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Estimation of peak oxygen pulse from body mass, resting heart rate, age, gender and systolic blood pressure in Chinese adults aged 20-39

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ABSTRACT

Background: Peak oxygen pulse (O_2P_{peak}) can reflect the condition of cardiovascular function and provide supplementary information for maximal oxygen uptake, but its direct measurement requires the precise instruments under the guidance of professionals, and the subjects should strive to the state of exhaustion.
Objectives: The aim of the present cross-sectional study was to establish a prediction equation to estimate O_2P_{peak} of Chinese adults aged 20–39, from routine measures of anthropometry and cardiovascular function.
Methods: 252 adults (20–39 years old) were recruited and randomly allocated to the validation group (n = 226) and the cross-validation group (n = 26). To be included in the study, subjects were required to be healthy, none-professional sports experience (healthy individuals who are not athletes or have had experience as athletes), and no medication taken recently. Subjects with cardiovascular diseases, lung disease and musculoskeletal diseases were excluded. The subjects' anthropometric and cardiovascular variables were measured and each subject performed a maximal exercise test on an electromagnetic cycle ergometer.
Results: The O_2P_{peak} estimated equation was developed using multiple linear regression models, O_2P_{peak} = 30.394 + 0.083 x body mass (kg) - 0.090 x resting heart rate (bpm) - 0.157 x age (years) - 2.710 x gender (1 = male, 2 = female) - 0.035 x systolic blood pressure (mmHg). The equation had the coefficient of determination (R^2) = 0.804 and the standard error of estimate (SEE) = 1.619 ml/beat. An ANOVA and Akaike's information criterion (AIC) were tested. Bland-Altman graphs were plotted to examine the distribution of bias. Cross-validation estimated O_2P_{peak} and directly measured O_2P_{peak} did not show significant difference while had a strong positive correlation (r = 0.89, $p < 0.001$).
Conclusions: The established equation has high effectiveness and reliability to predict O_2P_{peak} of adults aged 20–39.

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1. Introduction

Cardiovascular function is very important to human health, decreased function will lead to increased incidence of cardiovascular diseases [1–4]. Among the many variables of cardiovascular function measured in the cardiopulmonary exercise test (CPX), the peak oxygen pulse (O_2P_{peak}) is the ratio of maximal oxygen uptake (VO_2max) and peak heartrates (HR_{peak}). It has the physiological significance that the amount of oxygen that the body is able to take in with one heartbeat (also called the oxygen uptake per beat) [5].

The O_2P_{peak} reflects the left ventricular stroke volume [3,6], shown to be an independent predictor of all-cause mortality in healthy subjects and, as well in patients with cardiovascular diseases [3]. It has been employed to evaluate cardiovascular function [1,4]. The American Heart Association Scientific Statement on the Clinician's Guide to Cardiopulmonary Exercise Testing in Adults includes O_2P_{peak} as one of the important measures obtained from CPX [7]. In additional, O_2P_{peak} is closely related to the functional status of the heart, blood vessels, and lungs [8], reflecting the overall efficiency of the cardiovascular and respiratory systems [8–11].

Previous studies have reported that O_2P_{peak} is significantly lower in people with poor cardiovascular function [6,9,12]. The results of a 26-year follow-up study of 2227 middle-aged men showed that O_2P_{peak} was negatively correlated with cardiovascular diseases and all-cause mortality [13]. Another study found that individuals with higher O_2P_{peak} in youth can still maintain higher O_2P_{peak} levels in old age, while young people with lower O_2P_{peak} also have relatively lower cardiovascular function in old age and will be accompanied by an increase in the risk of cardiovascular diseases [2,5,14]. Therefore, the additional information of O_2P_{peak} would significantly improve the accuracy of risk assessment of cardiovascular diseases [1].

Although O_2P_{peak} has important application significance in the evaluation of cardiovascular function [1–4,6], its direct measurement requires special equipment (e.g., electromagnetic cycle ergometer, facemask, metabolic analyzer) with an incremental loading exercise protocol, so, the testing process is not convenient for cardiovascular function evaluation and cardiovascular diseases epidemiology investigation [1,6]. Therefore, researchers have tried the indirect method to predict the O_2P_{peak}, for example, O_2P_{peak} prediction equation for Brazil older people has been established and can estimate O_2P_{peak} from the data of body mass, Veterans Specific Activity Questionnaire (VSAQ) (metabolic equivalents, METs), gender, β-Blocker's use, and resting heart rate [4,15]. However, due to the differences in body size and race, it is necessary to establish the specific evaluation method of O_2P_{peak} according to the domestic population. With the purpose of developing a simple and accurate measurement of O_2P_{peak}, in the present study, we selected the morphological and functional indicators which are significantly related to O_2P_{peak}, and established and evaluated a O_2P_{peak} estimation equation for Chinese adults aged 20–39.

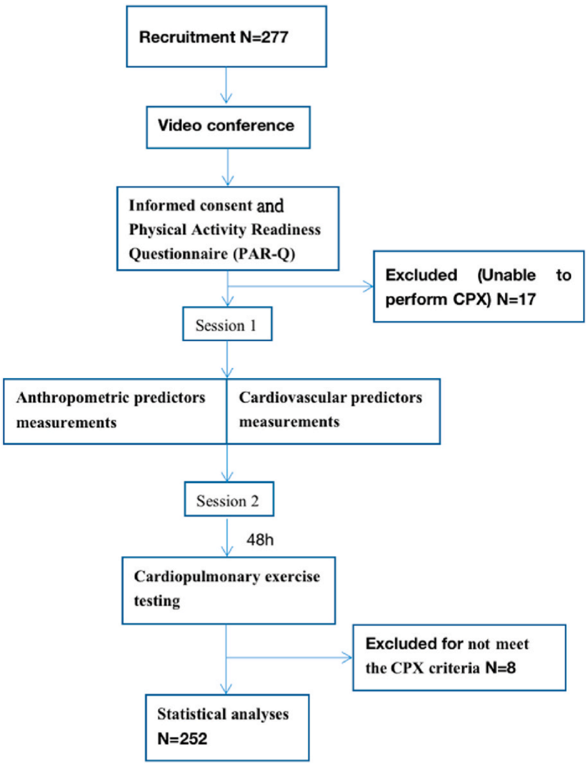

Fig. 1. Flowchart for recruitment in the study.

2. Materials and methods

2.1. Study design

The present cross-sectional observational study assessed the relationship between O_2P_{peak} with anthropometric predictors and cardiovascular predictors to build a simple method to measure O_2P_{peak}. We established the recruitment points in six communities in Tianjin and randomly recruited eligible subjects. The study was performed in line with the STROBE guidelines for observational studies [16].

2.2. Subjects

The subjects (125 male and 127 female) were recruited and admitted to the Exercise Physiology Laboratory of Tianjin University of Sport between September 2020 and October 2021 (Fig. 1). A priori sample size calculation was performed on G-power software 3.1.9.2 [17] for linear multiple regression (α level = 0.05 and number of predictors = 5), with the result showing that 65 participants were required in order to achieve a sample size power of 95 %. The ethics approval of the project was granted by the Ethical Committee of Tianjin University of Sport with the ID: TJUS2020-009. To be included in the study, subjects were required to be healthy, none-professional sports experience (healthy individuals who are not athletes or have had experience as athletes), and no medication taken recently; subjects with cardiovascular diseases, lung disease and musculoskeletal diseases were excluded. High-intensity exercise [18] and drink alcoholic and caffeine drinks were avoided within 48 h before the measurement.

Before the test, subjects attended a video conference to familiarize with testing projects and processes, and inform of testing standards and precautions [19]. Assessments were performed in two sessions, and the span between the two tests was 24 h, anthropometric and cardiovascular function measurements were in the first day morning at 8:00 a.m. and required subjects to have an empty stomach; then the CPX was in the second day morning at 8:00 a.m. All the measurements were completed by professionally trained personnels.

The subjects underwent electrocardiogram (ECG) examination and completed the Physical Activity Readiness Questionnaire (PAR-Q) [20], which was used to determine whether they appropriate for a maximal CPX. In addition, all exercise tests terminated early for clinical reasons were not considered maximal and were excluded from the study.

All subjects completed anthropometric measurements and CPX were considered eligible for the analysis, 17 subjects were excluded because they were unable to perform maximal CPX and eight subjects were excluded for did not meet the CPX criteria. The sample was randomly assigned into two groups [15]: the validation group (to establish the equation, n = 226, male = 112, female = 114) and the cross-validation group (to verify the equation, n = 26, male = 13, female = 13). All subjects provided their written informed consent prior to study enrollment.

2.3. Anthropometric predictors

Anthropometric measurements included height, body mass and BMI (body mass/height^2), the subjects wore lightweight clothing and stood barefoot on the instrument，by using a digital height and weight measurement equipment (Omron inc., model HNH-219, Dalian, China). Waist circumference (WC) and hip circumference (HC) were measured, the subject stood naturally, held their chest with both hands, wrapped the tape of the instrument around their abdomen, measured WC at 1 cm above the navel and HC at the widest part of the buttock. and then the waist-to-hip ratio (WHR) was calculated (Beijing Xindong Huateng Sports Facilities Company Ltd., model CMCS-3, Beijing, China).

2.4. Cardiovascular predictors

After breakfast of 30 min, cardiovascular function included resting heart beats (HR), systolic blood pressure (SBP) and diastolic blood pressure (DBP) were tested using a digital blood pressure measurement equipment (Maibobo® Inc., model BRP-9000c, Shenzhen, China). This measurement required subjects to sit in a chair, rested for 5 min, and then placed their right arm into the instrument. Lung function was measured by vital capacity (Beijing Xindong Huateng Sports Facilities Company Ltd., model CMCS-3, Beijing, China), the subjects inhaled as much as possible, then picked up the lung capacity instrument and slowly exhaled through the mouthpiece until the end. Each subject did the test two times and the better result was recorded.

2.5. Cardiopulmonary exercise testing

Temperature control at 20–22 °C, relative humidity of 40 %–50 %, all subjects performed a clinically supervised maximal exercise testing on an electromagnetic cycle ergometer (Cosmed Inc., model ergoselect 100, Roma, Italy) using the ramp protocol. Subjects underwent a 3-min familiarization trial to get accustomed to the procedures prior to the exercise test. Then subjects to ride ergometer with a facemask and the ECG set. The lord began with 25 W and increased 25 W every 2 min for both male and female until exhausted. Finally, there was a 2-min cool-down stage without load while the ramp was kept at 55–65 r/min. Rating of perceived exertion (RPE; 15-points) [21] was checked every 2 min during the CPX.

Gas exchange data were acquired every 15 s by the metabolic analyzer (Cortex Inc., model Meta Max 3B, London, UK). VO_2 max was defined as the highest value obtained within 15-s intervals during the test. HR was measured at rest in a sitting position and continuously during CPX by wireless HR beat (Polar inc., model H7, Oulu, Finland). ECG (Cosmed Inc., model Quark T12x, Roma, Italy) was continuously monitored by the 12-channel ECG stress test unit. Peak HR was also recorded as the highest value obtained using 15-s intervals during CPX. O_2P_{peak} was calculated by dividing VO_2 max by HR_{peak} and expressed in milliliters per beat. It is noteworthy to report that for all subjects VO_2 max and HR_{peak} were achieved at the same 15-s interval.

Subjects were verbally encouraged to exercise to volitional fatigue. Standard clinical criteria were used to terminate the test. These included moderate to severe angina, abnormal ST depression (>2.0 mm horizontal) or serious rhythm disturbances. The CPX was considered as maximal if the subjects satisfied at least three of four criteria [22]: (a) VO_2 not increased with load and presence of VO_2 plateau (a leveling off of $VO_2 < 2$ mL/kg/mins); (b) reach to age-predicted maximal HR (220 - age); (c) maximal respiratory exchange ratio (RER) > 1.10; and (d) subjects voluntary exhaustion and RPE 19 or 20 on Borg's 15-point RPE scale.

2.6. Statistical analyses

To ensure homogeneity between the validation group and the cross-validation group, differences between the two groups were tested by the Student's t-tests.

The conditions for using multiple linear regression were that the data satisfied normality and homogeneity of variance, as well as a linear relationship between the independent and dependent variables [23]. Data normality was confirmed by Shapiro-Wilk date normality test and data homogeneity was confirmed by Bartlett test. Using correlation matrices to identify potential predictor variables of O_2P_{peak}. Body mass, resting HR, age, gender, and systolic blood pressure (consider multicollinearity between variables and choose the most correlative variables first) were entered, respectively, into the first, second, third, fourth, and five blocks of the hierarchical linear regression procedure. The ANOVA was conducted to compare nested models [24]. Akaike's information criterion (AIC) of each model was computed to make contrasts between them. AIC is a measure of model fit and the model with lower AIC is considered as the optimal one; whereas the model with higher value of AIC is the suboptimal one [25]. To avoid collinearity problem of linear regression model, Variance inflation factors (VIF) were tested, the max value of VIF below 10 indicates means no multicollinearity [26]. Then, Bland-Altman graphs were plotted to examine the distribution of bias.

In order to detect the classification accuracy of the model, the coefficient of determination (R^2) and the standard error of estimate (SEE) were calculated and the prediction equation generated was examined within the cross-validation group, using the Pearson correlation between the estimated and actual O_2P_{peak}. Differences between predicted and measured O_2P_{peak} were also tested by Students t-tests. Two-tailed statistical significance for all analyses was accepted as $p \leq 0.05$. All calculations were performed using the SPSS software (version 26.0, IBM Corp., Armonk, New York, USA).

3. Results

3.1. Descriptive statistics

There were no differences between the validation and the cross-validation groups in any measured variables. All variables were normally distributed (Table 1).

Table 1
Descriptive statistics of subject's characteristics and CPX measurement results.

Measurement	Validation (n = 226)	Cross-validation (n = 26)	*p*
Demographic characteristics			
Gender (male/female)	112/114	13/13	
Age (years)	28.6 ± 6.8	28.7 ± 6.8	0.636
Height (cm)	169.1 ± 8.6	169.7 ± 7.6	0.707
Body mass (kg)	67.6 ± 15.7	66.0 ± 13.7	0.565
BMI (kg/m^2)	22.9 ± 3.5	22.4 ± 3.0	0.448
WC (cm)	78.2 ± 10.9	76.3 ± 9.6	0.412
HC (cm)	94.2 ± 6.7	93.2 ± 5.6	0.418
WHR	0.82 ± 0.08	0.82 ± 0.07	0.486
Cardiovascular function test (resting)			
RHR (bmp)	79.8 ± 13.7	76.2 ± 12.5	0.178
SBP (mmHg)	122.6 ± 12.1	123.7 ± 14.1	0.710
DBP (mmHg)	79.4 ± 3.9	78.7 ± 3.9	0.423
VC (ml)	3198.0 ± 900.0	3176.7 ± 846.7	0.905
Cardiopulmonary exercise testing (CPX)			
O_2P_{peak} (mL/beat)	16.1 ± 3.6	16.0 ± 3.5	0.840
VO_2max ($mL•min^{-1}$)	2871.9 ± 665.7	2842.0 ± 638.0	0.823
VO_2max ($mL•kg^{-1}$ min^{-1})	39.5 ± 7.1	43.7 ± 8.2	0.170
HR_{peak}	179.4 ± 9.9	178.4 ± 10.9	0.661
RER_{max}	1.13 ± 0.07	1.12 ± 0.06	0.495

Abbreviations: BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; RHR, resting heart rates; SBP, systolic blood pressure; DBP, diastolic blood pressure; VC, vital capacity; O_2P_{peak}, peak oxygen pulse; VO2max, maximal oxygen uptake; HR_{peak}, peak heart rates; RER_{max}, maximal respiratory exchange ratio.

3.2. Development of equations

There were low to moderate correlations of O_2P_{peak} with anthropometric variables (Fig. 2). The correlations of O_2P_{peak} with body mass, WC, HC, BMI, height, vital capacity, and WHR were positive, but negative with gender and resting HR (Fig. 2). The correlations of O_2P_{peak} with age and SBP were negative and low. O_2P_{peak} was not associated with DBP. The six anthropometric indicators (body mass, height, BMI, WC, HC, and WHR) showed moderate to strong associations with O_2P_{peak}.

The five selected variables were significantly associated with O_2P_{peak} ($p < 0.01$) after the linear regression procedure, i.e., body mass, resting HR, age, gender, and SBP, accounted for 58 %, 10 %, 6 %, 5 % and 1 % of the O_2P_{peak} variance, respectively. Then following prediction equation was generated: $O_2P_{peak} = 30.394 + 0.083$ x body mass (kg) - 0.090 x resting heart rates (bpm) - 0.157 x age (years) - 2.710 x gender (1 = male, 2 = female) - 0.035 x systolic blood pressure (mmHg). The SEE was 1.619 ml/beat.

3.3. Validity of equations

Based on the R^2 value, the obtained equation explained 80 % of the variability in O_2P_{peak}. All the equations were validity (Table 2, $p < 0.001$) and no multicollinearity (VIF <10). Equation 5 was the fittest model and have the lowest AIC compared with those of other equations (Table 2). Then to test and verify reliability of equation 5, there were solid linear relationships between estimated and measured O_2P_{peak} in the validation group (Fig. 3a). Bland-Altman graphs were between ±1.96 sd confidence limits, which suggested a normal distribution of equation 5 (Fig. 3c).

To verify the effectiveness of equation 5 in the cross-validation group, estimated O_2P_{peak} were calculated and compared with actual measured O_2P_{peak}. There was a strong positive linear relationship ($r = 0.89$, $p < 0.001$) between estimated and measured O_2P_{peak} (Table 3, Fig. 3 (b, d)) and had no difference between them ($t = -0.518$, $p > 0.05$).

4. Discussion

Evaluating cardiovascular function accurately is the first step to screen cardiovascular diseases and design effective exercise prescription for inactive-person [1] or people who need rehabilitation of cardiovascular diseases [6], especially for COVID-19 survivors [27]. To contribute new evidence to the cardiovascular function research, we established and evaluated a prediction equation of O_2P_{peak} for Chinese people and, to our best knowledge, this is the first study to establish O_2P_{peak} predicted equation for Chinese adults aged 20–39. The main results of the present study have shown that the equation has high effectiveness and reliability. There are other prediction equation of O_2P_{peak} in the literature. For example, there was a study established a O_2P_{peak} predicted equation for Brazil older adults, but had less sample size and need the additional information from the Veterans Specific Activity Questionnaire (VSAQ) [15]. Another study had achieved a O_2P_{peak} predicted equation by age and sex for Europe and America adults, but had bigger SEE (3.7ml/beat) compared with that of our equation (1.619ml/beat).

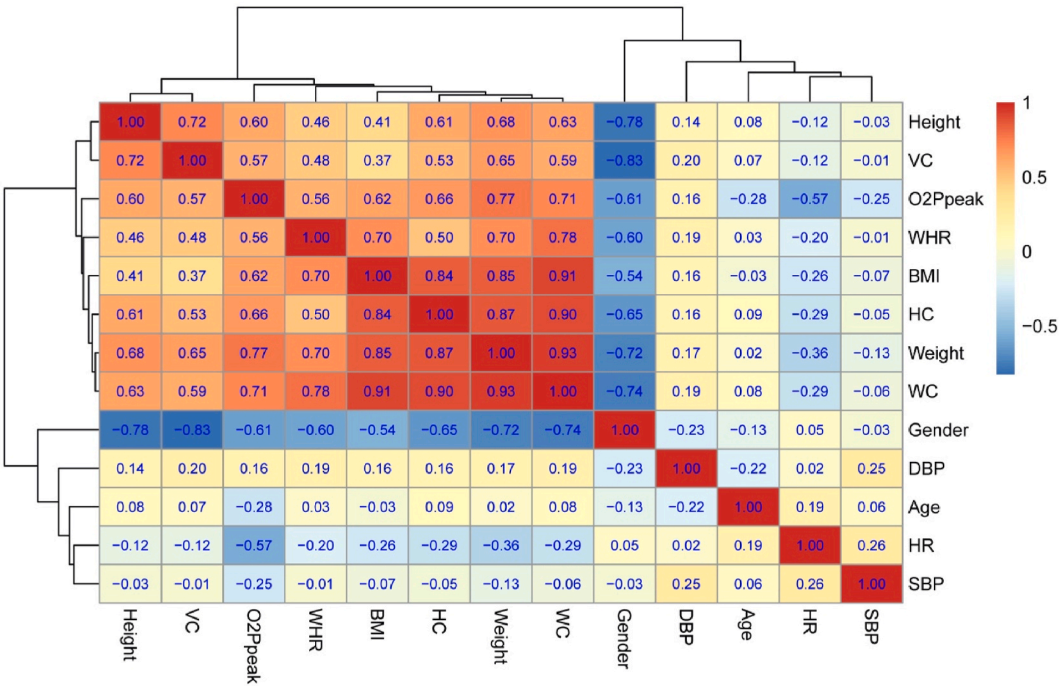

Fig. 2. Correction between O_2P_{peak} and anthropometric variables ($n = 226$).

Table 2
Linear regression models considering the measured O_2P_{peak} (ml/beat) as the dependent variable and the anthropometric measurements as independent variables in the validation sample (n = 226).

	Equation 1	Equation 2	Equation 3	Equation 4	Equation 5
Intercept	4.160	13.181	15.650	26.098	30.394
Body mass (kg)	0.177	0.148	0.154	0.088	0.083
RHR (bmp)		−0.089	−0.075	−0.096	−0.090
Age (years)			−0.140	−0.157	−0.157
Gender (male/female)				−2.567	−2.710
SBP (mmHg)					−0.035
$R_{Pearson}$	0.765	0.828	0.859	0.890	0.897
R^2(%)	0.586	0.686	0.738	0.792	0.804
SEE (ml/beat)	2.332	2.035	1.863	1.665	1.619
VIF_{max}	1.000	1.149	1.201	2.664	2.669
F	316.799	243.433	208.352	209.893	180.323
P	<0.001	<0.001	<0.001	<0.001	<0.001
AIC	1028.184	967.694	928.747	878.922	867.250

Abbreviations: RHR, resting heart rats; SBP, systolic blood pressure; $R_{Pearson}$, Person correction coefficient; R^2, coefficient of determination; SEE, standard error of estimate; VIF_{max}, maximal value of variance inflation factor; F, F-test in ANOVA statistics; *p*, *p* value of ANOVA statistics; AIC, Akaike's information criterion.

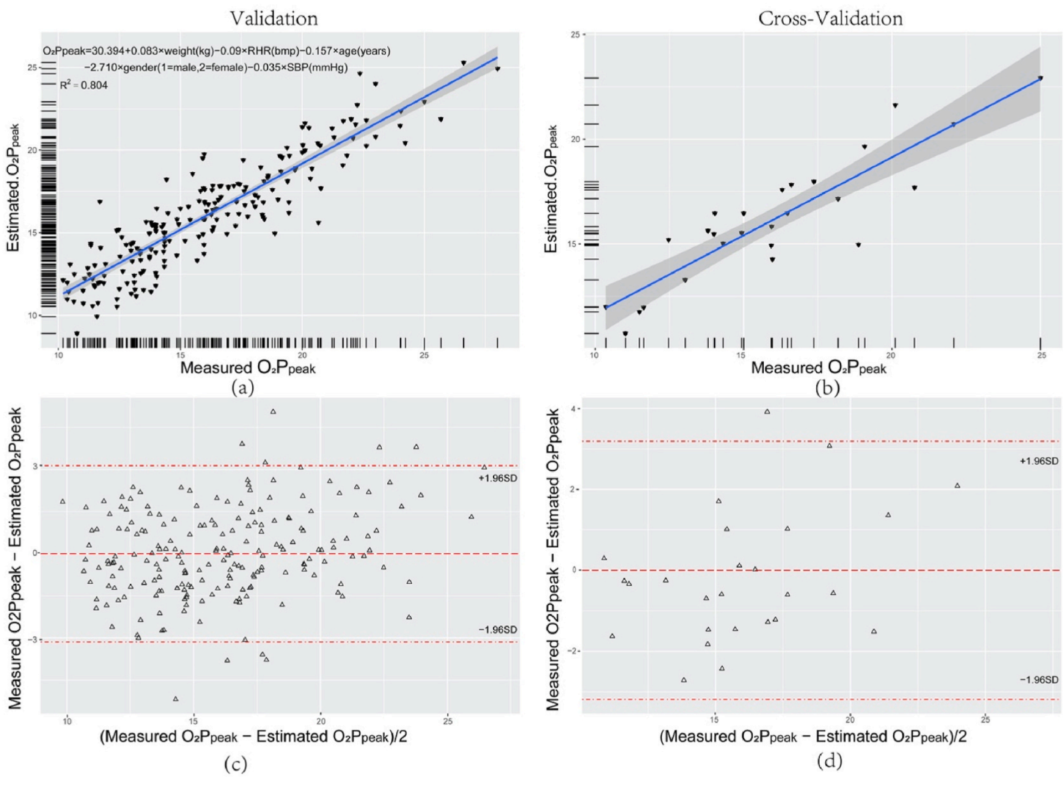

Fig. 3. Scatter diagram and Bland-Altman graphs of estimated and measured O_2P_{peak} in both validation and cross-validation groups. (a) Scatter diagram of estimated and measured O_2P_{peak} of validation. (b) Scatter diagram of estimated and measured O_2P_{peak} of cross-validation group. (c) Bland-Altman graphs of estimated and measured O_2P_{peak} in validation group. (d) Bland-Altman graphs of estimated and measured O_2P_{peak} in cross-validation group.

In the present study, we have established the O_2P_{peak} predicted equation from the results of anthropometric and cardiovascular measurement in adults. The selection of indicators is an important factor affecting the accuracy and applicability of the equation, which requires the selection of indicators that are easy to measure and significantly correlate with O_2P_{peak} [4,15]. There are many associations between anthropometric variables and cardiovascular function, and several studies have reported that height, body mass, WC, HC, WHR are important factors in O_2P_{peak} [15,28], and thus, the equations in our study incorporated height, body mass, BMI, WC, HC and WHR with reference to previous studies [11,28–30]. We found moderate correlation between morphological indicators and O_2P_{peak} (Fig. 2). Cardiovascular function indicators were illustrated directly correlate with O_2P_{peak} included resting HR, SBP, DBP and

Table 3
The difference and correlation of estimated and measured O_2P_{peak} in cross-validation group.

Estimated O_2P_{peak} (ml/beat)	Measured O_2P_{peak} (ml/beat)	Paired T test			Correlation	
		T	*P*	95 % CI	r	*p*
16.12	15.95	−0.518	0.609	−0.821~0.491	0.89	<0.001

Abbreviations: CI, confidence interval.

VC [10,28,31]. Resting HR is a reflection of the state of health of the body, the resting HR of athletes can be close to 60 beats/min [24], or even lower, so people often use resting HR to evaluate cardiac function. SBP, DBP and VC influence the transportation of oxygen from outside into muscle cells [8,15,30,32], we found that the correlation between cardiovascular function indicators and O_2P_{peak} reached moderate correlations (Fig. 2). Finally, we chose height, body mass, WC, HC, WHR, SBP, DBP and VC into multiple regression analyses, but because of multicollinearity between the variables, only body mass, resting HR, age, gender, SBP are into O_2P_{peak} establishment.

The equation we established showed good fitted $R^2 = 0.804$ and a lower SEE = 1.619 ml/beat. To test reliability and validity of equation, The ANOVA was performed in this study and the results showed that F = 180.323 ($p < 0.001$), indicating that the equations are significant (Table 2) and the accuracy is high, and also AIC of the model (equation5) is the lowest. In addition, multicollinearity is a reason that may affect the accuracy of the equation. To avoid multicollinearity in O_2P_{peak} equation, VIF test should be further performed. It is generally believed that the equation has multicollinearity when VIF >10 [25]; however, the VIF_{max} of the equations established in our study was 2.669, indicating that the O_2P_{peak} equations established do not suffer from multicollinearity. The residuals of the equation should also satisfy the independence between normal distribution and residuals, Bland-Altman graphs of estimated and measured O_2P_{peak} were plotted (Fig. 3). It can be explained that the residuals of the O_2P_{peak} estimation equation are independent of each other. Finally, out-of-sample regression tests (by the cross-validation group) was performed, the correlation coefficient between the estimated O_2P_{peak} and measured O_2P_{peak} reached r = 0.89 ($p < 0.001$), and the paired *t*-test showed that the difference was not significant, indicating that the validity of the O_2P_{peak} imputed equation was good.

The equation developed in the present study has the practical value to be used in clinical, exercise prescription design and epidemiology investigation of cardiovascular diseases. For example, for an individual male patient of 24 years old with body mass of 70 kg, resting HR 75 beat/min, SBP 135 mmHg, we can predict his $O_2P_{peak} = 30.394 + 0.083 \times 70–0.090 \times 75–0.157 \times 24–2.710 \times 1–0.035 \times 135 = 18.251$ ml/beat. And then using the predicted O_2P_{peak}, the clinician may easily monitor his cardiovascular function status after the rehabilitation program. In community, not necessary to run the cardiopulmonary exercise test, the equation may help clinicians to diagnose cardiovascular function in general population, and more specially, it can also be used easily to monitor the cardiovascular function status of people after the recovery from current COVID-19 disease.

5. Study limitations

There are limitations in our study. The source of the sample is an important aspect that affects the use of the regression equation, and the subjects of this study were adult people, so the equation cannot meet the needs of young and older individuals. The cardiopulmonary exercise test using a cycle ergometer in the present study may have measured a slightly lower O_2P_{peak} than that measured by a treadmill.

6. Conclusion

The prediction equation of the current study may provide an accurate and convenient method to estimate O_2P_{peak} from body mass, resting HR, age, gender and SBP in Chinese adults aged 20–39. The equation uses simple measurement indicators and has good applicability in the study of evaluation of cardiovascular function in large populations.

Ethics approval and consent to participate

- This study was reviewed and approved by Ethical Committee of Tianjin University of Sport, China, with the approval number: [TJUS2020-009].
- All participants/patients (or their proxies/legal guardians) provided informed consent to participate in the study.
- All participants/patients (or their proxies/legal guardians) provided informed consent for the publication of their anonymised case details and images.

Consent for publication

All authors have read and agreed to the publishing of this manuscript.

Availability of data and materials

The data used and/or analyzed during the current study are available from the corresponding author.

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Feng Zhanpeng: Investigation, Writing – original draft, Writing – review & editing. **Jiang Yan:** Data curation, Investigation. **Zhou Fengrong:** Methodology. **Tan Sijie:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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