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Prediction of Maximal Oxygen Uptake by Six-Minute Walk Test and Body Mass Index in Healthy Boys

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Objective To develop an equation to predict maximal oxygen uptake (VO2max) based on the 6-minute walk test (6MWT) and body composition in healthy boys.

Study design Direct VO2max, 6-minute walk distance, and anthropometric characteristics were measured in 349 healthy boys (12.49 ± 2.72 years). Multiple regression analysis was used to generate VO2max prediction equations. Cross-validation of the VO2max prediction equations was assessed with predicted residual sum of squares statistics. Pearson correlation was used to assess the correlation between measured and predicted VO2max.

Results Objectively measured VO2max had a significant correlation with demographic and 6MWT characteristics (R = 0.11-0.723, $P < .01$). Multiple regression analysis revealed the following VO2max prediction equation: VO2max (mL/kg/min) = 12.701 + (0.06 × 6-minute walk distance $_{m}$) – (0.732 × body mass index$_{kg/m2}$) ($R^2 = 0.79$, standard error of the estimate [SEE] = 2.91 mL/kg/min, %SEE = 6.9%). There was strong correlation between measured and predicted VO2max (r = 0.875, $P < .001$). Cross-validation revealed minimal shrinkage ($R^2p = 0.78$ and predicted residual sum of squares SEE = 2.99 mL/kg/min).

Conclusions This study provides a relatively accurate and convenient VO2max prediction equation based on the 6MWT and body mass index in healthy boys. This model can be used for evaluation of cardiorespiratory fitness of boys in different settings. *(J Pediatr 2018;■■:■■-■■).*

Cardiorespiratory fitness is an important health indicator that is measured in research, exercise, and health-related settings.[1,2] Maximal oxygen uptake (VO2max), which is measured during a maximal graded exercise test (GXT), is considered the best method for measuring cardiorespiratory fitness.[3] Nevertheless, direct measurement of VO2max is restricted by expensive and sophisticated equipment, qualified examiners, and long duration of testing sessions. Because the use of this method is difficult in many settings,[4] submaximal field exercise tests are useful alternatives to direct measurement of the VO2max.[2,3]

Submaximal field exercise tests provide a feasible, safe, easy-to-administer, and inexpensive technique for the prediction of VO2max.[3] Among field walking tests, the 6-minute walk test (6MWT) is used because of its ease of administration.[5] The 6MWT measures the maximal distance that a person can walk in 6 minutes (6-minute walk distance, ie, 6MWD).[4] There has been a substantial body of literature published about the validity and reproducibility of the 6MWT in healthy children and adolescents.[5-12]

Correlation between objectively measured VO2max and 6MWD in healthy children and adolescents was reported in a previous study (R = 0.44),[6] but no prediction of VO2max based on the 6MWT has been reported. Only 1 study has developed a VO2max prediction equation by the 6MWT in obese children and adolescents so that their VO2max could be estimated by the 6MWD and body mass index (BMI).[13] Some studies have reported the applicability of the 6MWT in prediction of VO2max in health and illness conditions.[14-18]

Furthermore, the 6MWT[17] and 3-minute walk test,[18] combined with demographic variables, provide a reasonable estimation of the VO2max in healthy adults ($R^2 = 0.60\text{-}0.72$). Therefore, we aimed to develop and cross-validate a new VO2max prediction equation based on the 6MWT and anthropometry indices in healthy boys.

Methods

In this cross-sectional study, 349 healthy boys aged from 8 to 17 years were recruited from schools. None of the participants had a background of cardiovascular,

6MWD	6-minute walk distance
6MWT	6-minute walk test
BMI	Body mass index
GXT	Graded exercise test
HR	Heart rate
SEE	Standard error of the estimate
VO2max	Maximal oxygen uptake

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respiratory, neuromuscular, or metabolic abnormalities, and they were not taking medications that could affect the study variables. They also did not participate in any regular sports or training. The research project was approved by the ethical committee of Medical Science University of Hamadan (UMSHA.REC.1394.116) and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Written consents were obtained from the parents of the boys.

Body mass (0.1 kg) and height (0.1 cm) were measured with a stadiometer (Digital Free-Standing Stadiometer BSM170; Inbody, Seoul, Korea). BMI was calculated by dividing the body mass in kilograms by the square of height in meters ($kg.m^{-2}$). Due to ethical considerations, we assessed the maturity of the boys by an equation that is a noninvasive, practical method predicting years from peak height velocity (a maturity offset value) by using anthropometric variables.[19] Physical activity was measured by a pedometer (Digi-Walker SW200; Yamax, Queensland, Australia).[20] The accuracy of the Yamax pedometer has been confirmed.[21] The boys were taught how to use the pedometer and were told to wear it on their belt or waistband at the right midline of the thigh from the moment they got up until they went to bed, except while bathing or swimming, for 7 consecutive days.

VO2max was measured with a maximal GXT according to the modified Bruce protocol[3] with a treadmill (Saturn 300/125; h/p/cosmos, Nussdorf-Traunstein, Germany) in the exercise physiology laboratory at 19-21°C, relative humidity 39-43% at 1860 m above sea level. Breath-by-breath gas samples were collected via a facemask (Hans Rudolph, Kansas City, Missouri) and were analyzed throughout the test by open-circuit calorimetry via ergospirometry (PowerCube; Ganshorn Medizin Electronic GmbH, Niederlauer, Germany). Heart rate (HR) was monitored during the GXT by telemetry (Heart Rate Transmitter Model T34; Kempele, Finland). The boys were asked to avoid heavy physical activities 24 hours before the GXT. VO2max was calculated as the greatest mean breath-by-breath VO2 during 20 consecutive seconds. To confirm that boys attained their VO2max, at least 2 of the 3 following criteria were met: (1) respiratory exchange ratio >1.10, (2) maximal HR was no less than 90% of the age-predicted maximal HR ($208 - 0.7 \times$ ages),[22] and (3) the subject was exhausted and unable to continue despite verbal encouragement.[23]

The 6MWT was administered using a 30-m long course in a corridor of selected schools according to the guidelines of the American Thoracic Society.[24] All participants were instructed to walk back and forth in a straight line as fast as possible with self-paced over a 6-minute period of time. During the 6MWT, subjects were given standardized phrases and informed of the time elapsed every 1 minute. HR was measured during the 6MWT by telemetry (Heart Rate Transmitter Model T34; Polar). At the end of the 6MWT, the total distance covered over 6 minutes was recorded as 6MWD. To confirm the reproducibility of the 6MWT, 80 boys randomly were asked to repeat the 6MWT with an interval of 1 week.

Statistical Analyses

Reproducibility of the 6MWT was assessed by determination of the intraclass correlation coefficient. Pearson product correlations were calculated between objectively measured VO2max and independent variables (age, height, weight, BMI, rest HR, and 6MWD). Multiple linear regression was used to create a VO2max regression equation using independent variables as predictor variables. Suitability and precision of the regression equations were evaluated via multiple coefficient of determination (R^2), the absolute standard error of estimate (SEE), and partial SEE (SEE%). Predicted residual sum of squares statistics[25] also were computed to estimate the degree of shrinkage one could expect when the VO2max prediction equation is used across similar, but independent, samples. Pearson correlation was used to assess correlation between measured and predicted VO2max.

We used the rule of 20 events per variable (≥20) to determine acceptable sample size.[26] Based on the literature, 5 independent variables that are easily obtained (ie, age, weight, height, BMI, and HR) were related to VO2max.[7,27-29] Therefore, the minimal sample size was 100 subjects to eliminate bias in regression coefficients. To eliminate bias in regression coefficients and improve the accuracy of the prediction models, a greater number of subjects was included (n = 349). Collinearity of the VO2max estimation models was controlled by the Durbin–Watson statistic, variance inflation factor, and tolerance indices.[30] Correlation coefficients (R) of 0.70 were considered high, between 0.50-0.70 good, between 0.30-0.50 fair, and 0.30 weak or no association.[31] All analyses were performed with SPSS software, version 24 (IBM Corp, Armonk, New York), and alpha level was set at $P < .05$.

Results

Demographic data, physical activity, characteristics of the 6MWT, and treadmill test of the subjects are shown in Table I.

Table I. Characteristic of participants and correlation of VO2max with independent variables (n = 349)

Variables	Mean ± SD	R
Age, y	12.33 ± 2.75	0.110*
Height, cm	153.75 ± 15.78	0.018
Weight, kg	47.71 ± 17.60	–0.367†
BMI, kg/m^2	19.55 ± 4.23	–0.624†
Physical activity, steps/d	13 886 ± 3583	0.672†
RHR, bpm	82.69 ± 9.66	–0.326†
Treadmill test		
VO2max, mL/kg/min	41.24 ± 6.00	—
RER	1.21 ± .007	—
HRmax, bpm	201.9 ± 48.7	—
%HRmax	%101.3	—
6MWT		
6MWD, m	716 ± 60	0.723†
6MWT HR, bpm	169 ± 12	–0.127*

%HRmax, percent of the theoretical maximal predicted heart rate; *6MWT HR*, heart rate at end of the 6MWT; *HRmax*, measured maximal heart rate; *R*, correlation coefficient; *RER*, respiratory exchange ratio; *RHR*, resting heart rate.
*$P < .05$.
†$P < .001$.

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