Development of maximal cardiorespiratory function in Saudi boys

A cross-sectional analysis

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ABSTRACT

Objectives: To provide normative data on maximal cardiorespiratory function for healthy Saudi boys between the ages of 7-15 years.

Methods: One hundred and thirty-seven Saudi boys from nearby schools in Riyadh, Kingdom of Saudi Arabia, participated in this study. Cardiorespiratory measurements were obtained during graded treadmill running until exhaustion. Gas exchange variables were assessed continuously throughout the test using open circuit spirometry.

Results: Normative values in the forms of means, standard deviation and percentiles were presented for 4 age groups. Mass-dependent cardiorespiratory variables were also classified based on body surface area. Absolute maximal oxygen uptake increased linearly from 1.2 ± 0.2 $L.min^{-1}$ at age 7-9 years to 2.5 ± 0.5 $L.min^{-1}$ at age 13-15 years. Maximal oxygen uptake relative to body mass ($ml.kg.^{-1}$ min^{-1}) or relative to lean body mass ($ml.kg.^{-1}$ lean body mass min^{-1}) did not show any appreciable changes across ages. Mass-dependent variables such as pulmonary ventilation ($L.min^{-1}$), tidal volume, and oxygen pulse (oxygen uptake/heart rate) also exhibited a linear increase with age, reflecting strong associations with body size indices (body mass, height and lean body mass). Maximal heart rate during childhood and adolescence appears to be independent of age. Ventilatory anaerobic threshold as a percentage of maximal oxygen uptake ranged from 66% for the younger to 77% for the older age groups.

Conclusions: Maximal oxygen uptake expressed relative to body surface area or scaled to body mass to the power of 0.75 or 0.67 appears to provide a more appropriate means of expressing changes in maximal oxygen uptake across ages in children and adolescents. Further, maximal pulse index (oxygen pulse/body surface area) seems to control for the strong association of oxygen pulse with the body size during growth.

Keywords: Stress testing, cardiorespiratory function, maximal oxygen uptake, children, adolescents, exercise.

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Pediatric stress (exercise) testing is an accepted mode of evaluating the functional capacity of children and adolescents with a wide range of cardiovascular, pulmonary, endocrine, metabolic, and musculoskeletal disorders.[1-4] The principle behind clinical exercise testing is simple and straight forward. When body systems are placed under physical stress, any functional deficiencies or abnormalities are very likely to be uncovered. Such abnormalities may not be evident in the resting state. Further, cardiopulmonary exercise testing offers a unique opportunity not only to diagnose specific pathophysiology involving the cardiovascular or ventilatory systems but also to quantify the severity of dysfunction.[5] Physicians are used to decision making on the basis of knowledge of normal

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measurements or responses. Description of cardiorespiratory responses in normal healthy subjects during maximal exercise would greatly aid in interpreting exercise data in patients who may suffer from any cardiopulmonary impairments.[5] Such normal values for cardiorespiratory responses of children and adolescents to maximal exercise testing were widely published in many countries.[6-14] However, despite its importance, comprehensive descriptions of cardiorespiratory capacity in Saudi children and adolescents are remarkably lacking. Previous local reports have only focused on such aspects as physical activity and fitness of Saudi children,[15,16] physical activity relative to coronary heart disease risk factors in Saudi children,[17,18] or training specificity of adolescent's cardiorespiratory system.[19] Therefore, it was the aim of this paper to present normative data on maximal cardiorespiratory function for a total of 137 healthy Saudi boys between the ages of 7-15 years.

Methods. ***Subjects.*** A total of 137 Saudi boys between the ages of 7-15 years participated in this study. They were drawn from nearby schools in the city of Riyadh, Kingdom of Saudi Arabia. The sample was considered heterogeneous, in terms of physical activity and body fatness. Informed consent was obtained from the parent of each boy.

Anthropometry and body composition. Body mass (kg) and height (cm) were measured using a Seca digital scale. Subscapular and tricep skinfolds were measured on the right side of the body using Harpenden caliper. Body fat percentage was then estimated using a regression equation developed for children and youths.[20]

Graded exercise testing. The exercise tests were conducted 2 hours after meals in a comfortable laboratory temperature, 22°C. The treadmill test began with a familiarization and warm-up period lasting 10-15 minutes. During the warm-up period the optimal running speed was also determined for each subject, which ranged from 7-12 km hour, depending on the persons age and ability to run comfortably. The test protocol consisted of running at a constant speed with the treadmill elevation being increased by 2% every 2 minutes until exhaustion. The boys were verbally encouraged to put forth maximal effort. A member of the testing staff was positioned close to each person throughout the test.

Cardiorespiratory measurements. Expired air was collected and analyzed using an automated open-circuit system with 30 second sampling intervals (EOS-Sprint, Jaeger, Germany). Tidal volume (VT) and minute ventilation (VE) were measured using a pneumotachometer. Oxygen and carbon dioxide were analyzed using paramagnetic and infrared analyzers. Gas analyzers were calibrated before each test with a known mixture of gases. Oxygen uptake was considered maximal when the respiratory exchange ratio (RER) exceeded 1.0, and heart rate level exceeded 90% of the maximal predicted heart rate. Heart rate was continuously monitored and recorded during the exercise test using a CM5 lead and a single-channel electrocardiogram (ECG) monitor and recorder (Helligi, Germany). In addition, ventilatory anaerobic threshold (VAT) was determined nonivasively through the gas exchange method.[21] Emphasis was placed on the linear increase in the ventilatory equivalent for oxygen (VE/VO_2) without an increase in ventilatory equivalent for CO_2 (VE/VCO_2).

Statistical analysis. Descriptive statistics using the SPSS-PC Program (Version 10, Chicago, USA) were obtained for all anthropometric and physiological variables, according to age category. Analysis of variance (ANOVA) with Scheffe post hoc test was performed to test difference in the subjects characteristics based on age groups. Partial correlation coefficient controlling for age was also used to test the relationships between anthropometric and cardiorespiratory variables for the whole group. In addition, allometric scaling procedures relating VO2max to body mass were applied and mass exponents of 0.75 and 0.67 were used.[22-24]

Results. Anthropometric characteristics of the subjects, classified into 4 age groups, are shown in Table 1. There were progressive increments in body mass, height, body surface area (BSA), body mass

Table 1 - Anthropometric characteristics of the subjects (mean ± standard deviation).

Variable	Age (years)			
	7-9	>9-11	>11-13	13-15
Number of subjects	23	40	37	37
Age (yr)	8.1 ±0.52	10.4[a] ±0.37	11.8[b] ±0.58	14.2[c] ±0.77
Body mass (kg)	25.0 ±5.0	31.7[a] ±7.0	36.9[b] ±8.4	49.2[c] ±10.7
Body height (cm)	125.7 ±6.8	135.9[a] ±6.3	142.9[b] ±6.8	157.6[c] ±9.8
Body mass index ($kg.m^{-1}$)	15.7 ±2.3	17.1 ±2.9	18.0[a] ±3.3	19.6[b] ±3.1
Body surface area (m^2)	0.94 ±0.11	1.09[a] ±0.13	1.21[b] ±0.14	1.47[c] ±0.18
Body fat content (%)	14.2 ±5.0	17.3 ±7.4	18.8 ±8.9	16.2 ±9.1
Lean body mass (kg)	21.3 ±3.4	25.8[a] ±3.5	29.4[b] ±4.3	40.7[c] ±7.1

a=significantly different from age 7-9 years, b=significantly different from age 7-9 years and 9-11 years, c=significantly different from age 7-9 years, 9-11 years and 11-13 years. Level of significance is 0.05 or less.

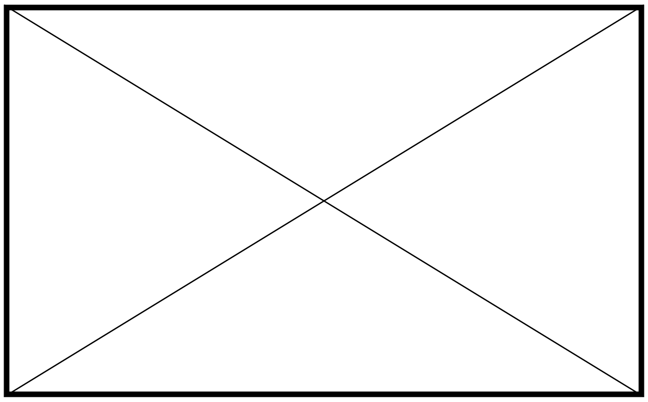

Figure 1 - Absolute maximal oxygen uptake (L/min) relative to body surface area (L/m^2. min) in Saudi children and adolescents. Data is mean ± standard deviation (a=significant differences from age 7-9 years, b=significant differences from age 7-9 years and 9-11 years. c=significant differences from age 7-9, 9-11 and 11-13, $p<0.05$).

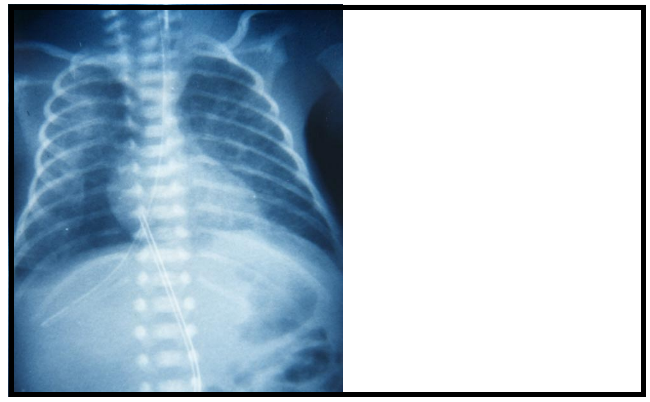

Figure 2 - Maximal oxygen uptake relative to body mass (ml/kg.min) and relative to lean body mass (ml/kg.lean body mass.min) in Saudi children and adolescents. Data is means ± standard deviation (for multiple comparison symbols see Figure 1)

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index (BMI) and lean body mass (LBM) from younger to older boys. However, there was no significant difference among groups in body fat percent. For the groups as a whole, roughly 17% of the boys were considered obese (body fat percent is above 25% of body mass). The subjects physical characteristics including body composition are not different from those values previously published for a representative group of Saudi boys living in Riyadh.[25] Results of maximal cardiorespiratory function are presented in Table 2 and Figures 1-4. As shown in Figure 1, absolute maximal oxygen uptake (VO_2max L.min^{-1}) and relative to BSA (L.$m.^{-2}$ min^{-1}) showed an almost linear increase with age. Absolute VO_2max (L.min^{-1}) was doubled at age 13-15 years compared to age 7-9 years. Such magnitude of increase is parallel to the increments in body mass and LBM during the same period. When VO_2max was expressed relative to body mass or to LBM as shown in Figure 2, no significant differences ($p< 0.05$) were seen between 7 and 15 year old boys. However, relating VO_2max to body mass raised to the power of 0.75 or to the power of 0.67, as illustrated in Figure 3, showed an essentially linear increase, with the older boys being significantly different ($p<0.05$) from the younger boys. Figure 4 presents values of maximal oxygen pulse (VO_2max (ml.min^{-1})/ maximal heart rate) and maximal oxygen pulse index (O_2 PI = O_2 pulse/BSA). Oxygen pulse showed linear increments with growth reflecting the increases in absolute VO_2max across age groups (since no

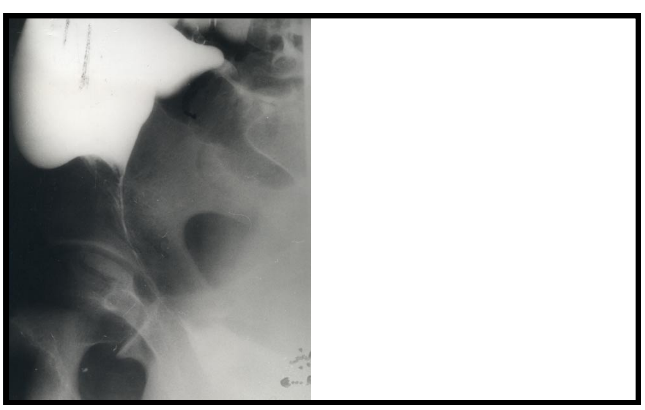

Figure 3 - Maximal oxygen uptake relative to body mass raised to the power of 0.75 (ml/kg. $^{0.75}$ min) and to power of 0.67 (ml/kg. $^{0.67}$ min) in Saudi children and adolescents. Data is mean ± standard deviation. (for multiple comparison symbols see Figure 1).

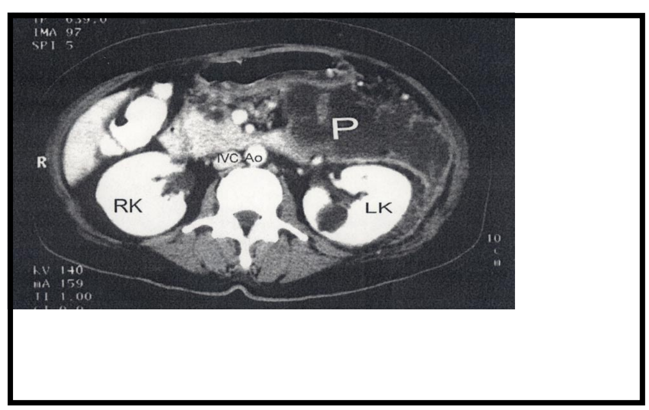

Figure 4 - Maximal oxygen pulse (O_2 pulse) and maximal oxygen pulse index (O_2PI) in saudi children and adolescents. Data is mean ± standard deviation (for multiple comparison symbols see Figure 1).

Table 2 - Maximal cardiorespiratory function in Saudi boys (mean ± standard deviation),

Variable	Age (years)			
	7-9	>9-11	>11-13	13-15
V_E (L.min^{-1})	42.6 ±7.7	53.9[a] ±10.2	63.9[b] ±10.1	89.9[c] ±19.8
V_T(L)	0.63 ±0.13	0.83[a] ±0.19	0.96[a] ±0.18	1.48[c] ±0.34
fb (min)	69.1 ±13.2	66.5 ±11.6	68.2 ±12.8	61.8 ±10.0
MET	13.7 ±1.7	14.1 ±1.9	14.2 ±1.8	14.6 ±1.9
RER	1.11 ±0.08	1.14 ±0.10	1.15 ±0.10	1.12 ±0.11
HR (b.min^{-1})	193.4 ±7.7	199.0 ±6.9	198.2 ±7.1	198.5 ±6.7
VAT ml.kg^{-1} min^{-1}	31.4 ±3.7	32.0 ±5.2	34.4 ±6.2	38.8[c] ±7.3
VAT (% of VO_2max)	66.4 ±5.2	65.5 ±5.5	69.0 ±7.4	76.8[c] ±4.8
HR at VAT (b.min^{-1})	151.8 ±8.0	152.9 ±8.8	159.4 ±12.5	169.2[c] ±11.7
VE max/VO_2 max	35.7 ±4.1	35.4 ±3.9	35.6 ±2.8	36.3 ±4.2

VE=pulmonary ventilation, VT=tidal volume, fb=breathing frequency, MET=metabolic equivalent (multiple of resting VO_2), RER=respiratory exchange ratio, HR=heart rate, VAT=ventilatory anaerobic threshold, VO_2 max=maximal oxygen uptake, a=significantly different from age 7-9 years, b=significantly different from age 7-9 years and 9-11 years, c-significantly different from age 7-9, 9-11 and 11-13 years. Level of significance is 0.05 or less

Table 3 - Mean (standard deviation) and selected percentiles for mass-independent maximal cardiorespiratory function in Saudi boys to 7-15 year old (n=137).

Variable	Percentiles					
	Mean (SD)	10	25	50	75	90
VO_2max (ml.kg.$^{-1}$min^{-1})	49.6 (6.6)	40.7	44.6	49.9	54.4	58.0
VO_2max (ml.kg.$^{-0.75}$min^{-1})	120.8 (16.9)	99.0	107.8	120.0	132.3	144.0
VO_2max ml.kg$^{-0.67}$min^{-1}	160.8 (24.3)	129.4	143.0	159.2	176.3	194.7
VO_2max ml.kg.LBM^{-1}min^{-1}	59.9 (6.4)	50.7	55.1	60.4	64.5	67.9
Heart rate (b.min^{-1})	197.7 (7.3)	188.8	192.0	198.0	203.0	207.9
O_2 pulse index (ml.b.$^{-1}$min.$^{-1}$cm^{-2})	7.5 (1.1)	6.1	6.7	7.3	8.1	8.9
VAT (ml.kg.$^{-1}$min^{-1})	34.4 (6.6)	26.4	29.5	34.4	38.8	44.0

VO_2 max=maximal oxygen uptake,VAT=ventilatory anaerobic threshold, O_2=oxygen, SD=standard deviation

Table 4 - Mean (standard deviation) for some maximal cardiorespiratory function, grouped by body surface area, in Saudi boys 7 to 15 years. (n=137).

Variable	Body surface area (cm^2)			
	<100 (n=26)	1.00-1.19 (n=46)	1.20-1.40 (n=36)	>140 (n=29)
VO_2max (L.min^{-1})	1.19 (0.18)	1.49 (0.22)	1.97 (0.22)	2.63 (0.48)
O_2 pulse (ml.b.$^{-1}$min^{-1})	6.09 (0.79)	7.58 (1.09)	9.96 (1.16)	13.30 (2.50)
$V_E$max (L.min^{-1})	43.4 (7.6)	53.4 (9.3)	68.6 (9.4)	95.6 (17.3)
V_T(L)	0.62 (0.13)	0.83 (0.17)	1.07 (0.19)	1.58 (0.34)

VO_2max=maximal oxygen uptake, O_2=oxygen, V_E=pulmonary ventilation, V_T=tidal volume, n=number

changes were seen in maximal heart rate (HR max) with age). However, O_2 PI is less dependent on body size. The differences between the younger and the older boys remained significant ($p<0.05$) after the effect of body size was removed from O_2 pulse (O_2 pulse/BSA).

Maximal ventilatory and cardiac responses of the Saudi boys to treadmill exercise testing are shown in Table 2. Maximal values for pulmonary ventilation (VE max) and tidal volume (VT) increased by more than 2 folds from ages 7 to 15 years, reflecting their association with body size. No significant differences ($p<0.05$) were seen in maximal breathing frequency (fb) across age, although there was a tendency toward a reduction in fb at the older age group. Maximal HR ranged from 193.4 to 199 beat min^{-1}. The respiratory exchange ratio, the ratio of CO_2 produced to O_2 consumed, rose to above 1.10 with no significant ($p<0.05$) differences between age groups. This reflect an increase in CO_2 production from buffering of lactate as well as changes in substrate utilization.[5,26] Ventilatory anaerobic threshold (VAT)

Table 5 - Partial correlation coefficients between some anthropometric and cardiorespiratory variables while controlling for age in Saudi boys (n=137).

Variable	Body mass	Height	BSA	FAT%	BMI	LBM
VO_2max ($L.min^{-1}$)	0.76**	0.61**	0.78**	0.29**	0.57**	0.84**
VO_2max ($L.m^{-2}min^{-1}$)	0.21*	0.15	0.21*	-0.07	0.15	0.19*
VO_2max ($ml.kg.^{-1}min^{-1}$)	-0.54**	-0.21**	-0.49**	-0.65**	- 0.59**	-0.26**
VO_2max ($ml.kg.LBM.^{-1}.min^{-1}$)	0.05	-0.15	-0.02	0.19*	0.14	0.09
VO_2max ($ml.kg.^{-0.75}min^{-1}$)	-0.19*	0.07	-0.12	-0.46**	-0.30**	0.09
VO_2max ($ml.kg.^{-0.67}min^{-1}$)	-0.05	0.17	0.02	-0.36**	-0.18*	0.23**
O_2 Pulse	0.77**	0.63**	0.79**	0.29**	0.57**	0.86**
VAT ($ml.kg.^{-1}min^{-1}$)	-0.52**	-0.17	-0.46**	-0.62**	-0.57**	-0.26**
VAT (% VO_2max)	-0.16	-0.01	-0.13	-0.29**	-0.23**	-0.02
V_Emax (L.min)	0.62**	0.58**	0.66**	0.15	0.40	0.74
V_T(L)	0.57**	0.64**	0.64	0.04	0.31**	0.77**

VO_2max=maximal oxygen uptake O_2=oxygen, VAT=ventilatory anaerobic threshold, V_E=pulmonary ventilation, V_T=tidal volume
BSA= body surface area, BMI=body mass index, LBM=lean body mass, *=P<0.05 (2 tailed), **=P<0.01 (2 tailed)

as expressed relative to body mass ($ml.kg.^{-1}min^{-1}$) or as % of VO^2max showed no significant ($p<0.05$) changes between the age of 7 to 13 years. But at age group 13-15 years VAT was significantly ($p<0.05$) higher than in the other age groups. Maximal ventilatory efficiency, as reflected by the ratio of VE max to VO_2max, did not exhibit any significant ($p< 0.05$) changes across age groups. Table 3 presents mean values and selected percentiles for weight – independent maximal cardiorespiratory function. These are useful for comparison purposes, especially when testing pediatric patients with subnormal cardiorespiratory responses. Table 4, on the other hand, shows selected maximal cardiorespiratory function, which are basically size-dependent. Subjects are therefore, classified into 4 groups according to body surface area. Such data also represents useful normative values for healthy Saudi boys. Partial correlation coefficients between some anthropometric and cardiorespiratory variables, while controlling for the effect of age, is presented in Table 5. Indices of body size (body mass, height, BSA and LBM) correlated strongly with absolute cardiorespiratory measures (VO_2max, O_2 pulse, VE max and VT), with LBM having had the highest correlation among all of them. Maximal oxygen uptake relative to body mass ($ml.kg.^{-1}min^{-1}$) had a significantly ($p< 0.01$) negative correlation with body fat percent ($r = -0.65$) and BMI ($r = -0.59$). Further, VAT relative to body mass correlated strongly ($r = 0.75$; $p< 0.01$) with VO_2max ($ml.kg.^{-1}min^{-1}$).

Discussion. The present study is the first to report a comprehensive maximal cardiorespiratory data for Saudi children and adolescents between the age of 7 and 15 years. Such normative data considered useful in interpreting exercise responses in pediatric or adolescent patients, who may suffer from any cardiopulmonary limitation. The increase in absolute VO_2max with age seen in our sample is in agreement with both cross-sectional and longitudinal studies reported elsewhere.[6-9, 12-14, 27-31] Mean VO_2max values relative to body mass ($ml.kg.^{-1}min^{-1}$) of Saudi boys in the present study appears to be similar to those values reported worldwide for comparable age group.[8,14,27,30] However the Saudi VO^2max data was somewhat lower than those reported by other investigators.[12,13,29] Maximal oxygen uptake relative to body mass, is widely regarded as the traditional laboratory measure of aerobic fitness.[1,26,29] It depends upon components of O_2 delivery and utilization by the body. This involves the pulmonary, cardiovascular, hematological, and oxidative metabolism of the exercising child or adolescent. From a functional standpoint, VO_2max reflects performance capabilities in endurance events that are dependent on aerobic energy metabolism.[26]

Due to the confounding effect of body size differences, interpretations of the physiological changes relative to normal growth and development are not always without difficulties. Studies of respiratory responses to exercise have generally relied on measures relative to body mass (the ratio standard). This was presumably to remove the confounding effect of body size, when comparing individuals of different sizes. However, this approach does not seem to be totally body-size independent. Maximal oxygen uptake, for example, does not increase in direct proportion to the increase in body mass.[23,24,32] In the present study, VO_2max relative to body mass remained almost unchanged with advancing age. However, scaling VO_2max data to body mass raised to the power of 0.75 or 0.67 resulted in different VO_2max values relative to age. Welsman et al,[32] using the conventional ratio standard for VO_2max found no differences between prepubertal boys, circumpubertal boys and adult males. However, when their data were analyzed by allometric scaling, there were significant increases in VO_2 max from preadolescence to adulthood.

Oxygen pulse is the quantity of O_2 that is absorbed during one cardiac cycle.[14] The O_2 pulse is equal to the product of stroke volume (SV) and arterial-mixed venous O_2 difference (since VO_2 = SV x HR x C (a-v) O_2, then VO_2/HR = SV x C (a-v) O_2). Oxygen pulse in adults is considered an index of aerobic fitness.[5,29] In addition, patients with heart disease, anemia, high levels of carboxyhemoglobin, or have severe arterial hypoxemia tend to have low maximal O2 pulse.[5] In children and adolescents, maximal O2 pulse correlates strongly with body size.[14] In the present investigation, O_2 pulse correlated strongly with body mass ($r = 0.77$; $p < 0.01$) and BSA ($r = 0.79$; $p < 0.01$). To overcome the association of O_2 pulse with body size, O_2 pulse index is calculated (O_2 pulse/BSA). Maximal O_2 pulse index in the present study increased with increasing age especially at age group 13-15 years. This may likely reflect an increased maximal stroke volume in the growing adolescents. Using Doppler echocardiography as well as standard gas exchange variables, Rowland et al[33] studied the determinants of VO_2max in healthy 12-year-old boys and concluded that maximal stroke volume appears to be the critical factor that separates aerobically fit from unfit. Factors relating to hemoglobin concentration may be responsible for the changes in VO_2 max with growth. Blood hemoglobin concentrations in Saudi boys during childhood and adolescence were shown to increase from a value of 124 g. l^{-1} at ages 5-9 to a value of 137 g. l^{-1} at ages 12-15 years.[34] Maximal heart rate in the present study did not show a major differences across age. Contrary to middle and older years, maximal heart rate during childhood and adolescence appears to be independent of age.[35]

Maximal pulmonary ventilation and tidal volume were highly related to body mass and stature as shown in Table 5. Minute ventilation does not seem to limit VO_2max in healthy children and adolescents.[26] However, in respiratory patients pulmonary ventilation becomes less efficient.[5] Values of VAT in the present study were higher in the older boys compared to the younger ones. This may reflect higher fitness level at this age stage. It is known that at this age, adolescents are apt to engage in more organized sport activities, and therefore more level of training are expected. In trained adults, VAT is more closely related to running performance than VO_2max.[36]

In conclusion, this study presented normative data for maximal cardiorespiratory function in Saudi children and adolescents. Maximal oxygen uptake, a measure of aerobic performance, increased almost linearly over the age range 7 to 15 years when expressed in absolute amount (L.min^{-1}) or relative to BSA. However expressing VO_2 max data relative to body mass or relative to LBM did not show any appreciable change across age groups. Scaling VO_2 max to body mass exponents of 0.75 or 0.67 appeared to differentiate between the older and younger boys. Further, many of the mass-dependent variables such as VE, VT, and O_2 pulse exhibited a linear increase with age, reflecting their associations with body size. Maximal heart rate during childhood and adolescence seems to be independent of age. Finally, VAT did not show any significant differences among ages 7 to 13 years. However, boys at age 13-15 years had significantly higher VAT than the younger age group, which is likely an indication of higher level of aerobic fitness.

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