

Retrospective Analysis of the Relationship Between Hemoglobin Concentration and Exercise Tolerance

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Abstract:

Background: Hemoglobin plays an important role in oxygen transport and may influence functional exercise capacity. Reduced hemoglobin concentration can impair oxygen delivery and contribute to exercise limitation.

Aim: To retrospectively evaluate the relationship between hemoglobin concentration and exercise tolerance and to assess differences in functional and physiological exercise parameters according to anemia status.

Methodology: A retrospective observational study was conducted among 80 participants at the Department of Physiology, Government Medical College, Bettiah, Bihar. Demographic, clinical, hematological, pulmonary function, muscle strength, six-minute walk distance (6MWD), and cardiopulmonary exercise testing data were reviewed. Hemoglobin was analyzed as a continuous variable and according to WHO-defined anemia status. Associations with exercise-related outcomes were assessed using multivariable linear regression.

Results: Anemia was present in 29 (36.3%) participants. Compared with non-anemic participants, those with anemia had significantly lower 6MWD (348.2 ± 66.8 vs. 405.3 ± 69.1 m; $p < 0.001$), $VO_{2\max}$ (1.04 ± 0.27 vs. 1.26 ± 0.32 L/min; $p = 0.002$), handgrip strength, and quadriceps strength. Higher hemoglobin was independently associated with greater 6MWD ($\beta = 18.6$; $p < 0.001$) and $VO_{2\max}$ ($\beta = 0.082$; $p < 0.001$).

Conclusion: Higher hemoglobin concentration was significantly associated with better exercise tolerance and functional performance.

Keywords: Hemoglobin; Anemia; Exercise tolerance; 6-minute walk distance; $VO_{2\max}$; Muscle strength.

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Introduction

Haemoglobin is a crucial part of red blood cells and functions to transport oxygen from the lungs to the peripheral tissues [1]. During exercise, the amount of oxygen skeletal muscle requires is significantly higher, so the delivery of oxygen is especially important during exercise. Haemoglobin concentration thus plays a role in the transport of oxygen in the blood and may affect the capacity of an individual to perform and maintain their physical activity [2]. A fall in haemoglobin concentration can lead to a lower content of oxygen in the arteries and increase the demands that are put on the cardiovascular and respiratory systems during exercise.

Anaemia is defined as a haemoglobin concentration that is below the level needed to satisfy physiological requirements which depends on other factors such as age, sex, pregnancy status [3]. Haemoglobin concentration is an important indicator used by the World Health Organization (WHO) to diagnose and evaluate anaemia. Reduced haemoglobin may occur because of nutritional deficiencies, chronic diseases, infections, inflammation, blood loss and inherited disorders. People with low levels of haemoglobin

may be tired, weak, faint, short of breath and unable to do as much as they used to, especially during physical activity.

Exercise tolerance is the capacity to complete an exercise task at a specified level of intensity and duration without experiencing undue fatigue, breathlessness or other limiting symptom [4]. It is affected by a number of factors such as cardiovascular function, pulmonary function, skeletal muscle capacity, physical fitness, age, body composition and metabolic efficiency. An important part of this is oxygen transport as muscles need to have the right amount of oxygen around for aerobic energy production. Thus, haemoglobin concentration can affect exercise tolerance by affecting the delivery of oxygen to working tissues.

The physiological correlation between haemoglobin concentration and exercise tolerance can be largely attributed to the role of haemoglobin in the determination of the content of oxygen in the arteries [5]. If there is less haemoglobin, there will be less oxygen carried per blood. An increase in cardiac output, redistribution of blood flow and oxygen extraction by

peripheral tissues are partial compensatory mechanisms [6]. These can keep the oxygen supply going in light reductions in haemoglobin, but they may fail to compensate as the haemoglobin decreases even more or during heavy exercise.

Significant physiological research has shown that lower haemoglobin levels can have an impact on peak exercise capacity. A reduction of haemoglobin has been correlated with a decrease in maximal oxygen consumption and in maximal exercise performance [7]. At submaximal exercise, this decrease in haemoglobin could result in a proportionate increase in blood flow to ensure a constant delivery at a given workload. However, these adaptations do not necessarily counteract the decrease in oxygen carrying capacity on maximal exercise.

It has also been shown that haemoglobin plays a role in exercise performance in endurance exercise. The aerobic exercise capacity depends on a number of interrelated physiological factors but is important for the oxygen-carrying capacity [8]. Exercise performance is affected by total haemoglobin mass, red blood cell mass, cardiac output and the ability to extract and utilise oxygen from skeletal muscle. So, haemoglobin concentration should not be viewed simply as a part of the system—it is important to look at the whole system for exercise tolerance.

Another key factor in the relationship between haemoglobin and exercise capacity is iron status [9]. Iron deficiency can lead to anaemia and limit the amount of oxygen to exercising muscles. Furthermore, iron deficiency can influence cellular energy metabolism through other pathways, apart from the haemoglobin concentration. This means that a fall in haemoglobin may have little impact on the person, but still result in a decrease in physical performance when they are unable to access enough iron. This serves to highlight the need to take into account the cause of the changed haemoglobin level when assessing exercise tolerance.

Association between haemoglobin and exercise tolerance also may differ by physiological status and individual characteristics [10]. Haemoglobin concentration and exercise performance may be affected by age, sex, physical fitness, nutritional status, chronic disease, smoking, altitude and habits of physical activity. Whereas in the physically trained, alterations in plasma volume may lead to a relatively lower haemoglobin concentration which does not imply that the condition is pathological anaemia. Therefore, the haemoglobin results must be considered in the context of the person's demographics and clinical condition.

There are many clinical and functional markers of exercise tolerance like duration of exercise, exercise workload, heart rate response, exercise symptoms and perceived exertion. CPE can also offer objective indices like the maximal oxygen uptake and

ventilatory responses. Retrospective clinical records might include routine documentation of the exercise-test result or functional measures, which can be included to study the relationship between haemoglobin concentration and exercise capacity.

The physiological role of haemoglobin in oxygen transport is well recognised, but the potential for the relationship with exercise tolerance to differ between individuals and clinical populations. This relationship can be useful to know in a real world setting, and can be obtained from clinical data that is routinely collected. Thus, the present study is designed to look at the relationship between haemoglobin concentration and exercise tolerance, and to see if there is a relationship between variations in haemoglobin concentration and differences in exercise capacity in a retrospective study. The results could help to elucidate the functional meaning of haemoglobin variation, and may serve as a foundation for additional research on the issue of anaemia, oxygen transport and physical performance.”

Methodology

Study Design: The present study was conducted as a retrospective observational analysis of previously recorded clinical and exercise-related data. The study assessed the relationship between hemoglobin concentration and exercise tolerance using information available in the medical records of eligible patients. Relevant demographic, clinical, hematological, pulmonary function, muscle strength, six-minute walk test, and cardiopulmonary exercise testing data were retrospectively reviewed. Hemoglobin concentration was considered the principal hematological variable, while exercise tolerance was assessed using six-minute walk distance (6MWD) and exercise-related parameters, including maximal oxygen uptake ($\text{VO}_{2\text{max}}$). The analysis also considered potential clinical and physiological factors that could influence exercise performance.

Study Setting: The study was conducted in the Department of Physiology, Government Medical College, Bettiah, West Champaran, Bihar, India. Previously recorded clinical and physiological assessment data available in the department were reviewed for eligible participants. The available records included relevant hematological investigations, pulmonary function parameters, muscle strength measurements, six-minute walk test results, and exercise testing parameters required for assessment of the relationship between hemoglobin concentration and exercise tolerance.

Study Duration: The study was conducted over a period of one year from January 2023 to December 2023

Study Participants: Participants were selected from the available medical records according to pre-defined eligibility criteria.

Inclusion Criteria:

- Patients whose medical records contained the required clinical and physiological assessment data.
- Patients with documented hemoglobin concentration.
- Patients with available exercise tolerance assessment, including 6MWD and/or cardiopulmonary exercise testing parameters.
- Patients with available relevant pulmonary function and clinical assessment data.

Exclusion Criteria:

- Patients with severe cardiovascular disease.
- Patients with malignant diseases.
- Patients with systemic rheumatologic or connective tissue disorders.
- Patients with chronic renal failure.
- Patients receiving oral corticosteroid therapy.
- Patients receiving long-term oxygen therapy.
- Patients who were unable to perform the required exercise tests.
- Records with insufficient data for assessment of hemoglobin concentration and exercise tolerance.

Study Sampling: A retrospective sampling method was used for the study. Medical records available during the study period were reviewed, and participants fulfilling the predefined inclusion criteria and not meeting any exclusion criteria were considered eligible. Records were screened for availability of hemoglobin concentration and exercise tolerance-related parameters. Eligible records were included until the required sample size of 80 participants was obtained.

Study Sample Size: The study included a total of 80 participants. The sample size was determined using the standard formula for estimation of sample size based on prevalence:

$$n = \frac{Z^2 \times p \times q}{d^2}$$

where **n** represented the required sample size, **Z** represented the standard normal deviate corresponding to the desired confidence level, **p** represented the anticipated proportion, **q** = 1-**p**, and **d** represented the allowable margin of error. Based on the available study population and predefined study requirements, a final sample size of 80 participants was considered for the retrospective analysis.

Study Groups: For comparative analysis, participants were categorized according to their hemoglobin concentration. Participants with hemoglobin values below the specified threshold were classified as having anemia, while those without anemia were classified as the non-anemic group. Anemia was defined according to WHO criteria, with hemoglobin

concentration <12 g/dL in females and <13 g/dL in males. Hemoglobin concentration was also analyzed as a continuous variable to determine its relationship with exercise tolerance. Where applicable, participants with elevated hemoglobin concentrations were identified according to the predefined thresholds.

Study Parameters: The following parameters were assessed from the available medical records:

- Hemoglobin concentration.
- C-reactive protein (CRP) concentration.
- Age and sex.
- Smoking habits.
- Body weight, height, and body mass index (BMI).
- Comorbid conditions and Charlson Comorbidity Index (CCI).
- Functional dyspnoea using the Medical Research Council dyspnoea scale (MRC).
- Pulmonary function parameters, including FEV₁, FVC, and FEV₁/FVC.
- Handgrip strength.
- Quadriceps/isometric knee extension strength.
- Six-minute walk distance (6MWD).
- Maximal exercise capacity and VO₂max.
- Health-related quality of life assessed using the St. George's Respiratory Questionnaire (SGRQ), where available.

Study Procedure: The available medical records of eligible participants were retrospectively reviewed. Clinical and anthropometric information, smoking history, comorbidities, and relevant questionnaire-based assessments were extracted. Hemoglobin and CRP values obtained from peripheral venous blood investigations were recorded. Pulmonary function parameters, including FEV₁, FVC, and FEV₁/FVC, were extracted from spirometry records. Muscle strength measurements, including handgrip and quadriceps strength, were recorded where available. Exercise tolerance was assessed from documented 6MWD and cardiopulmonary exercise testing results. During the six-minute walk test, the total distance walked in six minutes was recorded. Cardiopulmonary exercise testing data included exercise-related parameters and VO₂, with VO₂max used as an indicator of maximal exercise capacity.

Study Data Collection: Data were collected retrospectively from the medical records using a structured data collection format. Demographic characteristics, clinical history, smoking status, comorbidities, anthropometric measurements, hemoglobin, CRP, pulmonary function parameters, muscle strength, 6MWD, VO₂max, and other relevant exercise-related parameters were extracted. The recorded information was checked for completeness before statistical analysis. Hemoglobin concentration was evaluated both as a continuous variable and according to the predefined anemia classification.

Data Analysis: The collected data were entered and analyzed using Statistical Package for the Social Sciences (SPSS), version 20.0. Continuous variables were expressed as mean $\pm$ standard deviation, while categorical variables were expressed as frequencies and percentages. Differences between participants with and without anemia were assessed using a two-sided independent-samples test for continuous variables and the Chi-square test for categorical variables, as appropriate. A p-value <0.05 was considered statistically significant. Linear regression analysis was performed to evaluate the association of anemia and hemoglobin concentration with exercise tolerance parameters, including 6MWD, VO_2max , handgrip strength, and quadriceps strength. Multivariable analyses controlled for relevant factors including age, sex, BMI, smoking habits, CRP levels, FEV_1 , and CCI.”

Result

Table 1 presents the demographic and baseline characteristics of the 80 study participants. The mean age of the study population was 59.8 ± 8.7 years, indicating a predominantly older adult population. Males constituted the majority of participants, accounting for 52 (65.0%), while females represented 28 (35.0%). The mean BMI was $22.9 \pm 3.4 \text{ kg/m}^2$. Regarding smoking status, 43 (53.8%) participants were current smokers, 21 (26.3%) were former smokers, and 16 (20.0%) had never smoked, indicating that more than half of the participants were currently exposed to tobacco smoking. The mean Charlson Comorbidity Index was 2.1 ± 1.2 , suggesting the presence of multiple comorbid conditions within the study population. The mean MRC dyspnoea score was 2.8 ± 0.9 , reflecting a moderate degree of respiratory symptoms. The mean CRP level was $6.7 \pm 3.9 \text{ mg/L}$, indicating the presence of systemic inflammatory activity among the participants.

Table 1: Demographic and baseline characteristics of study participants (N = 80)

Parameter	Findings
Age (years), mean $\pm$ SD	59.8 ± 8.7
Male, n (%)	52 (65.0)
Female, n (%)	28 (35.0)
BMI (kg/m^2), mean $\pm$ SD	22.9 ± 3.4
Current smokers, n (%)	43 (53.8)
Former smokers, n (%)	21 (26.3)
Never smokers, n (%)	16 (20.0)
Charlson Comorbidity Index, mean $\pm$ SD	2.1 ± 1.2
MRC dyspnoea score, mean $\pm$ SD	2.8 ± 0.9
CRP (mg/L), mean $\pm$ SD	6.7 ± 3.9

Table 2 presents the hemoglobin concentration and anemia classification among the 80 study participants. The overall mean hemoglobin concentration was $12.6 \pm 1.7 \text{ g/dL}$, with values ranging from 9.4 to 16.8 g/dL. Anemia was present in 29 (36.3%) participants, whereas 51 (63.8%) participants were classified as having no anemia. The mean hemoglobin concentration was considerably lower among participants with anemia ($10.8 \pm 0.9 \text{ g/dL}$) compared with those without anemia ($13.6 \pm 1.2 \text{ g/dL}$). This

indicates a clear difference in hemoglobin levels according to anemia status. The distribution shows that more than one-third of the study population had anemia, while nearly two-thirds had hemoglobin levels within the non-anemic range. The mean CRP level in the overall study population was $6.7 \pm 3.9 \text{ mg/L}$. Overall, the findings demonstrate considerable variation in hemoglobin concentration among participants, with a substantial proportion classified as anemic.

Table 2: Hemoglobin concentration and classification of participants (N = 80)

Hemoglobin-related parameter	Findings
Hemoglobin (g/dL), mean $\pm$ SD	12.6 ± 1.7
Hemoglobin range (g/dL)	9.4–16.8
Anemia present, n (%)	29 (36.3)
No anemia, n (%)	51 (63.8)
Mean Hb in anemia group (g/dL)	10.8 ± 0.9
Mean Hb in non-anemia group (g/dL)	13.6 ± 1.2
CRP (mg/L), mean $\pm$ SD	6.7 ± 3.9

Table 3 presents the pulmonary function, muscle strength, and exercise tolerance parameters among the 80 study participants. The mean FEV_1 was $1.54 \pm 0.48 \text{ L}$, while the mean FVC was $2.58 \pm 0.65 \text{ L}$,

with a mean FEV_1/FVC ratio of $59.7 \pm 8.4\%$. The mean handgrip strength was $25.8 \pm 6.2 \text{ kg}$ and the mean quadriceps strength was $18.7 \pm 5.1 \text{ kg}$, reflecting the overall muscle strength of the participants.

Exercise tolerance, assessed by the 6-minute walk distance, showed a mean walking distance of 384.6 ± 72.5 m. The mean VO_2max was 1.18 ± 0.32 L/min, providing an additional measure of exercise capacity. The mean SGRQ score was 48.6 ± 13.7 , indicating the overall health-related quality-of-life status

related to respiratory symptoms. Collectively, these findings describe the baseline pulmonary function, muscle strength, functional exercise capacity, and respiratory-related quality of life of the study population.”

Table 3: Pulmonary function, muscle strength and exercise tolerance parameters (N = 80)	
Parameter	Mean $\pm$ SD
FEV ₁ (L)	1.54 ± 0.48
FVC (L)	2.58 ± 0.65
FEV ₁ /FVC (%)	59.7 ± 8.4
Handgrip strength (kg)	25.8 ± 6.2
Quadriceps strength (kg)	18.7 ± 5.1
6-minute walk distance (m)	384.6 ± 72.5
VO_2max (L/min)	1.18 ± 0.32
SGRQ score	48.6 ± 13.7

“Table 4 compares exercise tolerance and related clinical parameters according to anemia status among the 80 participants. Mean hemoglobin was significantly lower in the anemia group (10.8 ± 0.9 g/dL) than in the non-anemia group (13.6 ± 1.2 g/dL; $p < 0.001$). FEV₁ was also significantly lower among participants with anemia (1.39 ± 0.42 L vs. 1.63 ± 0.50 L; $p = 0.031$), whereas the FEV₁/FVC ratio did not differ significantly ($p = 0.194$). Handgrip strength (23.1 ± 5.7 vs. 27.3 ± 6.1 kg; $p = 0.003$) and

quadriceps strength (16.9 ± 4.6 vs. 19.7 ± 5.1 kg; $p = 0.016$) were significantly lower in the anemia group. Similarly, 6-minute walk distance was significantly shorter (348.2 ± 66.8 vs. 405.3 ± 69.1 m; $p < 0.001$), and VO_2max was lower (1.04 ± 0.27 vs. 1.26 ± 0.32 L/min; $p = 0.002$). MRC scores were higher and SGRQ scores were significantly greater among participants with anemia ($p = 0.001$ for both), indicating greater dyspnoea and poorer respiratory-related quality of life.

Table 4: Comparison of exercise tolerance according to anemia status			
Parameter	Anemia (n = 29) Mean $\pm$ SD	No anemia (n = 51) Mean $\pm$ SD	p-value
Hemoglobin (g/dL)	10.8 ± 0.9	13.6 ± 1.2	<0.001
FEV ₁ (L)	1.39 ± 0.42	1.63 ± 0.50	0.031
FEV ₁ /FVC (%)	58.1 ± 8.1	60.6 ± 8.5	0.194
Handgrip strength (kg)	23.1 ± 5.7	27.3 ± 6.1	0.003
Quadriceps strength (kg)	16.9 ± 4.6	19.7 ± 5.1	0.016
6MWD (m)	348.2 ± 66.8	405.3 ± 69.1	<0.001
VO_2max (L/min)	1.04 ± 0.27	1.26 ± 0.32	0.002
MRC score	3.2 ± 0.8	2.6 ± 0.8	0.001
SGRQ score	55.2 ± 12.8	44.8 ± 12.7	0.001

Table 5 presents the multivariable linear regression analysis of the relationship between hemoglobin concentration and exercise tolerance. Hemoglobin concentration showed a significant positive association with 6MWD, with a β coefficient of 18.6 (95% CI: 9.4–27.8; $p < 0.001$), indicating greater walking distance with higher hemoglobin concentration. Similarly, VO_2max was positively associated with hemoglobin concentration ($\beta = 0.082$, 95% CI: 0.041–0.123; $p < 0.001$). Significant positive associations were also observed for handgrip strength

($\beta = 1.21$, 95% CI: 0.52–1.90; $p = 0.001$) and quadriceps strength ($\beta = 0.96$, 95% CI: 0.31–1.61; $p = 0.004$). In contrast, hemoglobin concentration showed a significant negative association with MRC dyspnoea score ($\beta = -0.18$, 95% CI: -0.31 to -0.05 ; $p = 0.007$) and SGRQ score ($\beta = -2.41$, 95% CI: -4.12 to -0.70 ; $p = 0.006$). Overall, higher hemoglobin concentration was significantly associated with better exercise capacity, greater muscle strength, lower dyspnoea, and improved respiratory-related quality of life.

Table 5: Multivariable linear regression analysis of the relationship between hemoglobin concentration and exercise tolerance

Outcome variable	β coefficient	95% CI	p-value
6MWD (m)	18.6	9.4–27.8	<0.001
VO ₂ max (L/min)	0.082	0.041–0.123	<0.001
Handgrip strength (kg)	1.21	0.52–1.90	0.001
Quadriceps strength (kg)	0.96	0.31–1.61	0.004
MRC dyspnoea score	–0.18	–0.31 to –0.05	0.007
SGRQ score	–2.41	–4.12 to –0.70	0.006

Discussion

In the present study, this correlation between levels of hemoglobin and exercise tolerance was clearly demonstrated in 80 subjects. The mean age of the study participants was 59.8 ± 8.7 years, and 65.0% of them were male. Over half of the participants were current smokers (53.8%) and the mean Charlson Comorbidity Index was 2.1 ± 1.2 , and the mean MRC dyspnoea score was 2.8 ± 0.9 . The mean CRP concentration was 6.7 ± 3.9 mg/L, suggesting that other than haemoglobin, there may have been other factors contributing to functional limitation. In chronic cardiac and respiratory disease, pulmonary dysfunction, systemic inflammation, comorbidities, anemia and muscle impairment are all possible factors that can affect exercise capacity (Ferrari et al., 2015; Okonko et al., 2011) [11,12] similar multifactorial determinants of exercise capacity have been described in chronic respiratory and cardiovascular disease.”

“Among 75 people, 29 (36.3%) were anemic and 51 (63.8%) were non-anemic. The average hemoglobin (mean $\pm$ SD) was 12.6 ± 1.7 g/dL. The mean hemoglobin concentration was significantly lower among the participants with anemia compared with those without anemia (10.8 ± 0.9 g/dL for the anemic group vs. 13.6 ± 1.2 g/dL for the non-anemic group). Clinically, the relatively high percentage of anemia in the current population is significant because hemoglobin is an important indicator of oxygen-carrying capacity of blood. It was found that acute changes in hemoglobin concentration were correlated with changes in oxygen transport and maximal aerobic capacity (Calbet et al., 2006) [13] that the greater the hemoglobin available, the greater the oxygen delivery during exercise, while the lower the hemoglobin concentration, the lower the oxygen delivery during exercise. Therefore, a decrease in hemoglobin observed among anemic subjects in the present study may have been a factor contributing to exercise performance.

One of the primary results of the present study is that there was a significant difference in functional exercise capacity based on anemia status. A significant difference was found in the mean distance walked in 6-minutes between the participants with anemia and participants without anemia (348.2 ± 66.8 m vs. 405.3 ± 69.1 m; $p < 0.001$). This result was in

agreement with Ranucci et al. 2011 [14] which found that patients with lower postoperative hemoglobin levels had a poorer six-minute walking performance. In the patients with hemoglobin below 10 g/dL, their study found a mean walking distance of about 258 m, while in those with higher hemoglobin concentrations, the mean walking distance was about 306 m. With different populations and clinical settings, both studies demonstrated a relationship between lower hemoglobin levels and decreased walking ability.

The present results were especially similar to those of Ferrari et al (2015) who studied the association between anemia and exercise capacity for people with chronic obstructive pulmonary disease. They found significantly reduced exercise capacity in anemic patients and showed that the hemoglobin concentration was an independent predictor of 6MWD. In the present study, approximately 57 m difference between anemic and non-anemic subjects further confirmed the clinical significance of hemoglobin concentration in evaluating functional exercise. Ferrari et al. (2015) also found a relationship between hemoglobin levels, dyspnoea and quality of life, as was seen in this study.

There was also a significant difference in the values of VO₂max between the two groups. The mean value of VO₂max was 1.04 ± 0.27 L/min in participants with anemia, versus 1.26 ± 0.32 L/min in non-anemic participants ($p = 0.002$). This finding is consistent with the physiological findings of Calbet et al. (2006) who showed that haemoglobin concentration is an important determinant of maximal oxygen uptake. Likewise, in the METS study population, Bartoszko et al. 2019 [15] reported that an association between preoperative hemoglobin concentration and cardiopulmonary exercise capacity was significant. They found that hemoglobin was an independent predictor of variation in both the peak oxygen consumption and the anaerobic threshold. The present study therefore endorses the notion that hemoglobin concentration is one of the components of the oxygen transport system which plays a role on the maximum exercise capacity.

The present study also exhibited significantly reduced peripheral muscle strength in the anemic group. Handgrip strength was 23.1 ± 5.7 kg in the anemia group compared with 27.3 ± 6.1 kg in the

non-anemia group ($p = 0.003$), while quadriceps strength was 16.9 ± 4.6 kg versus 19.7 ± 5.1 kg, respectively ($p = 0.016$). These results indicated that subjects with lower hemoglobin concentration also showed impaired muscular function besides impaired walking ability. Ferrari et al. (2015), however, found the link between hemoglobin and muscle strength to be less consistent when other clinical factors were taken into account. Thus, the present correlation may be due partly to the effects of anemia, pulmonary dysfunction, systemic inflammation, other diseases and decreased physical activity, and not to the direct effects of hemoglobin on skeletal muscle strength.”

“Participants who had anemia were also significantly more dyspnoea and less respiratory-related quality of life. The mean MRC score was 3.2 ± 0.8 in the anemia group compared with 2.6 ± 0.8 in the non-anemia group ($p = 0.001$), while SGRQ scores were 55.2 ± 12.8 and 44.8 ± 12.7 , respectively ($p = 0.001$). A similar association between anemia and increased dyspnoea and decreased quality of life among COPD patients was also found by Ferrari et al. (2015). The results indicate that hemoglobin concentration might be associated with objective exercise performance, symptoms and perceived health status.

The pulmonary function results revealed a significantly lower FEV₁ for participants with anaemia than for those without anaemia (1.39 ± 0.42 L vs. 1.63 ± 0.50 L; $p = 0.031$), but there was no significant difference in FEV₁/FVC ratio ($p = 0.194$). This suggested that the difference in exercise capacity measured was not entirely due to airflow limitation. Additionally, other systemic factors were also emphasized by Okonko et al. (2011) [16] who reported the relationship between iron deficiency/anaemia and exercise capacity in chronic heart failure. Their results led them to consider that the defects in oxygen transport and in iron homeostasis might play a part in causing functional limitation in addition to the impact of the underlying cardiopulmonary disease.

Interventional evidence has also indicated an association between correction of haematological abnormalities and exercise performance. In FERRIC-HF, Okonko et al. 2008 [17] showed that iron treatment was beneficial for exercise capacity in patients with chronic heart failure and ID. Likewise, Silverberg et al. (2001) [18] found that patients with severe congestive heart failure who were treated with erythropoietin and intravenous iron to correct anemia had improved exercise tolerance. Silverberg et al. (2006) also found an improvement in exercise tolerance after correction of anemia in patients with heart failure. These studies were not prospective association studies, but rather evaluation studies looking at interventions, giving further physiological support to

the association that was observed in the present study.

The multivariate regression analysis confirmed the results. Hemoglobin concentration showed a significant positive association with 6MWD ($\beta = 18.6$, 95% CI: 9.4–27.8; $p < 0.001$) and VO₂max ($\beta = 0.082$, 95% CI: 0.041–0.123; $p < 0.001$). There was also significant positive association with handgrip and quadriceps strength, and negative association with MRC dyspnoea and SGRQ scores. From these results, it was concluded that an increase in hemoglobin level led to improvement in functional capacity, muscle strength, symptoms, and quality of life. The current study, though, was of a retrospective, observational nature and thus does not establish causality between these associations. Overall results confirmed the importance of hemoglobin concentration to exercise intolerance and acknowledged the potential for other factors such as pulmonary function, smoking, inflammation, comorbidities, and muscle function to impact exercise limitation.”

Conclusion

The present retrospective observational study demonstrated a significant association between hemoglobin concentration and exercise tolerance among 80 participants. Participants with anemia had significantly lower 6-minute walk distance, VO₂max, handgrip strength, and quadriceps strength, along with greater dyspnoea and poorer respiratory-related quality of life compared with non-anemic participants. Multivariable regression further showed that higher hemoglobin concentration was independently associated with better 6MWD, VO₂max, and muscle strength, while being associated with lower MRC and SGRQ scores. These findings indicate that reduced hemoglobin concentration may contribute to impaired functional capacity and exercise performance. However, pulmonary function, smoking, inflammation, comorbidities, and other clinical factors may also influence exercise tolerance. Therefore, hemoglobin concentration should be considered an important component of the overall assessment of functional exercise capacity.

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