978.3±412.5 | 1045.2±517.0       | 0.55 |
| VO₂ max (ml/kg/min)       | 30.3±3.7    | 31.0±6.0           | 0.73 |
| VO₂ percentage predicted  | 80±10       | 80±15              | 0.92 |
| _O₂_ 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 |
| _SpO₂_ at rest (%)         | 94.0±5.0    | 95.2±3.4           | 0.24 |
| _SpO₂_ 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 means±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

Boskers 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 VO₂ 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, _SpO₂_ 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 _SpO₂_ 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              |    |
| VO₂ max (ml/min)                  | 615.0±231               | 613.0±250       | 0.97|
| VO₂ max (ml/kg/min)              | 33.5±5.8                | 32.3±6.3        | 0.55|
| VO₂ max percentage predicted     | 89±16                   | 86±16           | 0.51|
| O₂ 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|
| SpO₂ at rest (%)                 | 81.1±4.9                | 87.5±5.0        | 0.0002|
| SpO₂ 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 (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.

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