Six-Minute Walking Test to Assess Exercise Tolerance and Cardiorespiratory Responses During Training Program in Children With Congenital Heart Disease

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Abstract

This study assessed the exercise tolerance and the cardiorespiratory responses to a training program by the six-minute walk test (6'WT) in children with congenital heart disease (CHD). Seventeen cardiac and 14 healthy children performed maximal cardiopulmonary exercise test (CPET) and 6'WT. Reliability of 6'WT was assessed in all subjects (test-retest) by Bland-Altman plots. Cardiac subjects were randomly divided in training (T-CHD) and control groups (C-CHD). T-CHD underwent an individualized training exercise at the ventilatory threshold (VT) intensity during 12 weeks. We found that the 6'WT is a reliable and reproducible test. CHD children walked a lower distance than healthy children before training (472.5 ± 18.1 vs. 548.8 ± 7.7 m, respectively, $p < 0.001$). Likewise, power output, oxygen uptake ($\dot{V}O_2$), and heart rate (HR) at the maximum and the VT levels, were significantly lower in patients ($p < 0.001$). After training, a significant improvement of walking distance (WD) was shown in T-CHD (529.6 ± 15.3 vs. 467.7 ± 17.1 m, $p < 0.001$). The power output, $\dot{V}O_2$, HR, and $\dot{V}E$ increased slightly (6 to 10%, $p > 0.05$) at peak exercise and significantly at ventilatory threshold level ($p < 0.05$) in T-CHD. Significant relationships between WD and $\dot{V}O_{2max}$ as well as $\dot{V}O_2$ at VT were founded ($p < 0.05$). We concluded that the 6'WT is a useful and reliable tool in the assessment and follow-up of functional capacity during rehabilitation program in children with CHD.

Key words
Six minute walk test · children · training · congenital heart disease

Introduction

Physical training is recognized as a therapy that has become more and more important over the last decade [16,30], and is often included in the rehabilitation programs [28]. The beneficial effects of exercise were reported mainly in adults and rarely in children [8,10]. The practice of regular physical exercise in both healthy persons and patients with various pathologies, such as congenital heart disease (CHD), improves their functional capacities and their quality of life [3,22]. Physical activity lowers their threshold of fatigue and their feeling of dyspnea. The evaluation of exercise tolerance and the follow-up of the effects of training require various clinical examinations. These clinical examinations allow the diagnosis and the determination of symptomatic anomalies and they are used to establish and adjust an individualized intensity for training program [12].

The cardiopulmonary exercise test (CPET) with measurement of respiratory gas exchange is currently a standard test used. Maximum oxygen uptake ($\dot{V}O_{2max}$) and ventilatory threshold are usually the best indices assessing aerobic fitness, but they require expensive equipment and trained medical personnel [7,15]. In addition, this test remains not tolerated by severely limited patients who cannot be subjected to the maximal exercise inten-

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sity. Furthermore, fatigue of leg muscles during CPET contributes to limit the capacity of subjects to overcome the pedalling resistance of the ergocycle. However, several authors recommend for patients the use of tests reflecting the activity of daily living [9,21]. Recently, Solway et al. [26] indicated that the six-minute walk test (6'WT) is easy to administer, better tolerated, and more reflective of activities of daily living. This test which was described as a simple test, inexpensive, noninvasive, and reliable has been shown to be reproducible, and valide [11,20]. Moreover, the 6'WT solicitudes a greater total muscular mass and induces less local muscular fatigue than CPET [1,25].

The exercise tolerance and cardiorespiratory responses to training program were often assessed by CPET, and seldom by walk tests. Since no study has reported the effects of training in children with a CHD using the 6'WT, the aims of this study were thus [1] to assess exercise tolerance, and [2] to investigate how the 6'WT could be a useful test in the follow-up of rehabilitation program in children with CHD.

Material and Methods

Subjects

Seventeen children with CHD in New York Heart Association (NYHA) class II or III, and fourteen healthy children aged 12 to 16 years serving as controls, participated in the study. The left ventricle ejection fraction (LVEF) of CHD group was < 40% and they didn't have any pacemakers. All patients had undergone cardiac surgery reconstruction for complex heart disease. Seven had a surgical operation for transposition of great arteries (Senning/Mustard procedure), 4 patients had undergone right ventricular outflow tract reconstruction for tetralogy of Fallot, 4 had pulmonary valve atresia (Fontan procedure), and 2 had atrial septal defect correction (suture closure). The CHD subjects had to be stabilized with drug treatment for at least three months; their medication was the same during the training period. Medical therapy included diuretics, cardiotonics, antivitamins K, and angiotensin-converting enzyme inhibitor, but no beta-blockers. Full advice about possible risks and discomfort was given to the subjects and their parents, and all signed a written informed consent in accordance with the ethical standards of the Helsinki Declaration of 1975. Controls children were randomly selected from those who volunteered; they practiced sports and physical activity only at school. All tests were conducted in the Pediatrics Cardiopulmonary Explorations Department. Characteristics of CHD group and controls are presented in Table **1**.

Table **1** Anthropometrics, diagnosis, and spirometric characteristics of the subjects

	All CHD (n = 17)	*Controls (n = 14)*	*p*
Anthropometric			
– *age (yr)*	13.5 ± 0.5	12.9 ± 0.3	NS
– *weight (kg)*	50.5 ± 3.3	49.1 ± 2.8	NS
– *height (cm)*	161.1 ± 1.5	157.0 ± 2.5	NS
– *BMI ($kg \cdot m^{-2}$)*	19.6 ± 1.2	20.0 ± 0.9	NS
Diagnosis			
– *TGA*	7	–	
– *PA*	4	–	
– *TOF*	4	–	
– *ASD*	2	–	
Spirometric			
– *FEV_1 (%pred)*	78.0 ± 5.3	92.3 ± 3.1	0.05
– *FVC (%pred)*	88.7 ± 6.0	99.7 ± 3.0	NS
– *TLC (%pred)*	89.3 ± 4.3	90.4 ± 3.2	NS
– *FEV_1/FVC*	0.89 ± 0.01	0.93 ± 0.02	NS

Values are presented as the mean ± SEM. BMI, body mass index; TGA, transposition of the great arteries; PA, pulmonary atresia; TOF, tetralogy of Fallot; ASD, atrial septal defect; FEV_1, forced expiratory volume in 1 s; FVC, forced vital capacity; TLC, total lung capacity; %pred, percentage of predicted value. NS, no significant difference

Measurements and tests

Lung function

Pulmonary function tests were obtained in all subjects. The measurements were obtained using a spirometer (Master Lab, Jaeger. Germany). We determined the forced expiratory volume in 1 second (FEV_1), the forced vital capacity (FVC), and the total lung capacity (TLC). Values were expressed as percentages of predicted values. The FEV_1/FVC ratio was then calculated.

Six-minute walking test (6'WT)

The 6'WT was performed at the hospital on a plane surface in a 30 m long covered corridor marked every two meters. The tests were performed at the same time of the day before and after training according to the recommendations of the American Thoracic Society [1]. Subjects were instructed to walk the longest distance possible at their own pace during the allotted time. Subjects were allowed to stop and rest during the test, but were instructed to resume walking as soon as they felt able to do so. Standardized encouragements were given to the children as reported by Guyatt et al. [11]. The 6'WT was supervised by the same person for all subjects. The subjects were informed of the remaining time of the test every minute. Before beginning the test, subjects sat on a chair for at least 10 min to determine rest values of HR and transcutaneous arterialized oxygen saturation (SaO_2). These parameters were also recorded every minute during and 5 min after the test. No subject performed the test under oxygen. The HR and SaO_2 were obtained by an oxymeter pulse (Nellcor, NPB-40, Ireland). Dyspnea scores were measured on a Borg scale before and at the end of the test [6]. The subject indicated the number corresponding to the perception of his effort and his feeling of breathlessness. The 6'WT was repeated later on the same day in both CHD group and controls to assess the reliability of the test. The children with CHD performed again the 6'WT after three months of training at the same time of the day with the same tests and measurements.

Cardiopulmonary exercise test (CPET)

All subjects underwent a CPET on an electromagnetically braked cycle ergometer (Jaeger Ergoline, ER800, Germany). Only children with CHD performed a CPET after the training period. Gas exchange (ventilation $\dot{V}E$, carbon dioxide output $\dot{V}CO_2$ and $\dot{V}O_2$) were determined breath-by-breath by means of a respiratory gas analyzing system (MGA 1100 Medical, Marquette Electronics,

USA). The subjects wore a nose clip and breathed through a mouthpiece (Hans-Rudolph) connected to a pneumotachograph for continuous measurements of inspired and expired gas flows. Before each test, gas analyzers were calibrated with known reference gases (12% O_2, 5% CO_2, and 83% N_2). A 12-lead electrocardiogram (ECG) (Inlays Box 8000, 12 SL Program, Marquette Electronics, USA) was continuously monitored and recorded every minute to determine HR. Blood pressure and SaO_2 were also measured continuously.

Protocol of the CPET

The CPET was performed according to a progressive incremental protocol. The increase in workload was individualized and was calculated according to the Wasserman norms as a function of sex, weight, and age of each child [29]. The test involved four consecutive periods: 1) a 3-min rest period, 2) a 2-min period of warm-up against a workload corresponding to 20% of the theoretical maximal power output, 3) an 8- to 12-min exercise period with increases in the workload each minute until exhaustion, and 4) a recovery period, with active recovery (workload equivalent to that used for the warm-up period) during 2 min and a passive recovery (rest) during 3 min. During the exercise, the child had to maintain a regular pedalling rhythm of 60 revolutions per min (rpm). The subjects were encouraged in a standardized way to develop their maximum effort. Tests were considered maximal when at least two of the following criteria were achieved: 1) stability of the oxygen uptake in spite of the increase in workload, 2) predicted maximum heart rate achieved, 3) a respiratory ratio greater than 1.1, and 4) exhaustion of the subject or inability to maintain a pedalling rate of 60 rpm [12].

Determination of the ventilatory threshold

After completion of each CPET, ventilatory threshold (VT) was determined for each subject using the V-slope method [2]. This method involves the analysis of variations of $\dot{V}CO_2$ as a function of $\dot{V}O_2$. The VT corresponds to the breakdown point of the linearity of the curve $\dot{V}O_2$ according to the $\dot{V}CO_2$. This point was determined graphically on the computer by two persons having no prior knowledge of any results or subject identities. In the rare cases of disagreement, a third person was used to establish a consensual determination. The HR corresponding to this threshold was used as training intensity.

Protocol of training program

To study the changes in cardiorespiratory fitness over the course of training, children with CHD were divided in two groups. Nine children with CHD were randomly chosen to participate as training group (T-CHD), and eight children served as control group (C-CHD). The training lasted 12 weeks with three sessions per week. Each training session lasted 1 hour and had the following components: 1) a 10-min warm-up period at unloaded charge, 2) a 45-min exercise period according to an interval training by alternating active 10-min periods at a HR within ± 5 bpm of that corresponding to the VT (individualized intensity) and passive 5-min periods of pedalling against an unloaded charge, and 3) a 5-min recovery. The training was performed at home; the children were informed and instructed about the sequence of rehabilitation and the use of materials. Each child took home a cycle ergometer (Decathlon by Form Inertia. France) and a pulse monitor (Sport tester, Polar Magnet OY-INW EP 4000, Finland). The pulse monitor was set to beep if the subject exceeded ± 5 bpm of the determined HR at the VT. Thus, the subject could hear this beep and adjust its pedalling intensity accordingly. At the beginning of the training, the children were assisted by a physical education teacher in order to ensure that exercise was performed at the appropriate intensity. In addition, pulse monitors were checked every week to insure that the intensity of the exercise had been adhered to.

Statistical analysis

All data were expressed as mean values and standard errors of the mean (± SEM). The data collected were evaluated using the StatView software, SAS Institute Inc. An analysis of variance (ANOVA) was used to compare mean values. We used an unpaired Student's *t*-test to compare the difference between healthy and CHD patients before training period. Normality of the distribution was evaluated by the Kolmogorov-Smirnov test. The Mann-Whitney test was used if the distribution was not normal. To study training effects, we compared the data of T-CHD and C-CHD before and after the training by a two-way ANOVA for repeated measures. And a posteriori Fisher's procedure for learning systems design (PLSD) test was used when the ANOVA-F ratio was significant. A linear regression was used to define relationships between WD and $\dot{V}O_{2max}$ and $\dot{V}O_2$ at VT, as well as for change between $\dot{V}O_{2max}$ and $\dot{V}O_2$ at VT (T-CHD before – after). We assessed reliability and reproducibility of 6'WT (two test sessions, WD1 and WD2, done on the same day) by the method of Bland-Altman [5]. A p value less than 0.05 was considered to be statistically significant.

Results

Anthropometric characteristics and spirometric data

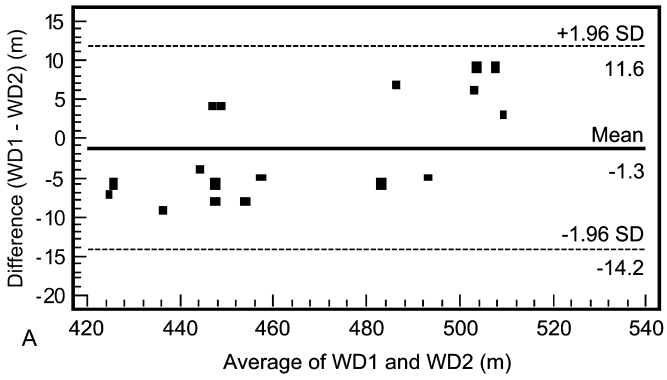
The children's morphological characteristics and the results of pulmonary function tests are presented in Table **1**. There were no differences in anthropometric variables between children with CHD and controls. All pulmonary parameters were normal; no subjects presented restrictive or obstructive syndrome. FEV_1 (% pred) was significantly different between CHD and controls ($p < 0.05$). There was no significant difference for FEV_1/FVC, TLC, and FVC between the two groups. All T-CHD patients have completed their training program.

6'WT

6'WT was completed by all the subjects without premature end or breaks. No symptoms or clinical complications occurred (arrhythmia, cyanosis, etc.) during exercise training or testing in CHD group. Fig. **1** contains the Bland-Altman plots illustrating the mean difference (± 1.96 SD) between WD measurements against their mean. Overall, the difference in scores was within the 95% confidence interval, showing that both tests (test 1 and test 2) agree closely and indicate the reliability of the 6'WT. The 95% limits of agreement were therefore from – 14.2 to 11.6 m and – 9.8 to 7.1 m for CHD and control subjects, respectively (Fig. **1**).

Walk test performance

The mean distance walked during 6'WT was significantly longer in controls than in CHD (Table **2**). After training period, T-CHD group increased significantly their WD ($p < 0.001$) whereas no



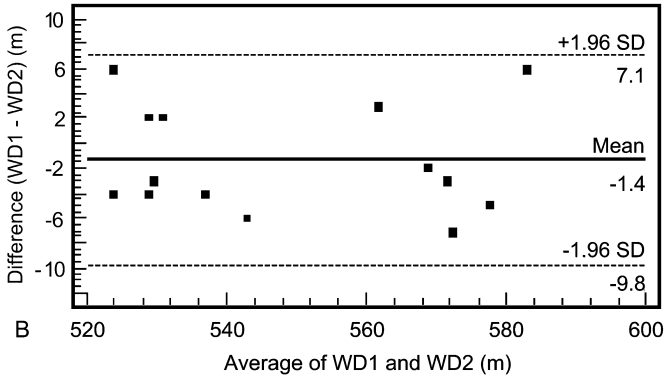


Fig. **1 A** and **B** The difference in WD (test 1, WD1 – test 2, WD2) plotted against the average of the measurements for CHD subjects (**A**) and control subjects (**B**).

changes were noted in C-CHD group (Table **2**). The improvement in performance of T-CHD group represented an increase of 62 m (13%) compared to the test before training. After the training period, no difference in distance covered was shown between T-CHD and healthy children.

HR

At rest, HR values were similar between controls and CHD; they were not modified by training (Table **2**). After the training period, T-CHD group had a higher HR_{max}. During recovery, the HR of T-CHD group dropped gradually and followed the profile of healthy children whereas no changes were observed in C-CHD group.

SaO_2

No significant difference for SaO_2 was noted, neither at rest nor during exercise in all groups (Table **2**).

Dyspnea

None of the subjects were dyspnoeic. The score of dyspnea measured at the end of the 6'WT for all groups are presented in Table **2**. After the 3-month training program, dyspnea dropped down in T-CHD and remained unchanged in C-CHD. Dyspnea scores were not significantly different neither between controls and CHD nor between controls and T-CHD group after the training period.

CPET

Before training, cardiopulmonary variables were significantly higher in control subjects compared to CHD for peak power output ($p < 0.001$), peak oxygen uptake ($\dot{V}O_{2max}$: $p < 0.001$), and HR_{max} ($p < 0.001$) (Table **3**). Moreover, mean maximum minute ventilation ($\dot{V}E_{max}$) was higher in controls group without significant difference. After training, T-CHD improved their tolerance to exertion, i.e. power output, $\dot{V}O_{2max}$, HR_{max}, and $\dot{V}E_{max}$ increased, but not significantly. No desaturation during CPET was observed between all groups neither before nor after the training period. Cardiopulmonary variables at ventilatory threshold were significantly higher in controls than in CHD before training. After 12 weeks of training, the ratios power output at VT/peak power output ($p < 0.01$), HR at VT (HR_{VT})/HR_{max} ($p < 0.05$), $\dot{V}O_2$ at VT ($\dot{V}O_{2VT}$)/$\dot{V}O_{2max}$ ($p < 0.01$), and $\dot{V}E$ at VT ($\dot{V}E_{VT}$)/$\dot{V}E_{max}$ ($p < 0.05$) increased significantly in T-CHD and was not modified in C-CHD (Table **3**). $\dot{V}O_{2max}$, and $\dot{V}O_{2VT}$ were significantly correlated with WD in T-CHD before training. Correlation coefficients were $r = 0.76$, ($p < 0.01$) and $r = 0.69$, ($p < 0.05$) between WD and $\dot{V}O_{2max}$ and $\dot{V}O_{2VT}$, respectively. After training, correlation coefficients were $r = 0.95$, ($p < 0.001$) and $r = 0.93$; ($p < 0.001$) between WD and $\dot{V}O_{2max}$ and $\dot{V}O_{2VT}$, respectively. Likewise, the relationship between performance improvement in T-CHD (after training – before training) between WD and $\dot{V}O_{2max}$ as well as $\dot{V}O_{2VT}$ was statistically significant, respectively $r = 0.76$, ($p < 0.01$) and $r = 0.67$, ($p < 0.01$) (Fig. **2**).

Table **2** 6'WT results

			T-CHD		C-CHD	
	All CHD	*Controls*	*Before*	*After*	*Before*	*After*
Walking distance (m)	472.5 ± 18.1	548.8 ± 7.7§	467.7 ± 17.1	529.6 ± 15.3Ψ	477.3 ± 19.1	485.8 ± 12.1
Dyspnea	1.70 ± 0.27	1.13 ± 0.13	1.69 ± 0.27	1.14 ± 0.33	1.70 ± 0.27	1.73 ± 0.31
HR at rest (bpm)	91.6 ± 6.3	90.2 ± 1.9	91.3 ± 5.9	91.0 ± 3.2	92.0 ± 6.7	92.9 ± 4.8
HR_{max} (bpm)	110.2 ± 7.3	121.8 ± 2.2	111.2 ± 6.9	116.3 ± 4.3	109.3 ± 7.8	110.8 ± 8.5
SaO_2 at rest (%)	96.4 ± 0.6	98.6 ± 0.2	96.8 ± 0.4	97.5 ± 0.1	96.1 ± 0.8	95.9 ± 0.4
SaO_2 at end (%)	95.7 ± 0.2	97.5 ± 0.1	95.8 ± 0.4	96.0 ± 0.4	95.7 ± 0.1	95.6 ± 0.4

Values are presented as the mean ± SEM. § Significant difference between controls and all CHD patients; Ψ significant difference between T-CHD and C-CHD before and after the training period

Table **3** Cardiopulmonary data obtained at the maximum CPET and at the ventilatory threshold levels for controls, T-CHD, and C-CHD before and after training

			T-CHD		C-CHD	
	All CHD	*Controls*	*Before*	*After*	*Before*	*After*
Maximum CPET						
– *peak power output (W)*	105.5 ± 5.8	159.6 ± 7.1§	106.9 ± 5.4	115.6 ± 7.1‡	104.1 ± 6.2	103.6 ± 9.3
– $\dot{V}O_{2max}$ *(ml/min/kg)*	28.9 ± 1.7	46.5 ± 1.8§	29.6 ± 1.9	32.8 ± 2.0‡	28.2 ± 1.6	29.8 ± 1.1
– $\dot{V}E_{max}$ *(l/min)*	64.8 ± 3.7	80.6 ± 3.3	66.4 ± 4.8	70.5 ± 5.5	63.3 ± 2.7	64.1 ± 2.5
– HR_{max} *(bpm)*	163.5 ± 6.2	197.2 ± 2.9§	162.8 ± 6.2	173.8 ± 3.7‡	164.2 ± 5.9	166.2 ± 4.0
– SaO_2 *(%)*	95.4 ± 0.7	95.6 ± 0.4	95.6 ± 0.8	95.88 ± 0.4	95.2 ± 0.7	95.1 ± 0.3
Variables at the VT						
– *power output at* $_{VT}$*(W)*	45.2 ± 3.0	95.7 ± 6.2§	46.2 ± 3.1	70 ± 5.1‡ψ	44.2 ± 3.0	46.0 ± 5.1
– $\dot{V}O_{2\,VT}$ *(ml/min/kg)*	17.8 ± 1.5	32.1 ± 1.8§	18.3 ± 1.1	23.8 ± 1.0‡ψ	17.3 ± 1.9	19.8 ± 1.2
– $\dot{V}E_{VT}$ *(l/min)*	28.6 ± 1.7	39.8 ± 2.3§	28.2 ± 1.9	36.4 ± 2.6ψ	29.1 ± 1.6	31.3 ± 2.0
– HR_{VT} *(bpm)*	115.7 ± 3.2	146.1 ± 2.1§	115.2 ± 3.0	128.2 ± 3.6‡ψ	116.2 ± 3.5	120.3 ± 2.7
– SaO_{2VT} *(%)*	97.2 ± 0.4	97.7 ± 0.1	97.6 ± 0.5	96.4 ± 0.4	96.9 ± 0.4	95.8 ± 0.8
VT in % of the maximum						
– *power output at* $_{VT}$ *(%)*	42.5 ± 2.4	59.7 ± 2.4§	43.3 ± 1.9	60.7 ± 2.5ψ	41.8 ± 2.9	48.1 ± 3.0
– $\dot{V}O_{2VT}$ *(%)*	63.2 ± 2.0	68.5 ± 1.8	62.3 ± 2.1	74.0 ± 2.5ψ	64.1 ± 1.9	66.3 ± 2.1
– $\dot{V}E_{VT}$ *(%)*	44.6 ± 2.9	50.0 ± 3.0	44.1 ± 2.8	53.6 ± 3.4	45.2 ± 3.1	45.6 ± 2.9
– HR_{VT} *(%)*	70.8 ± 1.7	74.3 ± 1.4	71.3 ± 1.8	77.4 ± 1.4	70.3 ± 1.7	73.0 ± 1.8

Values are presented as the mean ± SEM. $\dot{V}O_2$: oxygen uptake; HR: heart rate; $\dot{V}E$: ventilation minute; SaO_2 = transcutaneous arterial oxygen saturation; VT: ventilatory threshold. § Significant difference between controls and all CHD patients; ψ significant difference between T-CHD after and before, and T-CHD after, and C-CHD after; ‡ significant difference between controls and T-CHD after

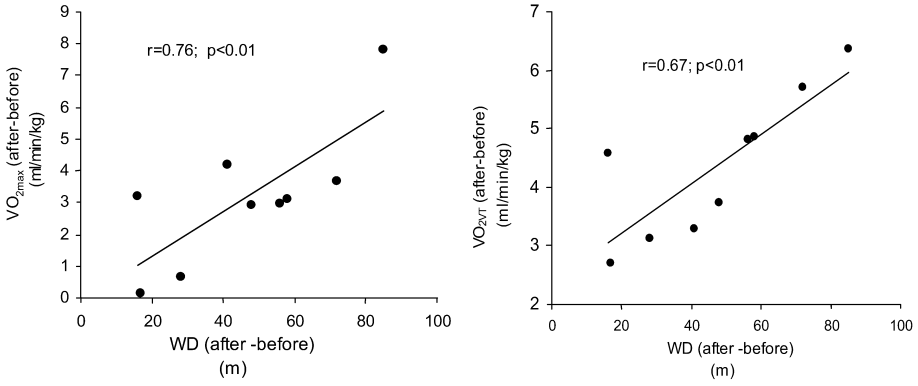


Fig. **2** Relationship between improvement of WD and improvement of $\dot{V}O_{2max}$ as well as improvement of $\dot{V}O_{2VT}$ in T-CHD group (after training – before training).

Discussion

Our study demonstrated the interest of the 6'WT as a simple and useful clinical tool for the assessment of exertion tolerance in children with CHD. The results indicate that cardiac children have lower physical fitness values compared to control subjects. We demonstrated that both WD and performance improvement were correlated with $\dot{V}O_{2max}$ and $\dot{V}O_{2VT}$ in T-CHD. It was also found that variables at the VT and the WD covered are increased after training showing an improvement of physical capacities in cardiac children. The 6'WT allows also the quantification of training progress.

Walking is one of the normal activities of life; it reflects the capacity to undertake daily activities [9]. Compared to the CPET, the 6'WT did not provide specific information on the function of each system or mechanism implicated in exercise limitations. In fact, this test cannot determine maximum O_2 consumption, diagnose the cause of dyspnea, or describe mechanisms of exertion intolerance. The 6'WT has, however, two advantages: firstly, its simplicity and its low cost; secondly, it is a submaximal exercise which can be performed by children and especially those with a severe illness who do not tolerate maximum exercise [17]. Consequently, subjects manage better with walking than with the CPET [18]. In the present study, we used Bland-Altman plots in either CHD and control children and demonstrated that 6'WT is a reproducible and a reliable test. Moreover, we found a significant correlation between WD and peak $\dot{V}O_2$ as well as $\dot{V}O_2$ at VT before and after training. Likewise, the correlation between improvement of WD with $\dot{V}O_{2max}$ and $\dot{V}O_{2VT}$ revealed that the subjects with the greatest improvement in $\dot{V}O_{2max}$ and $\dot{V}O_{2VT}$ after training have the greatest increase in WD. Our findings are con-

trary to previous studies [19,24]. Roul et al. [24] have reported in patients with chronic heart failure a significant correlation between WD and peak $\dot{V}O_2$ ($r = 0.65$, $p < 0.01$). Opasich et al. [19] concluded also that 6'WT is related to exercise capacity. They reported a relationship between WD and peak $\dot{V}O_2$ and between WD and VT ($r = 0.59$ and $r = 0.54$, respectively).

Following the three months of individualized training program performed by T-CHD group, we noted an increase in the ventilatory threshold and higher values of power output, $\dot{V}O_2$, HR, and $\dot{V}E$ parameters. This indicates a later setting of glycolytic metabolism. The children with CHD have an early ventilatory threshold. In addition, their kinetics and the use of oxygen is delayed, i.e. a delay in O_2 consumption during exercise which can explain the large use of anaerobic metabolism in a short progressive exercise [18]. The delayed action of ventilatory threshold explains less hyperventilation at the same exercise power output, i.e. a weaker production of CO_2 for the same $\dot{V}O_2$. This gives the subject a respiratory ease and a lower feeling of breathlessness. Cardiopulmonary changes imply a better exercise tolerance and a better tissue oxygenation due to the increase in stroke volume [16].

The 6'WT allows the assessment of the physical fitness of patients who choose their own pace, with the possibility of pausing to rest during the test [1,17]. In our study, all subjects finished the test without difficulty or premature stop. We found a 62-m (13%) improvement in WD in T-CHD group, in agreement with results of Bittner et al. [4], who showed a 15% improvement in subjects with different heart diseases. Redelmeier et al. [23] reported that an improvement in WD of at least 54 m is clinically significant, in that it represents a noticeable modification to the functional status. After twelve weeks of training, the significant difference ($p < 0.05$) between T-CHD and control subjects that existed before training disappeared whereas C-CHD did not modify their performance. The testing of cardiopulmonary variables in T-CHD group during CPET showed also beneficial effects following training. Certainly, we noted an improvement in maximal parameters (peak power output, $\dot{V}O_{2max}$, $\dot{V}E_{max}$, and HR_{max}) of CPET after training, but the differences were not statistically significant. However, improvements of these parameters at VT are strongly significant. Thus, evaluation of training program was more important and significant by both 6'WT and VT. Two reasons can explain these results, first, 6'WT is a functional submaximal exercise [1], and second, training intensity was fixed at the ventilatory threshold of each child (submaximal intensity). Furthermore, maximal performance exerted by patients with CHD was mostly limited by symptoms [10]. Therefore, to fulfill benefits of cardiac rehabilitation, training and tests should be performed at submaximal intensities.

Heart rate is an index of exertion tolerance [13,27] that varies according to the WD covered. Before training, the HR of CHD group was lower compared to controls. After training, T-CHD group reached an identical profile to that of controls but only during recovery. The rapid fall of the HR at the end of the 6'WT before training substantiates a less developed physical effort. The identical kinetics of the HR found in T-CHD during the 6'WT before and after training for a better walking performance is an indication of a better exertion tolerance and to changes in autonomic tone as a result of endurance training.

The effort perception estimated by the Borg scale was not significant, but we observed lower average values of dyspnea in control subjects compared to CHD group. These values dropped in T-CHD after training, which explains less breathlessness and a weaker dyspnea. This finding coincides with ventilation increase after training as assessed by CPET. Our interpretations concerning dyspnea agree with the study of Langenfeld et al. [14] who validated the 6'WT following its correlation with power output, HR, SaO_2, and dyspnea evaluated during CPET.

In conclusion, our results show that the 6'WT is a reliable test which can be used as a practical tool for assessing the exercise tolerance. To our knowledge, this is the first study that evaluated physiological responses in children with congenital heart diseases by the 6'WT after 12 weeks of training. WD is a useful indicator of physical fitness. Consequently, the 6'WT can be used both in the assessment and follow-up of functional capacity during training in children with CHD.

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