





Original Article



Impact of Inspiratory Muscle Strength and Lung Function on Functional Exercise Capacity in Post-myocardial Infarction Patients: A Cross-sectional Study

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Abstract

OBJECTIVE: This study aims to investigate the contribution of lung function and respiratory muscle strength in predicting functional exercise capacity in post-myocardial infarction (MI) subjects.

MATERIAL AND METHODS: This cross-sectional study included 56 stable post-MI subjects. Lung function was assessed using a digital spirometer, and respiratory muscle strength was measured using an intraoral pressure meter. The 6-minute walk distance (6MWD) was conducted to assess functional exercise capacity. Correlations and multiple regression analyses were performed to evaluate predictors of 6MWD, considering demographic factors, lung function, and respiratory muscle strength. The Bland-Altman plot was used to investigate the agreement between observed and predicted 6MWDs.

RESULTS: Significant positive correlations were found between 6MWD and forced vital capacity (FVC)_{%predicted} ($r = 0.528$, $P = 0.022$) and maximum inspiratory pressure (MIP)_{%predicted} ($r = 0.640$, $P = 0.022$). Age ($r = -0.350$, $P = 0.008$) and body mass index (BMI) ($r = -0.561$, $P < 0.001$) were negatively correlated with 6MWD. The best regression model included MIP_{%predicted} ($\beta = 0.332$, $P = 0.002$), BMI ($\beta = -0.264$, $P = 0.012$), being male ($\beta = 0.262$, $P = 0.003$), age ($\beta = -0.210$, $P = 0.020$), and FVC_{%predicted} ($\beta = 0.219$, $P = 0.026$) as significant unique contributors. The final multiple linear regression model was significant [$F(5, 50) = 19.08$, $P < 0.001$] and explained 65.6% of the variance ($R^2 = 0.656$) in the 6MWD.

CONCLUSION: Lung function and respiratory muscle strength significantly contribute to functional exercise capacity in post-MI. This study emphasizes the importance of comprehensive respiratory function assessments in rehabilitation strategies to improve exercise capacity in patients with post-MI.

KEYWORDS: Myocardial infarction, lung function, respiratory muscle strength, functional exercise capacity, 6-minute walk test

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INTRODUCTION

Cardiovascular diseases represent a significant public health challenge, being the leading cause of mortality worldwide. Myocardial infarction (MI), commonly referred to as a heart attack, is a critical condition that contributes substantially to the overall burden of cardiovascular diseases.^{1,2} Individuals who experience MI often suffer from impaired lung function, reduced respiratory muscle strength, and decreased self-confidence, which limit functional exercise capacity and daily activities.^{3,4} These physiological changes can adversely affect the patient's ability to perform tasks and reduce functional exercise capacity.

The 6-minute walk test distance (6MWD) is an easy-to-perform, valid, and reliable submaximal exercise test to assess the functional exercise capacity of various populations, including those with cardiovascular conditions.⁵⁻⁸ It is a popular fitness-based functional exercise capacity test in which individuals are instructed to walk as far as possible within

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a set time interval.⁹ This test is widely used in the clinical management of patients with chronic lung^{6,7} and heart^{5,8} diseases. Studies indicate that assessment of 6MWD is safe for post-MI patients.⁹

Studies have shown that MI patients exhibit reduced inspiratory muscle strength, which is associated with poorer exercise tolerance.¹⁰ Improvements in maximum inspiratory pressure (MIP), an indicator of inspiratory muscle strength, have been associated with 6MWD, emphasizing the importance of respiratory muscle function in predicting functional exercise capacity.^{11,12} In addition, the interaction between respiratory muscle strength and lung function parameters such as forced vital capacity (FVC) emphasizes the importance of evaluating both parameters.^{11,13} Post-MI patients commonly experience impairments in respiratory function due to reduced cardiopulmonary reserve, deconditioning, and potential respiratory muscle weakness.¹⁰ Inspiratory muscle strength, typically measured via MIP, has been shown to be a significant determinant of functional capacity in both cardiac and pulmonary populations.^{11,12,14-16} Reduced MIP is associated with dyspnea and exercise intolerance, while improvements in MIP correlate with enhanced walking distance and daily functional status.^{11,12,14-16} Lung function, particularly FVC, is also considered a key parameter reflecting ventilatory mechanics and pulmonary reserve. Given that respiratory muscle strength and lung function are interdependent and may synergistically affect exercise capacity, incorporating both parameters into predictive models provides a more comprehensive understanding of functional limitations in post-MI patients.^{11,13} Therefore, MIP and FVC were included as independent variables in this study based on their physiological relevance and prior evidence linking them to exercise performance. Understanding the contributions of these factors to the 6MWD provides valuable insights for optimizing rehabilitation strategies. This study aims to investigate the contribution of demographic factors, respiratory muscle strength, and lung function in predicting 6MWD in post-MI patients.

MATERIAL AND METHODS

Study Design and Participants

In this cross-sectional study, a total of 56 clinically stable post-MI patients (≥ 18 years) were consecutively recruited from the Cardiology Department of Dokuz Eylül University Hospital between January 2024 and May 2024. Furthermore, since the main guidelines for assessment of 6MWD and lung function tests recommend a minimum of 1 month after the MI, to perform the tests, participants were recruited at least 1

month after MI.^{9,17} Exclusion criteria were followed: not stable acute myocardial infarction, acute myocardial infarction with arrhythmia, atrial fibrillation, chronic obstructive pulmonary disease, asthma, class 3-4 angina pectoris according to Canadian Cardiovascular Society classification,¹⁸ exercise-induced myocardial ischemia, aortic stenosis, pericardial disease, any heart valve disease, resting heart rate (HR) more than 120, resting systolic blood pressure ≥ 180 mmHg, resting diastolic blood pressure ≥ 100 mmHg, resting peripheral O₂ saturation $\leq 90\%$, and not being in good physical condition to perform a walking test (such as having any orthopedic disease that may affect walking performance).

The study was conducted following the Declaration of Helsinki and its later amendments or comparable ethical standards and was approved by the Institutional Ethical Board of Dokuz Eylül University (approval number: 2023/29-04, date: 20.09.2023). All participants gave informed consent before the study. We followed the Strengthening the Reporting of Observational Studies in Epidemiology guideline for reporting this study.¹⁹

Assessments

Once the demographic and clinical parameters were recorded, lung functions, respiratory muscle testing, and 6MWD were assessed.

According to the guidelines of the American Thoracic Society (ATS) and the European Respiratory Society, lung function and respiratory muscle strength were measured using standardized methods, using a digital spirometer and an intraoral pressure meter device (CosmedR Pony FX, Italy).^{20,21} Lung function tests were repeated with three satisfactory maneuvers by measuring the total volume of air exhaled from total lung capacity to maximal expiration, and the highest values were recorded.²⁰ Peak expiratory flow (PEF) and FVC were measured in lung function tests. Respiratory muscle strength tests, including MIP and maximal expiratory pressure (MEP), were measured from residual volume and total lung capacity. The highest value of three maneuvers, varying by less than 10%, was recorded.^{21,22} All tests were performed in a seated position, with participants wearing nose clips and using a standard mouthpiece during the maneuver.^{20,21} All parameters are presented as percentages (%) of predicted values.

The 6MWD was performed in a covered, flat, 30-m corridor marked with cones in the cardiology department, according to the ATS guidelines.⁹ The test was performed by a physiotherapist in a setting where the unit's medical staff could be called upon if necessary. HR, blood pressure, peripheral oxygen saturation (SpO₂), and the modified Borg Scale for perceived exertion were measured at baseline and post-test, respectively. HR and SpO₂ were also monitored during the test performance using a pulse oximeter. Signs and symptoms of exertional intolerance (chest pain, intolerable dyspnea, leg cramps, staggering, diaphoresis, and pale or ashen appearance) were used as criteria to interrupt the test.²³ In this case, patients were initially excluded, then immediately assessed by medical staff, and, if necessary, provided with additional tests and medication.

Main Points

- Lung function contributes to functional exercise capacity in post-myocardial infarction (MI) patients.
- Respiratory muscle strength is a highly predictive factor of functional capacity in post-MI patients.
- Respiratory muscle strength assessments in rehabilitation can optimize outcomes by addressing individual functional limitations in post-MI patients.

Statistical Analysis

Data were analyzed using Statistical Package for the Social Sciences (SPSS) for Windows version 21.0 (SPSS Inc., Chicago, IL, USA). Data were checked for distribution and presented as means±standard deviation. Categorical variables were presented in percentages. The relationship between 6MWD and other parameters was analyzed using the Pearson correlation coefficient (*r*), and a stepwise regression analysis was carried out to evaluate independent parameters explaining the variance in the 6MWD. Sex was assigned a dummy value (0 = female; 1 = male). The variance inflation factor (VIF) was used to assess multicollinearity, with a VIF value below 5 indicating that the independent variables did not demonstrate multicollinearity.

We extracted a reference equation (based on the final model) to check how the regression model explains contributions of parameters. First, we used regression lines displaying the slope and intercept to confirm the calibration of observed 6MWD vs. predicted 6MWD (calculated from the regression equation). In the next stage, we investigated the agreement between observed and predicted 6MWDs using the Bland-Altman method. $P < 0.05$ was considered statistically significant for all analyses.

We calculated an estimated required sample size for this study using G*Power software version 3.1.9.2, based on the correlation between MIP and 6MWD in a relevant study in the literature.²⁴ We found an estimated required sample size of at least 50 participants with an expected correlation of at least $r = 0.4$, assuming a 5% margin of error ($\alpha = 0.05$) and 85% power ($1 - \beta = 0.85$). We invited a total of 60 subjects to participate in the study, estimating a ~20% non-participation rate.²⁵

RESULTS

A total of 102 subjects were screened for eligibility to participate in the study. Of these, 42 were excluded for not meeting the inclusion criteria. In total, 60 subjects were invited to the study and 4 of them declined to participate. Therefore, the study was completed with the 56 subjects who agreed to participate.

The mean age of the patients was 56.9 ± 10.2 years, and their body mass index (BMI) was 25.6 ± 3.3 kg/m². The mean 6MWD was 487.2 ± 82.8 meters. Demographic and clinical characteristics of patients are presented in Table 1.

There were significant positive correlations between 6MWD and height ($r = 0.305$, $P = 0.022$), $FVC_{\%predicted}$ ($r = 0.528$, $P = 0.022$), $PEF_{\%predicted}$ ($r = 0.376$, $P = 0.022$), $MIP_{\%predicted}$ ($r = 0.640$, $P = 0.022$), and $MEP_{\%predicted}$ ($r = 0.425$, $P = 0.022$). There were significant negative correlations between 6MWD and age ($r = -0.350$, $P = 0.008$), weight ($r = -0.370$, $P = 0.002$), and BMI ($r = -0.561$, $P < 0.0001$) (Figure 1, Table 2).

The best model included $MIP_{\%predicted}$ ($\beta = 0.332$, $P = 0.002$), BMI ($\beta = -0.264$, $P = 0.012$), being male ($\beta = 0.262$, $P = 0.003$), age ($\beta = -0.210$, $P = 0.02$), and $FVC_{\%predicted}$ ($\beta = 0.219$, $P = 0.026$), as significant unique contributors. The final multiple linear regression model was significant [$F(5, 50) = 19.08$,

$P < 0.001$, Table 3] and explained 65.6% of the variance ($R^2 = 0.656$) in the 6MWD (Table 2).

Therefore, the reference equation including respiratory functions (final model) was as follows: $6MWD(m) = 534.311 + (52.412 \times \text{sex}) - (6.546 \times \text{BMI kg/m}^2) - (1.702 \times \text{age years}) + (1.078 \times FVC_{\%predicted}) + (0.909 \times MIP_{\%predicted})$. In the equation, sex is 1 if male and 0 if female.

When comparing the observed values to the predicted values of 6MWD in relation to the regression model's calibration, there was no correlation between the differences (bias) and the mean, and the fitted line was less sloped compared to the main diagonal (observed and predicted 6MWDs correlation: $r = 0.810$, $P < 0.001$) (Figure 2).

In Figure 3, the Bland-Altman plot illustrated a good level of agreement between observed and predicted 6MWD, with no evidence of systematic bias. Although a slight bias was observed for high and low values of distance covered, most of the differences were within the limits of agreement.

Table 1. Demographic and clinical characteristics of patients

Variables	
Demographic and anthropometric data	
Sex	
Male, n (%)	44 (78.6)
Female, n (%)	12 (21.4)
Age (years)	56.9 ± 10.2
Height (m)	1.72 ± 0.07
Weight (kg)	75.3 ± 10.1
BMI (kg/m ²)	25.6 ± 3.3
Angina Classification	
Class 1, n (%)	40 (71.4)
Class 2, n (%)	16 (28.6)
Class 3, n (%)	-
Class 4, n (%)	-
Smoking status	
Current smokers, n (%)	19 (33.9)
Ex-smokers, n (%)	22 (39.3)
Non-smokers, n (%)	15 (26.8)
Lung function	
$FVC_{(\%predicted)}$	89.5 ± 16.8
$PEF_{(\%predicted)}$	63.9 ± 18.8
$MIP_{(\%predicted)}$	87.3 ± 30.3
$MEP_{(\%predicted)}$	73.8 ± 21
6-minute walk distance (m)	487.2 ± 82.8

Data are presented as mean±SD or n (%).

SD: standard deviation, BMI: body mass index, FVC: forced vital capacity, PEF: peak expiratory flow, MIP: maximal inspiratory pressure, MEP: maximal expiratory pressure

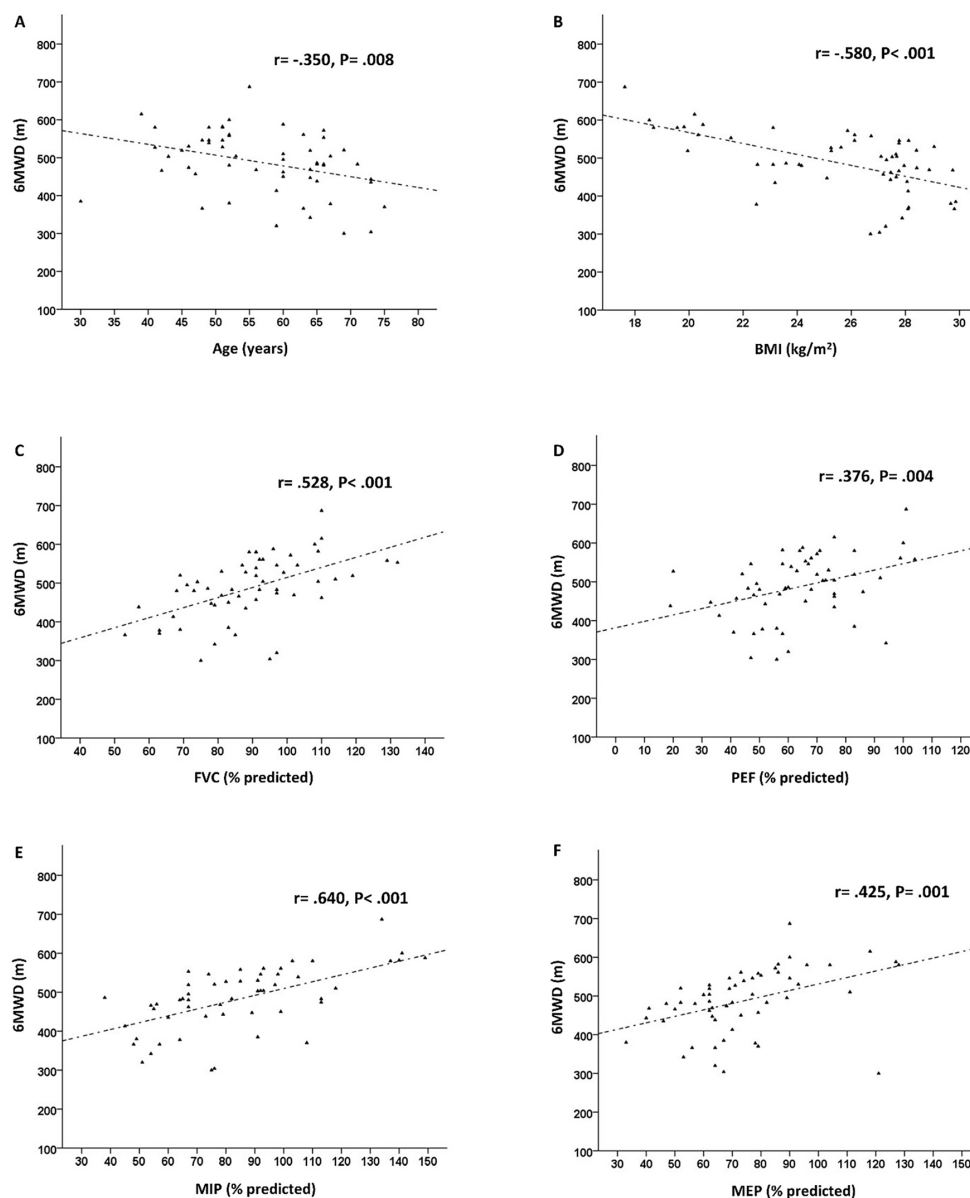


Figure 1. Relationship of the 6MWD with (A) age, (B) BMI, (C) FVC_{%predicted}, (D) PEF_{%predicted}, (E) MIP_{%predicted}, (F) MEP_{%predicted}

6MWD: 6-minute walk distance, BMI: body mass index, FVC: forced vital capacity, PEF: peak expiratory flow, MIP: maximal inspiratory pressure, MEP: maximal expiratory pressure

Table 2. Correlations for the 6MWD with demographic parameters and respiratory function

Variables	6MWD	
	r	P
Age (years)	-0.350	0.008
Height (m)	0.305	0.022
Weight (kg)	-0.401	0.002
BMI (kg/m ²)	-0.580	<0.001
FVC (% _{predicted})	0.528	<0.001
PEF (% _{predicted})	0.376	0.004
MIP (% _{predicted})	0.640	<0.001
MEP (% _{predicted})	0.425	0.001

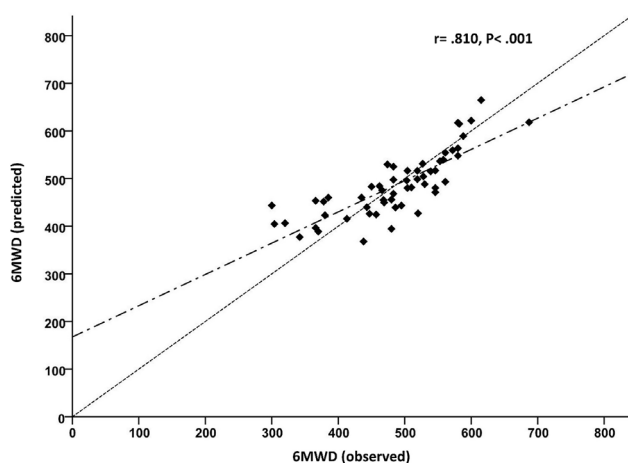
BMI: body mass index, FVC: forced vital capacity, PEF: peak expiratory flow, MIP: maximal inspiratory pressure, MEP: maximal expiratory pressure

Table 3. Linear regression analysis between 6-minute walk distance and maximal inspiratory pressure, body mass index, gender, age, and forced vital capacity

	B	SE	β	VIF	t	P
Constant	534.311	111.907			4.775	0.000
MIP (%predicted)	0.909	0.276	0.332	1.477	3.298	0.002
BMI (kg/m ²)	-6.546	2.508	-0.264	1.482	-2.610	0.012
Male	52.412	17.001	0.262	1.050	3.083	0.003
Age (years)	-1.702	0.707	-0.210	1.103	-2.408	0.020
FVC (%predicted)	1.078	0.471	0.219	1.331	2.290	0.026

Final model, dependent variable: 6-minute walk distance, $R^2 = 0.656$, $F(5, 50) = 19.08$, $P < 0.001$. * $P < 0.05$.

B: unstandardized beta, SE: standard error for B, β : standardized beta, t: Student's t-test statistic, VIF: variance inflation factor, MIP: maximal inspiratory pressure, BMI: body mass index, FVC: forced vital capacity

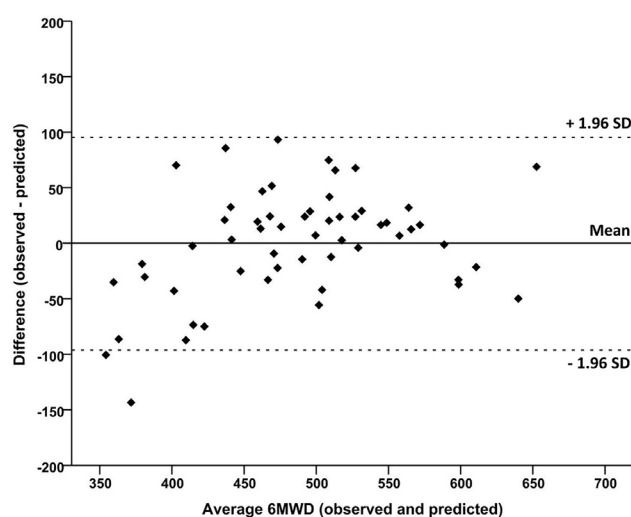
**Figure 2.** Calibration plot of the observed vs predicted values for the 6MWD

6MWD: 6-minute walk distance

DISCUSSION

The current study aimed to investigate the contribution of lung function, respiratory muscle strength, and demographic factors to 6MWD in post-MI patients. The key findings of this study suggest that demographic factors (age, BMI, and sex), lung function (FVC_{%predicted}), and inspiratory muscle strength (MIP_{%predicted}) are significant predictors of 6MWD in post-MI patients.

The relationships between respiratory functions, specifically FVC and MIP, and the 6MWD in post-MI patients are a critical area of research. Understanding these relationships is important for evaluating functional exercise capacity, cardiovascular mortality, and morbidity risk, and overall prognosis in this population.²⁶⁻²⁸ Studies have demonstrated that both FVC and MIP correlate positively with functional exercise capacity, as measured by 6MWD, across different populations.²⁸⁻³⁵ Luchesa et al.³⁰ found that FVC and MIP were independent contributors to the 6MWD in obese Brazilian women. Similarly, Huzmeli et al.³⁴ reported significant correlations between pulmonary functions, including FVC and MIP, and 6MWD in patients with stable angina. Moreover, in individuals with chronic heart failure, reduced MIP has been associated with reduced exercise capacity, impaired quality of life, and increased mortality risk.²⁸

**Figure 3.** Bland altman plot of the averaged values and the differences (observed-predicted values) for 6MWD

6MWD: 6-minute walk distance, SD: standard deviation

In line with these findings, our results showed that FVC and MIP were independently associated with 6MWD, reinforcing the relevance of respiratory function in post-MI patients. These findings suggest that impairments in FVC and MIP may limit functional exercise capacity and highlight the value of incorporating respiratory assessments into routine clinical evaluation for patients recovering from MI.

There is also growing evidence supporting the efficacy of inspiratory muscle training (IMT) in improving respiratory muscle strength and functional capacity in the cardiac disease population. Beaujolin et al.³⁶ (2024), in a recent systematic review, demonstrated that IMT significantly increased both MIP and 6MWD in patients with cardiovascular diseases. Similarly, a meta-analysis by Azambuja et al.³⁷ (2020) concluded that isolated IMT resulted in an increase in inspiratory muscle strength, functional capacity, and quality of life in patients with heart failure. These findings lend support to our suggestion that MIP is a modifiable determinant of 6MWD and may be a viable target for cardiac rehabilitation.

In addition to physiological variables, demographic factors were also significant predictors of 6MWD in this study. Age and BMI were negatively associated with walking distance, consistent with the existing literature.^{4,30,38} Age-related declines in skeletal muscle mass, cardiovascular efficiency, and pulmonary function may collectively contribute to reductions in exercise capacity.^{39,40} Similarly, higher BMI may lead to increased effort during physical activity due to excess body weight, which can reduce functional exercise capacity.³⁰ Conversely, males were found to have positively contributed to 6MWD in our study, suggesting that men, in general, have greater walking capacity than women. This may reflect differences in muscle mass, body composition, and lung function between sexes.⁴ This result also aligns with the American Heart Association statistic, which found that men engage in more physical activity than women.¹ This is expected to further increase the 6MWD by positively affecting the muscle strength and aerobic capacity of men. Besides, men usually have greater height than women, which also affects step length and, consequently, walking distance.¹ This result is consistent with other studies conducted in different populations.^{4,41,42}

A notable strength of our study is that, to the best of our knowledge, it is the first study to present a reference equation for the 6MWD in post-MI patients that considers both lung function and respiratory muscle strength as independent variables for the predictive model. However, there are several limitations worth noting. First, the cross-sectional design of the study precludes conclusions about causality. Future longitudinal studies are needed to determine whether interventions targeting respiratory muscle strength can lead to improvements in 6MWD over time. Moreover, the study assumes linear relationships among MIP, FVC, and 6MWD without accounting for the complex physiological and behavioral interactions, such as cardiac remodeling, pharmacological influences, peripheral fatigue, and variability in patient adherence to exercise, that may mediate or moderate these associations. Although BMI was included in our regression model as an independent predictor, other potentially important confounding variables, such as hemoglobin levels, smoking status, medication use, and prior physical activity, were not adjusted for, which may influence the internal validity of the findings. Additionally, our sample size, while adequate, was relatively small and limited to patients from a single center, which may affect the generalizability of our findings. Although patients with general deconditioning or lower functional status were not excluded, the exclusion of individuals with orthopedic conditions affecting gait may have unintentionally resulted in a relatively healthier sample. This reduced the representation of frailer or mobility-limited individuals, thereby limiting the generalizability of our findings to the broader patient population.

CONCLUSION

In conclusion, our findings highlight the importance of assessing lung function, respiratory muscle strength, and demographic factors in predicting functional exercise capacity in post-MI patients. The development of a predictive equation for 6MWD may help clinicians tailor rehabilitation programs to individual patient profiles, ultimately improving outcomes and quality of life. Interventions, such as IMT, aimed at improving

these predictors of 6MWD could enhance functional exercise capacity and overall outcomes in this population. Further studies are needed to show how 6MWD would change by improving lung function and inspiratory muscle strength in this population.

Ethics

Ethics Committee Approval: The study was conducted following the Declaration of Helsinki and its later amendments or comparable ethical standards and was approved by the Institutional Ethical Board of Dokuz Eylül University (approval number: 2023/29-04, date: 20.09.2023).

Informed Consent: All participants gave informed consent before the study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: Ö.O.A, H.D., Concept: R.A., Ö.O.A, S.Ö., H.D., Design: R.A., Ö.O.A, S.Ö., H.D., Data Collection or Processing: Ö.O.A, Analysis or Interpretation: R.A., Literature Search: R.A., Ö.O.A, S.Ö., Writing: R.A., Ö.O.A, S.Ö., H.D.

Conflict of Interest: No conflict of interest was declared by the authors.

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