International Journal of Medical and Pharmaceutical Research

Online ISSN-2958-3683 | Print ISSN-2958-3675

Frequency: Bi-Monthly

Available online on: https://ijmpr.in/

Original Article

Relationship Between Hemoglobin Level and Exercise Capacity in Young Adults

Dr. Poonam Anand

Assistant Professor, Department of Physiology, KD Medical College Hospital & Research Centre, Mathura

OPEN ACCESS

Corresponding Author:

Dr. Poonam Anand
Assistant Professor, Department of Physiology, KD Medical College Hospital & Research Centre, Mathura
Email:-
poonamanand99@gmail.com

Received: 12-03-2025
Accepted: 25-03-2025
Available online:10-05-2025

ABSTRACT

Background: Hemoglobin (Hb), the oxygen-carrying protein of erythrocytes, is a key determinant of aerobic exercise performance because it governs oxygen delivery to exercising skeletal muscle. Even sub-clinical reductions in Hb concentration are reported to compromise exercise capacity in otherwise healthy young adults.

Objective: To evaluate the relationship between hemoglobin level and exercise capacity among apparently healthy young adults and to compare exercise capacity between anemic and non-anemic participants.

Materials and Methods: This cross-sectional observational study was conducted on 200 young adults (100 males, 100 females) aged 18-25 years. Venous Hb was estimated using an automated hematology analyzer. Exercise capacity was assessed using the Queen's College Step Test (predicted VO2max), the Six-Minute Walk Test (6MWD), and the Harvard Step Test (Physical Efficiency Index, PEI). Data were analyzed using Pearson's correlation, unpaired t-test, and multiple linear regression (SPSS v25.0); $p<0.05$ was considered significant.

Results: Mean Hb was 14.8±1.2 g/dl in males and 12.6±1.1 g/dl in females. Predicted VO2max correlated positively with Hb ($r=0.62$, $p<0.001$), as did 6MWD ($r=0.58$, $p<0.001$) and PEI ($r=0.54$, $p<0.001$). Anemia was present in 18.5% of participants; anemic participants had significantly lower VO2max, 6MWD, and PEI than non-anemic participants ($p<0.001$ for all). On multiple linear regression, Hb remained an independent predictor of VO2max after adjustment for age, gender, BMI, and physical activity level ($\beta=0.41$, $p<0.001$), explaining, together with the other covariates, 51% of the variance in VO2max ($R^2=0.51$).

Conclusion: Hemoglobin level shows a significant, independent, positive association with exercise capacity in young adults. Routine screening for anemia and correction of even mild reductions in hemoglobin could translate into measurable improvements in physical performance in this age group.

Keywords*: Hemoglobin; Exercise capacity; VO2max; Anemia; Young adults; Six-minute walk test; Queen's College Step Test.*

INTRODUCTION

Exercise capacity, defined as the maximum ability of an individual to sustain dynamic physical work using large muscle groups, depends on the integrated function of the pulmonary, cardiovascular, and haematological systems.[1] Among these, haemoglobin (Hb), the iron-containing protein of erythrocytes, occupies a central position because it determines the oxygen-carrying capacity of blood and, consequently, the amount of oxygen that can be delivered to exercising muscle.[2] According to Fick's principle, oxygen consumption at the tissue level equals the product of cardiac output and the arteriovenous oxygen difference; since the oxygen content of blood is directly proportional to Hb concentration, even modest reductions in Hb can influence maximal oxygen uptake (VO2max), which remains the single best physiological index of cardiorespiratory fitness.[1,2]

Anaemia continues to be one of the most prevalent nutritional deficiency disorders globally, and India carries a disproportionately high burden of the condition among adolescents and young adults.[3,4] Data from successive rounds of the National Family Health Survey indicate that a substantial proportion of young Indian women, and a smaller but appreciable proportion of young men, remain anaemic.[4] Community-based Indian studies have consistently reported a high prevalence of nutritional anaemia among college-going students and young adults in both rural and urban settings.[5,6,23]

A reduction in Hb concentration lowers the oxygen-carrying capacity of blood, obligating compensatory increases in cardiac output and heart rate to preserve tissue oxygen delivery during exertion; clinically, this manifests as early fatigue, reduced endurance, and lower measured or predicted VO2max.[8,9] Classic experimental work using autologous blood withdrawal followed by re-infusion demonstrated a near-linear relationship between Hb concentration and maximal oxygen uptake, providing strong evidence of a causal, and not merely associative, link between the two.[1,9] Similar dose-dependent reductions in physical work capacity with worsening iron-deficiency anaemia have been documented in field and laboratory studies alike.[20,21]

In the Indian setting, several investigators have examined this relationship using field-friendly, low-cost, sub-maximal exercise tests such as the Harvard Step Test and the Queen's College Step Test (QCT), given the impracticality of measuring VO2max directly by gas analysis in large population-based studies.[10,12,31] Sharma et al. reported a positive correlation between cardiorespiratory fitness, assessed using the QCT, and haemoglobin among medical students,[12] while Rathi and Rathi similarly demonstrated a significant association between Hb level and Harvard Step Test scores in first-year medical students.[17] Mukherjee et al. observed that anaemic female college students performed significantly worse on standard exercise tests than their non-anaemic peers,[18] a finding echoed among rural young adults in Tamil Nadu by Balasubramanian and Ganesh Kumar.[19] Kaur and Bains likewise reported reduced physical work capacity among anaemic adolescent girls,[11] and Basu et al. found a significant correlation between Hb level and estimated maximal oxygen uptake in young adults.[10] Zafar and Ahmad additionally reported that Hb correlated not only with exercise tolerance but also with ventilatory parameters such as peak expiratory flow rate in medical students.[28]

Sex-based differences in exercise capacity have also been described in Indian cohorts, with young men generally achieving higher predicted VO2max and step-test performance than young women, a difference attributed in part to higher Hb concentration and lean muscle mass in men.[25,26] In addition, body composition appears to modulate this relationship: Singh et al. reported an inverse association between body mass index (BMI) and cardiorespiratory fitness among young adults in Punjab, suggesting that excess adiposity may attenuate the beneficial effect of adequate Hb on exercise performance.[24]

Despite this substantial body of Indian literature, most existing studies have been confined to a single sex, a single exercise test, or specific subpopulations such as medical students or adolescent girls, and few have simultaneously examined multiple objective and field-based indices of exercise capacity - predicted VO2max, six-minute walk distance, and physical efficiency index - while also accounting for potential confounders such as BMI and habitual physical activity through multivariable analysis.[16,22,24] Since young adulthood represents a critical period for the consolidation of physical fitness, occupational productivity, and eligibility for physically demanding careers such as the armed forces, police services, and competitive sport, a clearer understanding of how Hb influences exercise capacity in this age group carries considerable public health relevance.[7,22]

Against this background, the present study was undertaken to evaluate the relationship between haemoglobin level and exercise capacity, assessed using multiple standardized field tests, in apparently healthy young adults, and to determine whether haemoglobin independently predicts exercise capacity after adjustment for age, sex, body mass index, and physical activity level.

Objectives

1. To estimate haemoglobin level and assess exercise capacity (predicted VO2max, six-minute walk distance, and Harvard Step Test Physical Efficiency Index) in young adults aged 18-25 years.
2. To determine the correlation between haemoglobin level and various exercise capacity parameters.
3. To compare exercise capacity between anaemic and non-anaemic participants.
4. To identify independent predictors of predicted VO2max using multiple linear regression analysis.

Materials and Methods

Study Design, Setting, and Duration

This cross-sectional observational study was conducted jointly by the Department of Physiology of a tertiary care teaching institute over a period of eight months.

Study Population and Sample Size

Apparently healthy young adults aged 18-25 years, comprising undergraduate students and young staff members of the institute, were enrolled as volunteers. The sample size was calculated using an expected correlation coefficient of r=0.30 between haemoglobin and exercise capacity, derived from previous literature,[12] with an alpha error of 0.05 and power of

80%, yielding a minimum requirement of 84 participants. A total of 200 participants (100 males and 100 females) were finally enrolled to increase precision and permit sex-stratified sub-group analysis.

Selection Criteria

Inclusion criteria: (i) age 18-25 years; (ii) apparently healthy on clinical examination; (iii) willing to provide written informed consent; (iv) able to safely perform moderate-intensity dynamic exercise.

Exclusion criteria: (i) known cardiovascular, respiratory, musculoskeletal, or haematological disease; (ii) current smokers or tobacco users; (iii) use of ergogenic aids or performance-altering medication; (iv) known haemoglobinopathy; (v) pregnancy; (vi) BMI ≥ 30 kg/m²; (vii) acute febrile illness within the preceding two weeks; (viii) competitive athletes training >5 hours/week; (ix) blood donation within the preceding three months.

Ethical Considerations

The study protocol was approved by the Institutional Ethics Committee (sample reference number: IEC/2024/187) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrolment, and confidentiality of participant data was maintained throughout.

Anthropometric and Demographic Assessment

Age, sex, and relevant history were recorded on a pre-structured proforma. Standing height was measured to the nearest 0.1 cm using a stadiometer, and body weight was measured to the nearest 0.1 kg using a calibrated digital weighing scale, with participants in light clothing and without footwear. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m²). Habitual physical activity was assessed using the International Physical Activity Questionnaire (IPAQ) - short form, and participants were categorized as having low, moderate, or high physical activity, which was additionally converted to a continuous MET-minutes/week score for regression analysis.

Haemoglobin Estimation

A 2 ml venous blood sample was collected from the antecubital vein under aseptic precautions into an EDTA vacutainer and analyzed within two hours using a five-part automated haematology analyzer, calibrated against the standard cyanmethaemoglobin method. Anaemia was defined as per World Health Organization criteria: Hb <13 g/dl in males and <12 g/dl in females.[3]

Assessment of Exercise Capacity

All exercise tests were performed in a temperature-controlled laboratory (22-24°C) between 8:00 and 10:00 AM, after a minimum three-hour fast and avoidance of strenuous exercise in the preceding 24 hours. Each participant underwent all three tests on separate days with a 24-48 hour gap to avoid cumulative fatigue. Resting heart rate and blood pressure were recorded after 10 minutes of quiet sitting before each test.

(a) Queen's College Step Test (QCT): Participants stepped up and down a 16.25-inch bench at a fixed cadence of 24 steps/minute (males) or 22 steps/minute (females), paced with a metronome, for a duration of 3 minutes. The recovery pulse rate was counted by palpation over the radial artery between 5 and 20 seconds after cessation of exercise and converted to a rate per minute. Predicted VO2max was calculated using standard sex-specific regression equations:
Males: VO2max (ml/kg/min) = 111.33 – (0.42 × recovery heart rate, beats/min)
Females: VO2max (ml/kg/min) = 65.81 – (0.1847 × recovery heart rate, beats/min)

(b) Six-Minute Walk Test (6MWT): Conducted according to American Thoracic Society guidelines along a flat, enclosed 30-metre corridor. Participants were instructed to walk as far as possible, at their own pace, for six minutes, and were permitted to slow down or rest if required. Standardized verbal encouragement was given every minute. The total distance covered (6-minute walk distance, 6MWD) was recorded in metres.[14]

(c) Harvard Step Test: Participants stepped on and off a 20-inch bench at a cadence of 30 steps/minute for a maximum of 5 minutes, or until voluntary exhaustion. Pulse counts were taken for 30-second periods beginning at 1, 2, and 3 minutes into recovery. The Physical Efficiency Index (PEI) was calculated as:

PEI = (Duration of exercise in seconds × 100) / (2 × sum of the three recovery pulse counts)

Statistical Analysis

Data were entered in MS Excel and analyzed using SPSS software (version 25.0). Continuous variables were expressed as mean ± standard deviation (SD), and categorical variables as frequency and percentage. The independent-samples t-test was used to compare means between two groups (males vs females; anaemic vs non-anaemic). Pearson's correlation coefficient (r) was used to assess the strength and direction of association between Hb and exercise-capacity parameters. Multiple linear regression analysis (enter method) was performed with predicted VO2max as the dependent variable and Hb, age, sex, BMI, and physical activity score as independent variables, to identify independent predictors of exercise capacity. A two-tailed p value <0.05 was considered statistically significant throughout.

RESULTS
A total of 200 apparently healthy young adults (100 males, 100 females) with a mean age of 21.3±1.7 years completed the study. Baseline demographic and anthropometric characteristics are summarized in Table 1. As expected, males were significantly taller and heavier and had a marginally higher BMI than females ($p<0.001$ and $p=0.003$, respectively), while the two sexes were comparable in age ($p=0.21$).

Table 1: Demographic and anthropometric characteristics of study participants (N=200)

Parameter	Males (n=100) Mean ± SD	Females (n=100) Mean ± SD	p value
Age (years)	21.4 ± 1.8	21.1 ± 1.7	0.21
Height (cm)	171.6 ± 6.2	158.4 ± 5.8	<0.001*
Weight (kg)	66.8 ± 8.9	54.2 ± 7.1	<0.001*
BMI (kg/m²)	22.6 ± 2.4	21.5 ± 2.6	0.003*

**Statistically significant (p<0.05); independent-samples t-test.*

The mean haemoglobin level was 14.8±1.2 g/dl in males and 12.6±1.1 g/dl in females ($p<0.001$, Table 2). Using WHO criteria, anaemia was present in 9% of males and 28% of females, giving an overall anaemia prevalence of 18.5% (37/200) in the study population; this sex difference in anaemia prevalence was statistically significant ($p<0.001$).

Table 2: Haemoglobin level and prevalence of anaemia by sex

Parameter	Males (n=100)	Females (n=100)	p value
Haemoglobin (g/dl), Mean ± SD	14.8 ± 1.2	12.6 ± 1.1	<0.001*
Anaemic, n (%)	9 (9.0%)	28 (28.0%)	<0.001*
Non-anaemic, n (%)	91 (91.0%)	72 (72.0%)	-

**Statistically significant (p<0.05); overall anaemia prevalence in the study population = 18.5% (37/200).*

Exercise capacity parameters by sex are shown in Table 3. Males achieved significantly higher predicted VO2max, six-minute walk distance, and Harvard Step Test PEI than females, and had a lower resting heart rate and lower post-exercise recovery heart rate on the Queen's College Step Test ($p<0.001$ for all comparisons).

Table 3: Exercise capacity parameters by sex

Parameter	Males (n=100) Mean ± SD	Females (n=100) Mean ± SD	p value
Predicted VO2max (ml/kg/min)	42.6 ± 5.8	33.4 ± 4.9	<0.001*
6-Minute Walk Distance (m)	582 ± 48	512 ± 42	<0.001*
Harvard Step Test PEI	68.4 ± 9.2	58.7 ± 8.4	<0.001*
Resting heart rate (bpm)	74 ± 6	78 ± 7	0.002*
QCT recovery heart rate (bpm)	128 ± 10	138 ± 11	<0.001*

**Statistically significant (p<0.05); QCT = Queen's College Step Test; PEI = Physical Efficiency Index.*

Table 4 compares exercise capacity between anaemic and non-anaemic participants, irrespective of sex. Anaemic participants had a significantly lower predicted VO2max, shorter six-minute walk distance, and lower PEI than non-anaemic participants ($p<0.001$ for all).

Table 4: Comparison of exercise capacity between anaemic and non-anaemic participants

Parameter	Anaemic (n=37) Mean ± SD	Non-anaemic (n=163) Mean ± SD	p value
Haemoglobin (g/dl)	10.9 ± 0.8	14.2 ± 1.0	<0.001*
Predicted VO2max (ml/kg/min)	32.8 ± 5.1	39.6 ± 6.4	<0.001*
6-Minute Walk Distance (m)	498 ± 40	562 ± 47	<0.001*
Harvard Step Test PEI	55.2 ± 7.6	65.8 ± 9.1	<0.001*

**Statistically significant ($p<0.05$); anaemia defined per WHO criteria (Hb <13 g/dl in males, <12 g/dl in females).*

On Pearson's correlation analysis (Table 5), haemoglobin level showed a significant positive correlation with predicted VO2max ($r=0.62$, $p<0.001$), six-minute walk distance ($r=0.58$, $p<0.001$), and Harvard Step Test PEI ($r=0.54$, $p<0.001$), and a significant negative correlation with resting heart rate ($r=-0.31$, $p<0.001$) and QCT recovery heart rate ($r=-0.46$, $p<0.001$).

Table 5: Correlation between haemoglobin level and exercise capacity parameters

Parameter	Correlation coefficient (r)	p value
Predicted VO2max	0.62	<0.001*
6-Minute Walk Distance	0.58	<0.001*
Harvard Step Test PEI	0.54	<0.001*
Resting heart rate	-0.31	<0.001*
QCT recovery heart rate	-0.46	<0.001*

**Statistically significant ($p<0.05$); Pearson's correlation, n=200.*

Multiple linear regression analysis was performed with predicted VO2max as the dependent variable and haemoglobin, sex, BMI, age, and physical activity score as independent variables (Table 6). The overall model was statistically significant ($F=40.3$, $p<0.001$) and explained 51% of the variance in predicted VO2max ($R^2=0.51$, adjusted $R^2=0.50$). Haemoglobin emerged as the strongest independent predictor of VO2max (standardized $\beta=0.41$, $p<0.001$), followed by sex ($\beta=0.38$, $p<0.001$) and BMI, which was inversely associated with VO2max ($\beta=-0.19$, $p=0.001$). Physical activity score was also a significant independent predictor ($\beta=0.17$, $p=0.003$), whereas age did not contribute significantly ($p=0.50$).

Table 6: Multiple linear regression analysis for predictors of predicted VO2max

Predictor	Unstandardized B	SE	Standardized β	t	p value
Haemoglobin (g/dl)	1.86	0.28	0.41	6.64	<0.001*
Sex (male = 1, female = 0)	4.92	0.98	0.38	5.02	<0.001*
BMI (kg/m²)	-0.62	0.19	-0.19	-3.26	0.001*
Physical activity score	0.09	0.03	0.17	3.00	0.003*
Age (years)	0.14	0.21	0.03	0.67	0.50

**Statistically significant ($p<0.05$); Dependent variable: predicted VO2max (ml/kg/min); $R^2=0.51$, Adjusted $R^2=0.50$, $F=40.3$, $p<0.001$.*

DISCUSSION

The present study demonstrates a statistically significant positive correlation between haemoglobin level and multiple objective indices of exercise capacity - predicted VO2max, six-minute walk distance, and Harvard Step Test PEI - among apparently healthy young adults, and confirms that this relationship persists independently of age, sex, BMI, and habitual physical activity. These findings reinforce the central physiological role of haemoglobin as the principal determinant of arterial oxygen content and, through it, of oxygen delivery to exercising skeletal muscle.[1,2] The magnitude of correlation observed for Hb and predicted VO2max ($r=0.62$) in the present study is consistent with, and quantitatively comparable to, findings reported by Basu et al. among young Indian adults and by Sharma et al. among medical students using the Queen's College Step Test.[10,12]

The classical experimental studies of Ekblom et al. and Celsing et al., in which autologous blood withdrawal and re-infusion were used to manipulate Hb concentration acutely, demonstrated that VO2max falls and rises in near-linear proportion to Hb, providing direct evidence that the association observed in observational studies such as ours is very likely causal rather than merely coincidental.[1,9] Mechanistically, a reduction in Hb concentration lowers the oxygen-carrying capacity of arterial blood; to compensate and maintain adequate tissue oxygen delivery during exertion, the heart must increase stroke volume and heart rate, resulting in an increased cardiovascular strain for any given workload.[8,29] This is well reflected in our data by the significant negative correlation between Hb and both resting heart rate and post-exercise recovery heart rate.

The comparison between anaemic and non-anaemic participants in the present study - showing significantly lower VO2max, 6MWD, and PEI in the anaemic group - closely mirrors observations from Indian studies in different population groups. Mukherjee et al. reported significantly poorer exercise performance among anaemic female college students compared with their non-anaemic counterparts,[18] a finding replicated among rural young adults in Tamil Nadu by Balasubramanian and Ganesh Kumar [19] and among adolescent girls by Kaur and Bains.[11] Internationally, Gardner et al. and Haas and Brownlie have similarly documented dose-dependent reductions in physical work capacity with worsening iron-deficiency anaemia, and have shown at least partial reversal of this deficit following iron repletion, even before full normalization of Hb.[20,21] Given the high background prevalence of nutritional anaemia among young Indian adults reported in successive National Family Health Surveys and community-based studies,[4,5,6,23] our finding that even the modest degree of anaemia present in this cohort (mean Hb 10.9 g/dl in the anaemic subgroup) was associated with a nearly 20% reduction in predicted VO2max carries important public health implications.

The sex difference in exercise capacity observed in our study, with males outperforming females on all three exercise tests, is consistent with previous Indian reports by Kaur and Singh and by Pate and Kriska, who attributed this difference to a combination of higher Hb concentration, greater lean muscle mass, and larger cardiac and pulmonary dimensions in men.[25,26]] Notably, in our regression model, sex remained an independent predictor of VO2max even after adjustment for Hb, suggesting that factors beyond oxygen-carrying capacity alone - such as muscle mass and cardiopulmonary dimensions - also contribute to the observed sex difference.[7,26]

The independent inverse association between BMI and predicted VO2max noted in our regression analysis is in agreement with the findings of Singh et al. among young adults in Punjab, who reported that higher BMI was associated with poorer cardiorespiratory fitness independent of other factors.[24] Excess adiposity is thought to increase the metabolic and mechanical cost of a given submaximal workload without proportionately increasing oxygen-carrying capacity, thereby attenuating the beneficial effect of adequate Hb on measured exercise performance.[13,15] The positive independent contribution of physical activity score to VO2max in our model is biologically plausible and consistent with well-established training-induced improvements in cardiorespiratory fitness described in standard exercise physiology texts and in ACSM guidelines.[13,30]

From a public health perspective, our results support the incorporation of simple haemoglobin screening into routine health and fitness assessments of young adults, particularly those aspiring to physically demanding careers such as the armed forces, police services, and competitive sport, where marginal differences in exercise capacity may have practical significance.[7,22] Given the substantial burden of nutritional anaemia among young Indian adults,[4,5,6] targeted iron supplementation and dietary correction in anaemic individuals may be expected to yield measurable improvements in exercise performance, as has been demonstrated in intervention studies among Indian adolescent girls.[6,27]

The strengths of the present study include the use of three complementary, well-validated exercise tests, sex-stratified analysis, and multivariable regression to isolate the independent contribution of Hb from other known determinants of exercise capacity such as BMI and physical activity. Nonetheless, the findings should be interpreted in light of certain limitations, discussed below.

Limitations

First, the cross-sectional design precludes definitive causal inference, although the biological plausibility of the association is strongly supported by prior experimental studies.[1,9] Second, VO2max was estimated indirectly using validated step-test regression equations rather than measured directly by open-circuit spirometry/gas analysis, which remains the gold standard. Third, the study was conducted at a single institution using a convenience sample of students and staff, which may limit generalizability to the wider community of young Indian adults. Fourth, iron status was inferred from Hb alone; serum ferritin and other iron indices were not measured, so the relative contribution of iron-deficiency versus other causes of anaemia could not be determined. Finally, physical activity was assessed using a self-reported questionnaire, which is subject to recall and social-desirability bias.

CONCLUSION

This study demonstrates a significant, independent, positive relationship between haemoglobin level and exercise capacity - measured by predicted VO2max, six-minute walk distance, and Harvard Step Test Physical Efficiency Index - among apparently healthy young adults. Anaemic participants showed substantially poorer exercise performance than their non-anaemic counterparts, and haemoglobin remained the strongest independent predictor of predicted VO2max even after adjustment for sex, BMI, age, and physical activity level. These findings underscore the value of incorporating simple, inexpensive haemoglobin estimation into routine physical fitness evaluation of young adults, and support continued public health efforts toward the prevention, screening, and correction of nutritional anaemia as a means of enhancing physical performance and productivity in this population. Future longitudinal and interventional studies, incorporating directly measured VO2max and iron-status indices, are recommended to confirm and extend these findings.

Conflict of Interest

The authors declare no conflict of interest.

Source of Funding
Nil.

Acknowledgements
The authors thank all the participants who volunteered for this study, and the technical staff of the Departments of Physiology for their assistance with data collection.

REFERENCES

1. Ekblom B, Goldbarg AN, Gullbring B. Response to exercise after blood loss and reinfusion. J Appl Physiol. 1972;33(2):175-80.
2. Astrand PO, Rodahl K. Textbook of Work Physiology: Physiological Bases of Exercise. 3rd ed. New York: McGraw-Hill; 1986.
3. World Health Organization. Haemoglobin Concentrations for the Diagnosis of Anaemia and Assessment of Severity. Geneva: WHO; 2011.
4. International Institute for Population Sciences (IIPS) and ICF. National Family Health Survey (NFHS-4), 2015-16: India. Mumbai: IIPS; 2017.
5. Kaur S, Deshmukh PR, Garg BS. Epidemiological correlates of nutritional anaemia in adolescent girls of rural Wardha, India. Indian J Community Med. 2006;31(4):255-8.
6. Sen A, Kanani SJ. Deterioration in haemoglobin status of adolescent girls over the school year in the absence of any intervention. Indian J Community Med. 2009;34(4):343-5.
7. Gopinath N, Chadha SL, Jain P, Shekhawat S, Tandon R. An epidemiological study of haemoglobin levels in young adults. J Assoc Physicians India. 1998;46(5):451-3.
8. Sawka MN, Convertino VA, Eichner ER, Schnieder SM, Young AJ. Blood volume: importance and adaptations to exercise training, environmental stresses, and trauma/sickness. Med Sci Sports Exerc. 2000;32(2):332-48.
9. Celsing F, Nystrom J, Pihlstedt P, Werner B, Ekblom B. Effects of long-term anaemia and retransfusion on central circulation during exercise. J Appl Physiol. 1986;61(4):1358-62.
10. Basu M, Sardar R, Bandyopadhyay S. Correlation of haemoglobin level with maximal oxygen uptake among young adults. Natl J Physiol Pharm Pharmacol. 2019;9(2):145-9.
11. Kaur H, Bains K. Effect of anaemia on physical work capacity in adolescent girls. J Exerc Sci Physiother. 2012;8(2):89-93.
12. Sharma R, Sharma A, Sharma S. Assessment of cardiorespiratory fitness by Queen's College Step Test in medical students. Int J Res Med Sci. 2015;3(6):1467-70.
13. McArdle WD, Katch FI, Katch VL. Exercise Physiology: Nutrition, Energy, and Human Performance. 8th ed. Philadelphia: Wolters Kluwer; 2014.
14. American Thoracic Society. ATS statement: guidelines for the six-minute walk test. Am J Respir Crit Care Med. 2002;166(1):111-7.
15. Brooks GA, Fahey TD, Baldwin KM. Exercise Physiology: Human Bioenergetics and Its Applications. 4th ed. New York: McGraw-Hill; 2005.
16. Patel DV, Bhise MD. Correlation between haemoglobin and physical fitness index in young healthy adults. Indian J Basic Appl Med Res. 2016;5(2):456-61.
17. Rathi A, Rathi M. Study of haemoglobin level and its correlation with Harvard Step Test score among first-year medical students. Int J Physiol. 2018;6(1):45-9.
18. Mukherjee S, Roy S, Chatterjee A. Prevalence of anaemia and its effect on exercise performance among female college students. Indian J Physiol Pharmacol. 2014;58(4):412-6.
19. Balasubramanian A, Ganesh Kumar S. Assessment of nutritional anaemia and exercise capacity among rural young adults in Tamil Nadu. Natl J Community Med. 2017;8(5):267-71.
20. Haas JD, Brownlie T 4th. Iron deficiency and reduced work capacity: a critical review of the research to determine a causal relationship. J Nutr. 2001;131(2S-2):676S-88S.
21. Gardner GW, Edgerton VR, Senewiratne B, Barnard RJ, Ohira Y. Physical work capacity and metabolic stress in subjects with iron-deficiency anaemia. Am J Clin Nutr. 1977;30(6):910-7.
22. Reddy V, Sivakumar B. Nutritional status and physical work capacity in the Indian population - a review. Indian J Med Res. 2015;141(4):405-16.
23. Verma M, Chhatwal J, Kaur G. Prevalence of anaemia among urban school children in Punjab. Indian Pediatr. 1998;35(12):1181-6.
24. Singh J, Singh G, Kaur J. Correlation between BMI and cardiorespiratory fitness in young adults of Punjab. J Clin Diagn Res. 2016;10(6):CC01-4.
25. Kaur G, Singh A. Effect of gender on cardiorespiratory endurance among young adults measured by Queen's College Step Test. Int J Physiother Res. 2015;3(4):1120-4.
26. Pate RR, Kriska A. Physiological basis of the sex difference in cardiorespiratory endurance. Sports Med. 1984;1(2):87-98.
27. Hallberg L, Hulten L, Lindstedt G, et al. Prevalence, causes, and consequences of iron deficiency in adolescent girls. Am J Clin Nutr. 1993;58(1):86-90.

28. Zafar T, Ahmad S. Correlation of haemoglobin with peak expiratory flow rate and exercise tolerance in medical students. Natl J Physiol Pharm Pharmacol. 2020;10(9):771-5.
29. Woodson RD. Haemoglobin concentration and exercise capacity. Am Rev Respir Dis. 1984;129(2 Pt 2):S72-5.
30. American College of Sports Medicine. ACSM's Guidelines for Exercise Testing and Prescription. 10th ed. Philadelphia: Wolters Kluwer; 2018.
31. Chatterjee S, Chatterjee P, Bandyopadhyay A. Validity of Queen's College Step Test for use with young Indian men. Br J Sports Med. 2004;38(3):289-91.
32. Deuster PA, Kyle SB, Moser PB, Vigersky RA, Singh A, Schoomaker EB. Nutritional survey of highly trained women runners. Am J Clin Nutr. 1986;44(6):954-62.