Original Article

Treadmill Stress Test in Children and Adolescents: Higher Tolerance on Exertion with Ramp Protocol

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Summary

Objective: **Compare exercise tolerance by children and adolescents submitted to treadmill stress test (TST) following Bruce Protocol (BP) or Ramp Protocol (RP), as well as describe velocity and inclination reached with ramp protocol to help set protocol exercise standards.**

Methods: **Observational, case-based study, with history control of 1,006 children and adolescents in the 4 to 17-year-old range who were submitted to TST between October, 1986 and February, 2003, and who concluded one of the two protocols. Those who interrupted their ET for other reasons rather than physical exhaustion, those on medication that interfered in HR and those with physical constraints to exercise were excluded. Statistical analysis of data considered $p<0.05$ as significance level; with confidence interval at 95%.**

Results: **Exercise time close to 10 minutes in RP was significantly higher than in BP. HR max reached was higher than 180 bpm in both protocols. Inclination showed to be slightly higher in younger girls in Bruce Protocol. Velocity and VO_2 max showed to be higher for all age ranges for those in the Ramp Protocol.**

Conclusion: **Velocity and inclination reached with ramp protocol may be used as reference to help set ramp protocol exercise, which showed superior on exertion tolerance as compared to Bruce protocol. (Arq Bras Cardiol 2007;89(6):354-359)**

Key words: **Exercise test; child; adolescent.**

Introduction

TST is a diagnostic method with a number of indications[1] for children and adolescents (age ≤ 19 years of age)[2]. Protocol to be used must be individual so that treadmill velocity and inclination may be applied following the capabilities of patient under testing.[3] The risk posed by TST in children and adolescents is very low when compared to adults, and complications are not common, even if testing is carried out in children with cardiopathies.[4,5] Specific knowledge on the physiology of exercise, on the different behavior of heart rate, blood pressure and ECG, in addition to the use of sphygmomanometer are pre-requisites to TST in this group of patients.[6]

The treadmill has been used in most Brazilian laboratories and clinics where TST is performed. The most commonly used protocol is Bruce Protocol (BP)[7]. The ramp protocol (RP) is characterized by 8 to 12-minute time length, slight and progressive velocity and inclination increase following individual patient's gender and age, and based on expected maximum volume of oxygen (VO_2 max),[8-10] to be estimated using *American College of Sports Medicine* (ACSM)[11,12] formulas or "VSAQ" (*Veterans Specific-Activity Questionnaire*)[13,14] questionnaire.

The primary objective was to compare the variables to assess the tolerance of children and adolescents submitted to Bruce protocol or ramp protocol, and to test the assumption that both protocols are equivalent. The specific objective was to describe velocity and inclination reached with ramp protocol to help set protocol exercise standards.

Methods

An observational, case-based study was carried out with history control of children and adolescents in the 4 to 17-year-old range who were submitted to TST at the outpatient unit of a clinic in Recife, Pernambuco State, following one of the two protocols: BRUCE (history control, TST from October, 1986 through February, 1998), and RAMP (March, 1998 through February, 2003). Screening included only exams terminated due to fatigue. All other interruption causes as well as the use of medications that interfered in heart rate were excluded. Only the TSTs performed by one observer were evaluated following the two protocols (Bruce and Ramp). The analysis was based on objective data, and free of any observer interpretation: *exercise time length*, *maximum HR* (HR max); *maximum velocity* (km/h); *maximum incline* (%); *maximum oxygen volume* (VO_2 max – mml of oxygen used per kg/bodyweight per minute - ml.kg^{-1}.min^{-1}) calculated through the American College Sports of Medicine - ACSM[11,12] formula.

Anamnesis, physical exam, heart rate, blood pressure, and ECG were performed before stress test in all individuals. The procedures were repeated during the 3/3 minutes test on BP

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and during the 2/2 minutes on RP, and after the test at 1, 2, 4 and 6 minutes for all individuals. Data were entered in Excel 8.0 Microsoft®, and statistical analysis was carried out through Excel 8.0 and SigmaStat 3.0. Results are presented in tables, and classified by *test protocol, gender, and age range,* with four groups having been created (4-7, 8-11, 12-14 and 15-17 years of age). Homogeneity among groups was evaluated according to age, bodyweight, height and HR at rest through Student *t* test or Mann-Whitney test (in the absence of normal distribution or equal variances) as well as to the presence or absence of diseases through chi-square test (χ^2). Mann-Whitney test was used for the comparison of exercise time length, HR max, velocity, inclination, and VO_2 max in both protocols, with significance at $p < 0.05$ and 95% CI.

Ethical aspects - No experimental protocols were used. Bruce protocol was introduced in the clinical practice over 50 years ago. The ramp protocol, in 1981 for the cycloergometer, and in 1991 for the treadmill. The tests were required by assistant doctors, and performed by experienced professionals in the method. Parents or guardians were present, having been previously informed about the procedure. Data were collected from the children's and adolescents' medical records. Description and comparison of means from variables classified by TST protocol, gender, and age range guarantee full confidentiality of all study participants. The project was approved by the Institutional Ethics Committee for Research Involving Human Beings.

Results

One thousand and six (1,006) children and adolescents were evaluated. Six hundred and three (603) (59.9%) were males. From the 558 (55.5%) submitted to BP, 58.4% were males; from the 448 (45.5%) who performed RP 61.8% were males. In order to test homogeneity between BP and RP age, bodyweight, height, HR at rest and the presence or absence of disease were compared. No significant differences were shown between age and height either in males or females. Females did not show any difference regarding bodyweight or HR at rest. Among males, although significant difference was shown both for bodyweight and HR at rest between groups. When age range was considered, bodyweight showed to be homogeneous and HR at rest slightly higher in BP only in the 15 to 17-year-old range.

The groups were not homogeneous as to the presence or absence of disease (p<0.001). In the BP group 495 (88.7%) were healthy, while 63 (11.3%) had a condition (43 presented heart disease and 20 had asthma). In the RP 366 (80.0%) were healthy, and 92 (20.0%) had a condition (77 were cardiopaths, and 15 asthmatic).

Among females, maximum HR reached was 1 to 4 bpm in BP, showing significant difference only in the 8 to 11-year-old range. Exercise time length was significantly higher among 12 to 14-year-olds in RP (Table 1). Among male participants, higher values were also observed for HR max in BP (in average 3 bpm), showing significance only among 15 to 17-year-olds. Exertion time was not higher in BP among the 4 to 7-year-olds only. All other age ranges it was shown to be significantly higher (Table 2).

Table 1 - Maximum heart rate (bpm) and exercise time length (min:sec) per age range and Protocol - females.

	HRmax bpm							Time min:sec						
Protocol	BRUCE			RAMP			p	BRUCE			RAMP			p
Age range	Means		SD	Means		SD		Means		SD	Means		SD	
4-7	191.3	±	10.6	188.4	±	11.8	0.613	9:41	±	1:42	9:29	±	1:30	0.642
8-11	194.9	±	12.0	191.0	±	9.2	0.046	10:22	±	1:43	9:50	±	1:25	0.062
12-14	195.1	±	8.1	193.6	±	7.0	0.346	9:47	±	1:48	10:38	±	1:27	0.014
15-17	191.3	±	9.6	190.2	±	7.4	0.554	10:05	±	1:48	10:05	±	1:46	0.975
Total	193.4	±	10.5	191.1	±	8.8	0.018	10:02	±	1:46	10:04	±	1:34	0.897

Table 2 - Maximum heart rate (bpm) and exercise time length (min:sec) per age range and Protocol - males.

	HRmax bpm							Time min:sec						
Protocol	BRUCE			RAMP			p	BRUCE			RAMP			p
Age range	Means		SD	Means		SD		Means		SD	Means		SD	
4-7	187.1	±	11.4	183.4	±	15.8	0.391	9:51	±	2:03	10:35	±	1:57	0.129
8-11	190.7	±	10.7	187.9	±	13.8	0.144	11:39	±	2:31	10:27	±	1:43	<0.001
12-14	194.7	±	11.7	192.0	±	12.1	0.160	12:44	±	3:03	10:37	±	1:39	<0.001
15-17	194.8	±	10.0	190.2	±	9.9	0.005	12:34	±	2:11	10:39	±	1:49	<0.001
Total	191.9	±	11.2	189.5	±	12.8	0.023	11:48	±	2:40	10:34	±	1:44	<0.001

Among females, maximum inclination in BP was higher in the 4 to 11-year-old range, and lower in the 12 to 14-year-old range. No difference was observed among 15 to 17-year-old participants. Maximum velocity showed to be significantly higher in RP in all age ranges (Table 3). Among males, maximum inclination showed little difference, having been higher in BP only in the 12 to 14-year-old range. Maximum velocity reached was significantly higher in RP for all age ranges (Table 4).

The ACSM formula (jogging) was used to calculate maximum oxygen volume. Only girls in the 4 to 7-year-old range showed no significant difference between BP and RP. All other children and adolescents reached significantly higher values for VO_2 max in the RP – irrespective of gender and age range (Table 5).

Discussion

Despite the low prevalence of cardiopathies among children and adolescents, in addition to ruling out heart diseases and checking functional capability, TST helps assistant doctors to more confidently allow ordinary physical activities or sports practice to those with exercise-related symptoms. Regular TST may give parents more confidence as well to allow their children - whether they have a condition or not - to lead their lives as normally as possible, without the many times unnecessary constraints on their physical activities. A small number of publications has described the normal behavior of hemodynamic and metabolic variables in children and adolescents. Those publications are usually based on Bruce Protocol or Ramp Protocol with cycloergometer, but very few –

Table 3 - Velocity (km/h) and maximum inclination (%) per age range and Protocol - females.

	Velocity max								Inclination max						
Protocol	BRUCE			RAMP			p	BRUCE			RAMP			p
Age range	Means		SD	Means		SD		Means		SD	Means		SD	
4-7	6.1	±	0.9	6.6	±	0.6	0.014	15.0	±	1.4	14.0	±	2.0	0.011
8-11	6.4	±	0.8	7.2	±	0.9	<0.001	15.6	±	1.3	14.9	±	2.1	0.002
12-14	6.1	±	0.9	7.8	±	1.1	<0.001	15.1	±	1.3	15.9	±	2.1	0.034
15-17	6.2	±	1.0	7.7	±	1.6	<0.001	15.3	±	1.8	15.7	±	2.1	0.064
Total	6.2	±	0.9	7.4	±	1.2	<0.001	15.3	±	1.5	15.2	±	2.2	0.555

Table 4 - Velocity (km/h) and maximum inclination (%) per age range and Protocol - males.

	Velocity max							Inclination max							
Protocol	BRUCE			RAMP			p	BRUCE			RAMP			p
Age range	Means		SD	Means		SD		Means		SD	Means		SD	
4-7	6.2	±	1.0	7.2	±	1.2	<0.001	15.2	±	1.6	15.9	±	3.0	0.283
8-11	6.9	±	1.0	7.8	±	1.0	<0.001	16.3	±	1.6	16.2	±	3.1	0.128
12-14	7.3	±	1.2	8.6	±	1.3	<0.001	16.9	±	1.8	16.2	±	3.1	0.002
15-17	7.2	±	0.9	8.7	±	1.3	<0.001	16.9	±	1.6	17.1	±	3.4	0.703
Total	7.0	±	1.1	8.2	±	1.3	<0.001	16.4	±	1.7	16.4	±	3.2	0.033

Table 5 - VO_2 max ($ml.kg^{-1}.min^{-1}$ – calculated through ACSM formula (jogging) per gender. age range and Protocol

VO_2 max	Females							Males							
Protocol	BRUCE			RAMP			p	BRUCE			RAMP			p
Age range	Means		SD	Means		SD		Means		SD	Means		SD	
4-7	37.9	±	6.4	39.4	±	4.7	0.290	38.7	±	7.3	45.3	±	9.2	0.018
8-11	40.3	±	5.9	43.9	±	6.2	0.008	43.7	±	7.5	48.6	±	7.9	<0.001
12-14	38.0	±	6.1	48.3	±	7.3	<0.001	47.0	±	9.0	53.2	±	9.0	<0.001
15-17	38.9	±	7.9	47.8	±	10.1	<0.001	46.4	±	7.4	55.1	±	9.4	<0.001
Total	39.0	±	6.6	45.4	±	8.1	<0.001	44.2	±	8.2	51.4	±	9.3	<0.001

even the most recent ones - discuss the specific characteristics of ET protocols. The relevance of the present study resides in presenting RP on the treadmill involving a significant number of children and adolescents, in addition to suggesting criteria to help set treadmill velocity and inclination parameters in the protocol according to gender and age range.

A possible constraint in the present study is that not both protocols were used for all children and youngsters in the study so that real differences, with different characteristics in TST test results, could be compared. However, both groups were homogeneous as to age and height of males and females. HR at rest and bodyweight showed slight difference in the 15 to 17-year-old range for males only, which may contribute with higher confidence in comparing results of both groups submitted to different protocols.

Younger children are usually less cooperative for the assessment of maximum exercise. To make up for the difficulties in differentiating between capacity constraints to perform exercise and lack of cooperation in pediatric testing[6], examiner's experience and adolescents' courage - reluctant towards maximum exercise - are major components. Tolerance level to exercise in children may be the result of emotional factors rather than real fatigue[15]. Those conditions may justify the lower exercise time length and lower maximum HR reached by the younger ones.

Formulas used to calculate maximum HR expected in adults do not apply for maximum HR expected in pediatric populations. Children's physiologic response to exercise is similar to that of adults, with progressive increase proportional to exertion increase, but differs in the maximum values reached and in lowest correlation between HR and age range. Normal children in different age ranges reach HR max above 180 bpm. Values above 200 bpm are commonly found. Children with HR max < 180 bpm have either not been properly exercised or present chronotropic deficit[16].

In the present series, irrespective of protocol or gender, HR max was >180 bpm, which suggests all adolescents have been exercised properly. BP showed slightly increased HR max, although the 3 to 4 bpm difference at peak effort carries no clinical significance.

Different series studied following Bruce Protocol have described the following HR max: normal Canadians: between 193 and 206 bpm[17] and those with heart disease between 180 and 210 bpm[18]; Mexicans – 5-year-old boys and 5 and 6-year-old girls reached 180 bpm, all the others between 184 and 200 bpm[19]; North-Americans, between 180 and 200 bpm[20]; Italians (from Naples), 182±14 bpm for boys and 184±13 bpm for girls[21]; Turkish boys - 193±11 bpm and girls, 197±11.[22]

Few publications include normal children with RP in the treadmill. Rowland & Cunningham[23] have studied 15 children to evaluate VO_2 max. They all reached over 193 bpm. Török et al[24] have observed 29 normal boys to compare with those with plurimetabolic syndrome and isolated obesity syndrome: in the group of normal boys HR max was around 185 bpm.

In puberty, with higher muscular development boys are expected to have higher exertion tolerance – which BP characterizes as exercise time increase. In RP physical capacity cannot be evaluated based on exercise time, since effort is more intense for exercise average time - 10 minutes - to be kept.

Whipp et al[25] have described the ideal time – between 4 to 8 minutes – to reach peak effort on the cycloergometer. Buchfuhrer et al[26] have suggested average time length of 10 minutes for maximum tolerance – whether on the treadmill or on the cycloergometer. Shorter time tests show lower VO_2 max values, possibly due to muscular limitation from more intense effort. Likewise, in longer time tests, lower VO_2 max can also be found as a result of body temperature increase, higher dehydration, muscular discomfort, or the different energy substracts involved in prolonged exercise[26].

Bruce Protocol was used by Bozza & Loos[16] to study 114 Brazilians in the 4 to 18-year-old range. Average effort time increased 10 minutes for boys aged ≤ 7 up to 13.6 min for those ≥ 15 years of age. Younger girls showed an 8.9-minute increase, while the 11 to 14-year-old range showed up to 12 minutes increase, with a decrease for those over 14. Bruce protocol applied to very young children or those facing limitations may be of very short time length. For better trained children time may easily be longer than 12 minutes[27]. Cumming et al[17] have observed a higher correlation between VO_2 max and exercise time – and that may satisfactorily be used as a sign of exertion tolerance in the Bruce Protocol.

In the Ramp Protocol time length is expected to be between 8 and 12 minutes[8-10] - irrespective of gender, age range, or fitness level. As exercise time is relatively constant in the RP, VO_2 calculated through the same formula may be used to compare exertion tolerance. The two protocols showed different velocity and maximum inclination. For the sole purpose of comparison between BP and RP VO_2 max in all children and adolescents was calculated based on peak effort inclination and velocity through ACSM formulas for walking and for jogging. No significant difference was shown in jogging when compared to Balke formula (data not included in results). Body weight difference was corrected through $ml.kg^{-1}.min^{-1}$. Rather than an attempt towards patient functional classification based on calculated VO_2, a comparison was made for exercise tolerance in both protocols.

Similarly to other studies, VO_2 max showed to be higher among boys, increased with age, and maximum values were reached later in males. Although RP showed to include most individuals with heart disease in all age ranges, VO_2 max was higher in that protocol (RP=51.4±9.3 and BP=44.2±8.2 $ml.kg^{-1}.min^{-1}$). Most common referrals of individuals for TST in that age range for the assessment of either clinical or surgical management of congenital cardiopathies or valvopathies and physical exercises may justify the number of TST performed by children and adolescents with heart disease in most recent years.

Myers et al[8] have found calculated VO_2 to be higher than that recorded by all protocols under study, with the lowest difference (6%) in the Ramp Protocol, and the highest (16%) in the Bruce Protocol. Serra[9] recommends RP since it provides better identification of anaerobic threshold, as well as higher levels of VO_2 max. Maximum TST does not necessarily make the distinction between normal children and those with moderate to severe heart disease. Many of them with heart structure problems – whether corrected or not – report the same VO_2 max as the normal ones. Only cyanotic children or those with severe valvular disease have presented consisted reduction of functional capacity[18]. Among 7,514 Americans in the 12 to 17-year-old range estimated VO_2 max was slightly higher among Black children – it increased with age for boys and decreased for girls after puberty[28].

Data from this population resulted in Table 6, with velocity and initial inclination, and then at 10 minutes during exercise, with VO_2 max according to gender and age range, thus making the use of RP easier for children and adolescents. The suggestions that follow may also help in the prescription of RP exercise:

1. Time estimated should be 10 minutes. Two minutes added to or reduced from that time should accommodate most patients under study, with ideal exercise time between 8 and 12 minutes;

2. Velocity and inclination to be reached at 10 minutes should be selected previously. Data presented on Table 6 may serve as suggestion according to gender and age range;

3. baseline velocity should be equivalent to 50% or less than estimated maximum velocity to allow a 0.1 km/h increment every 10 or 15 seconds;

4. Baseline inclination absolute values should be 10% lower than maximum inclination to allow a 0.5% increment every 30 seconds;

5. Warm-up time and adaptation to ergometer should take approximately 2 minutes, with velocity and inclination at 50% as compared to baseline;

6. Recovery after exercise may be performed with no inclination (0%) and baseline velocity equivalent to 50% of maximum velocity reached, with a 10% reduction every 30 seconds. The combination of low incremental increases in inclination and velocity along exercise time length contributes with better comfort as compared to a sudden increase in workload, especially in younger female patients.

Conclusion

In the treadmill stress test performed in children and adolescents the comparison between Bruce protocol and Ramp Protocol showed that the parameters described for maximum oxygen volume, velocity and inclination reached with RP may be used as reference to help protocol prescription, since it showed superior exertion tolerance when compared to Bruce protocol.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

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Table 6 - Velocity(Km/h). inclination(%) suggested (at baseline and at 10 min) and VO_2 max(ml.Kg^{-1}.min^{-1}) reached per age range and gender. to define exercise practice in Ramp Protocol

	Females							Males						
	Velocity		Inclination		VO_2		max	Velocity		Inclination		VO_2		max
Age range	Baseline	10 min	Baseline	10 min	Média		DP	Baseline	10 min	Baseline	10 min	Média		DP
4-7	3.0	6.5	4.0	14.0	39.4	±	4.7	3.5	7.5	5.0	15.0	45.3	±	9.2
8-11	3.5	7.0	5.0	15.0	43.9	±	6.2	4.0	8.0	5.0	15.0	48.6	±	7.9
12-14	4.0	8.0	5.0	15.0	48.3	±	7.3	4.0	8.5	6.0	16.0	53.2	±	9.0
15-17	4.0	8.0	5.0	15.0	47.8	±	10.1	4.5	9.0	6.0	16.0	55.1	±	9.4

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