

Cardiopulmonary Exercise Testing in Young Asthmatic Children Ages 6-10 Years Old

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Abstract—The aim of this study was to establish the feasibility of a minute incremental exercise testing protocol in young asthma children. Twenty-two children with clinically diagnosed mild to moderate asthma volunteered to participate. The maximum incremental exercise test was performed using a cycle ergometer with an electromagnetic braking. A warm-up unloaded for 2 minutes then the workload was started at 40 watts for 2 minutes, and then stepwise increments of 8 watts per 2 minutes were applied. The pedaling frequency was set at 50 rpm. Ventilation and gas exchange were measured with a breath-by-breath automatic metabolic measurement system. Results showed that this test was well tolerated by all asthmatic children. Most of the children reached the VO_2 plateau and satisfied the criteria for maximal respiratory exchange ratio of ≥ 1 . This Study demonstrated that this testing protocol was suitable for young asthmatic children.

Keywords—Asthma, Child, Exercise, Pediatrics.

I. INTRODUCTION

DUE to the physical limitation and exercise-induced bronchoconstriction, children with asthma often avoid physical activities and have demonstrated a significant lower aerobic fitness level [1] and may be at increased risk of becoming obese [2] than the nonasthmatic peers. Although regular physical exercise cannot cure asthma, several studies have reported that physical or exercise training increases the cardiopulmonary conditioning and decreased the severity of asthma symptoms in asthmatics [3, 4, 5].

Maximal aerobic power or maximal oxygen uptake ($\text{VO}_{2\text{max}}$), the highest oxygen uptake elicited during an exercise test to exhaustion, is recognized to be the best single index of aerobic fitness and requires the subject to achieve clinical exhaustion. The level of activity or physical training and the $\text{VO}_{2\text{max}}$ measurements were also well correlated in children [6]. However, the criteria for maximal exercise described in adults are rarely satisfied in children and are very different from those in adults [7]. In addition, Several studies evaluated the training effects of aerobic fitness in asthmatic children [2, 3, 5, 8, 9, 10],

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but the criteria for maximal exercise tests for children did not describe in detailed. Moreover, up to now, most of the studies recruited the subjects were age over 8 years old. None of any study investigate the suitable workload increments for exercise testing in young asthmatic children age below 8 years old.

Studies suggested that lung function decline in children with asthma may occur predominantly in younger or preschool-age children [11]. Understanding of the normal changes of cardiopulmonary responses to exercise is important to asthmatic children. This study was focused on the methodology used for the tests performed. Its principle aim was to investigate the feasibility of a minute increasing workload protocol for exercise testing in asthmatic children. Secondary, we investigated whether this protocol makes it possible to satisfy the criteria for maximal exercise generally required in children.

II. METHODS

11 girls and 11 boys with mild to moderate asthma, 6 to 10 years of age (mean age, 6.86), were voluntary recruited for this study from the Mackay Memorial Hospital, HsinChu. The severity of asthma was clinically physician-diagnosed asthma [2]. The diagnosis of asthma was made on the basis of the following criteria: (1) personal or familial history of allergy; (2) personal history of acute wheezing; (3) positive specific immunoglobulin E to inhaled allergens by a multi-allergen allergosorbent test (Phadiatop, Pharmacia, Uppsala, Sweden) and/or a cutaneous hypersensitivity to one or several allergens; and (4) no evidence of other lung disease [3].

None of any children was following a regular exercise training programme. All the children were in a stable phase of the disease, with no exacerbation during the 30 days before the start of the tests. Anthropometric data and clinical classification of asthma are reported in Table 1. Written informed consent was approved by the Institutional Human Subject Ethics Board of our institute and obtained from the parent(s) before the test.

A maximum incremental exercise test was performed on an electronically braked cycle ergometer (SportsArt C5150, Woodinville WA, USA) to determine maximal aerobic power ($\text{VO}_{2\text{max}}$). Electronically braked cycle ergometer permitted resistance to be applied evenly regardless of the pedaling speed. The children cycled unloaded 2 min for warm-up. In the starting phase, the workload was start at 40 watts. Next stepwise increments of 8 watts per 2 minutes were applied. The pedaling frequency was 50 rpm. A recovery period with unloaded was given for at least 2 min to prevent fainting and to accelerate lactate removal.

We allowed the parents to be present through the exercise test.

They were very curious and wanted to understand the apparatus and the meaning of the measures and results. We also ask the parents to help us to encourage their child to achieve exhaustion during the test. Children were encouraged verbally to pedal to exhaustion, which typically meant their legs became too fatigued to continue. Exercise was stopped when the children could no longer continue the pedaling frequency. Ventilation and gas exchange were measured breath by breath with a portable metabolic system (K4 b2, COSMED s.r.l., Rome, Italy) that underwent volume and gas calibrations before every test.

The K4 b2 (COSMED s.r.l., Rome, Italy) is worn on the chest with a harness, and a heart rate receiver is mounted to one of the supporting straps. The K4 b2 uses a COSMED patented oxygen analyzer and an infrared non-dispersive thermostated carbon dioxide analyzer, and proprietary software (version 8.0b). The flowmeter uses a bidirectional digital turbine and opto-electric reader, and has a linear response in the ventilation range of 0-300 L/min. The flowmeter is attached to a flexible rubber facemask that covers the children's mouth and nose. The accuracy of the COSMED K4 b2 portable metabolic system was valid for measuring oxygen uptake over a fairly wide range of exercise intensities [12].

During the bicycle exercise, the following variables were measured with a breath-by-breath automatic metabolic measurement system K4 b2, including oxygen uptake (VO_2 = the volume of O_2 uptake per minute), heart rate and respiratory exchange ratio. VO_{2max} is generally expressed relative to body weight, in milliliters of oxygen consumed per kilogram of body weight per minute (ml/kg/min). The definition used for the achievement of a VO_2 plateau herein was an increase in VO_2 of no more than 2 mL/kg/min for an increase in work of 5 to 10% [13]. Predicted maximum HR (HRmax) was considered to have been achieved if the HR recorded was $\geq (210 - [0.65 \times \text{age}] \pm 10\%) [7]$.

All data were stored and analysed using the statistical package SPSS for windows 10.0 (SPSS Inc, Chicago, IL, USA). The student's t test was used to compare VO_{2max} values between boys and girls. Additionally, a Pearson product-moment correlation was calculated to determine the relationship between anthropometry characteristics and the ventilatory responses at maximal exercise testing. The level of significance for the statistical analysis was set at $p < .05$.

III. RESULTS

The children tolerated the protocol well. No particular complications were observed during these exercise tests in asthmatic children aged from 6 to 10 years, especially of cardiac and exercise induced asthma origin. Anthropometric characteristics of the subjects are outlined in Table I. No significant gender differences were observed in all the anthropometric variables.

TABLE I
AGE AND ANTHROPOMETRIC CHARACTERISTICS OF SUBJECTS

Characteristics	Boys (n=11)	Girls (n=11)	Total (n=22)
Age, yr	6.82 (1.54)	6.91 (1.14)	6.86 (1.32)
Height, cm	124.90 (9.91)	122.52 (8.57)	123.71 (9.12)
Weight, kg	25.45 (6.85)	23.57 (4.62)	24.51 (5.78)
BMI, kg/ m ²	16.05 (2.31)	15.59 (1.68)	15.82 (1.98)
BSA, m ²	0.93 (0.16)	0.90 (0.11)	0.92 (0.14)

Values are expressed as mean (SD). BMI, body mass index; BSA, body surface area.

All subjects achieved the clinical exhaustion. Table II lists ventilatory variables for boys and girls at maximal exercise. The average of maximal respiratory exchange ratios (RERs) was 1.00 ± 0.70 for boys and 1.04 ± 0.42 for girls indicated an equal exercise effort in all the subjects.

TABLE II
VENTILATORY RESPONSE OF ASTHMATIC CHILDREN AT MAXIMAL EXERCISE BY SEX

Variables	Boys (n=11)	Girls (n=11)	Total (n=22)
Heart rate, bpm	181.18 (8.42)	183.45 (7.51)	182.32 (7.88)
RERmax	1.00 (0.07)	1.04 (0.04)	1.02 (0.06)
VO_{2max} , mL/kg/min	37.61 (5.31)	37.20 (6.23)	37.41 (5.66)
Duration, sec	655.50 (113.12)	667.00 (113.08)	660.61 (109.89)

Values are expressed as mean (SD). RERmax = maximal respiratory exchange ratio; HR = heart rate; VO_{2max} = maximal oxygen uptake.

A VO_2 plateau was reached in 8 boys and 10 girls (82%). The mean RERmax (\pm SD) was 1.02 ± 0.06 (range from 0.91 to 1.13). A HRmax of > 180 beats/min was recorded in 4 boys and 8 girls (54%) and 4 boys and 7 girls (50%) reached the predicted HRmax with a mean value of 181.95 ± 8.19 beats/min.

A significant correlation was found between achievement of HRmax and a VO_2 plateau ($r = 0.53$). Moreover, VO_2 plateau was significantly highly correlated ($p < 0.01$) with age ($r = 0.74$), height ($r = 0.89$), weight ($r = 0.87$), body surface area ($r = 0.90$), and body mass index ($r = 0.57$). No significant correlation was found between a RERmax and a VO_2 plateau ($r = 0.30$) or between a RERmax and HRmax ($r = -.01$).

TABLE III
PEARSON CORRELATION COEFFICIENTS AMONG ANTHROPOMETRY AND VENTILATORY VARIABLES IN ASTHMATIC CHILDREN

	Age	Ht	Wt	BSA	BMI
Duration	0.24	0.34	0.51*	0.46	0.50*
VO_2 /kg	0.37	0.53*	0.01	0.38	-0/08
RERmax	0.36	0.25	0.18	0.22	0.04
HRmax	0.20	0.15	0.11	0.13	0.02
VO_2 /HR	0.74*	0.89*	0.87*	0.90*	0.57*
METS	0.36	0.51*	0.24	0.35	-0.09

* Significant correlation between variables: $P < 0.05$.

IV. DISCUSSION

This prospective study, carried out in 22 children with mild to moderate asthma, demonstrated the feasibility of this minute increasing workload maximal exercise protocol for young asthmatic children. In most cases, the exercise was maximal,

although the criteria of maximal exercise generally used in adult population were not systematically satisfied. The results of this study revealed that the predicted VO_{2max} was achieved in only 44% for asthmatic children implying using equation to predict the VO_{2max} in asthmatic children is not suitable.

In our experience, and as suggested by other study [14], large increments in workload may lead to the premature cessation of exercise before cardiac or respiratory limits are reached, due to exhaustion of the muscles of lower limbs, especially the quadriceps, particularly if the test is carried out with a cycle ergometer. The workload was increased very slowly (8W/2 min) in our study to prevent muscle limitation, which would have made it necessary to stop the exercise prematurely before maximal exercise was achieved. Additionally, clinical tolerance was good and no deleterious events during and after our test. At the end or after exercise test, none of any children had an exercise-induced bronchospasm.

In our study, it was necessary to achieve maximal exercise for several reasons: (1) to assess objectively the children's possibilities in terms of physical activities; (2) to achieve VO_{2max} as a quantifiable index. The results of our study demonstrated that the progressive incremental maximal cardiopulmonary exercise test with little increase in workload is feasible. Our study showed 82% of tested children satisfied the criteria for VO_{2max} plateau, demonstrated the integrated exploration of lung, cardiac and muscular functions involved in exercise. Moreover, the value of progressive incremental maximal cardiopulmonary exercise tests is not only for the measure of maximal exercise capacity, but also for the abnormal screening during the test. We believed that for our population of asthmatic children, it was important to assess both aerobic aptitude (exercise tolerance) and the adaptation in the various cardiorespiratory parameters measured during the incremental test.

Maximal exercise testing is important in evaluating and examination of the cardiopulmonary function for asthmatic children. Several studies used cycle ergometry testing to evaluate the cardiopulmonary capacities, but the increments of workload are vary [2, 3, 4, 5, 8, 9]. Because the subjects with asthma in most study were aged over 8 years old. The rate of increase in work affects the value of VO_{2max} achieved, with protocol involving large increments resulting in lower values of VO_{2max} due to a lack of muscle power [15]. Similarly, a low rate of increase in workload prolongs the duration of the test, making it a test of endurance, with lower values of VO_{2max} recorded.

For evaluating cardiopulmonary function with incremental exercise testing by either treadmill or cycle, selecting a work rate increment to bring the subject to the limit of tolerance in 10 ± 2 min [15]. The 8- to 12-minute exercise testing duration also recommended in most of the exercise testing guideline for optimal cardiopulmonary performance [14]. Because the mean age for our subjects was 6.86 years old, the increase of workload in this study was very small only at 8W/2 min. The mean maximal testing duration (SD) in our study was 660.61 (109.89) seconds, conformed to previous study and showed optimum

duration of our protocol. The duration of the test used herein made it possible to approach VO_{2max} in children.

Several criteria for maximal exercise were those used in progressive incremental cardiopulmonary exercise testing in adults. (1) Exhaustion of the subject or inability to maintain the required pedaling speed despite strong verbal encouragement; (2) VO_2 plateau reached (the VO_2 plateau is considered to have been reached if the final increase in VO_2 does not exceed 2 mL/kg/min for an increase in work of 5-10%); (3) predicted maximum HR (HR_{max}) achieved ($210 - \text{age} \pm 10\%$); and (4) maximal RER (RER_{max}) of >1.1 . Children, however, are not mini adults and the criteria of maximal exercise were needed to adjust due to the variability of cardiopulmonary responses observed during growth and maturation. In our study, we consulted several recent studies concerned the evaluation of maximal cardiopulmonary test [2, 3, 5, 7, 9, 16] and chose (1) and (2) items which mention above and adjusted the (3) to have been achieved if the HR recorded was $\geq 90\%$ of the predicted value [$210 - [0.65 \times \text{age}] \pm 10\%$] and the (4) RER_{max} >1.0 [7] as the criteria for maximal cardiopulmonary exercise.

Analysis of the criteria for maximality included exhaustion of the subjects, VO_2 plateau, HR_{max}, and RER_{max}. The motivation of the child to reach exhaustion was in most cases evident. Subjective signs of exhaustion towards the end of the rest (profuse sweating, inability to maintain the desired exercise intensity, decreased and unsteady pedaling rate) may provide the most useful indication that the children has attained maximal effort [13]. If exhaustion did not appear to us to be clinical clear, we kept the children at the same workload for a few extra seconds, or simply increased the workload again, but to a lesser extent than for the previous increments, to check that the variables monitored (ventilation and HR) and VO_2 did not increase [7].

A VO_2 plateau was achieved in 82% of all children. Previous studies reported that only about 30-50% prepubescent children fulfill a VO_2 plateau during progressive, incremental treadmill exercise testing [13, 16]. The minute incremental protocol and stationary bicycle exercise used in our study might make it possible to achieve the VO_2 plateau in a higher proportion of asthmatic children than with other protocols. Armstrong [16] have demonstrated that in children, a peak VO_2 taken over several seconds is an index of maximal exercise, even in the absence of a plateau.

In the absence of a VO_2 plateau it is conventional to seek confirmation of maximal effort through application of recommended secondary criteria based upon final values for heart rate and RER [13]. However, these criteria are not without problems. For example, a terminal heart rate of 200 beats/min ($\pm 5\%$) and/or a respiratory exchange ratio at least 1.1 are most frequently sought. Maximal heart rate are, however, extremely variable in children and adolescents and may range from 180 to 220 beat/min. RER is also highly dependent upon test protocol and mode of exercise with cycle ergometry typically eliciting higher values [17, 18]. However, in the presence of clear subjective indications of maximal effort, a leveling off in heart

rate and high RER do provide valuable confirmatory markers [17].

Armstrong et al [16] reported that RERmax was a reliable criterion for maximal exercise. In adults, the criterion used is a RERmax > 1.1, and this is also the best criterion for maximal exercise. In our study, RERmax was one another useful criteria for the determination of maximal exercise because the mean RERmax was 1.02 ± 0.06 (range from 0.91 to 1.13) and achieved in 77% of all asthmatic children. The predicted HRmax was achieved in 50% of all asthmatic children. As mentioned before, HRmax are extremely variable in children and may range 180 to 220 beats/min. The mean HRmax was >180 beats/min and ranged from 171 to 199 beats/min. HRmax determination is essential. The possible explanation might be the children in our study were so young and did not have such experience during maximal exhaustive exercise. Additionally, the mean RERmax recorded herein is similar to that generally observed in children and no correlations were found between RERmax and all the anthropometry characteristics [9, 19]. Study also reported that children lack the necessary mechanisms to generate sufficient energy anaerobically to enable them to continue exercising beyond the limits of aerobic metabolism [13]. More studies are needed to evaluate and demonstrate the mechanisms and interpretations for asthmatic children.

In the asthmatic children, the predicted VO_{2max} [20] was achieved in 44% of the children in our study. No difference between the sex in VO_{2max} recorded, with a mean value of 17.20 ± 6.23 mL/kg/min for girls and 37.61 ± 5.31 mL/kg/min for boys. Because most of the study recruited the asthmatic children age over 8 years old, it is hardly to compare the VO_{2max} values with those for healthy or asthmatic children of the same age.

This study shows that for a population of 22 young asthmatic children, this protocol for maximal exercise testing was possible and the clinical tolerance of exercise was high. The test was optimal duration (10 to 12 min). Besides the clinical exhaustion, this study demonstrated the best two criteria for confirming maximal exercise were VO_2 plateau and RERmax. Lower proportion was achieved in HRmax might be due to the peculiar, unusual exhaustion experience to young children. This methodology might make it possible to expand the use of incremental cardiopulmonary exercise tests in young asthmatic children, both for diagnosis and treatment.

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