The relationship between respiratory functions, exercise capacity and peripheral muscle strength in hemodialysis patients: a cross-sectional study

A relação entre funções respiratórias, capacidade de exercício e força muscular periférica em pacientes em hemodiálise: um estudo transversal

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Abstract

Introduction: Patients undergoing hemodialysis may experience a wide range of symptoms and functional limitations that can negatively affect their physical abilities and daily activities. **Objective:** To investigate the relationships between pulmonary function, inspiratory muscle parameters, exercise capacity, and peripheral muscle strength in hemodialysis patients. **Methods:** Thirty hemodialysis patients participated in this cross-sectional study. Respiratory function was evaluated using spirometry, and dynamic inspiratory muscle performance was assessed with the POWERbreathe K5 device to measure Strength Index (S-index), peak inspiratory flow (PIF), and inspiratory volume. Exercise capacity was evaluated using a six-minute walk test (6MWT), and lower extremity functional performance was assessed using a 30-second sit-to-stand test (30s-STS). Peripheral muscle strength was determined by measuring the strength of the biceps brachii in the dominant upper extremity and the quadriceps in both lower extremities. **Results:** The mean age of the patients was 53.53 ± 11.53 years. A significant positive correlation was found between forced expiratory volume in one second and both the six-minute walk distance (6MWD) ($r = 0.489$; $p = 0.006$) and the 30s-STS ($r = 0.512$; $p = 0.004$). Forced vital capacity was positively correlated with 6MWD ($r = 0.634$; $p < 0.001$), the 30s-STS ($r = 0.635$; $p < 0.001$), and biceps brachii muscle strength ($r = 0.430$; $p = 0.018$). S-index was associated with the 6MWD ($r = 0.477$; $p = 0.008$). PIF was associated with the 6MWD ($r = 0.465$; $p = 0.010$) and the 30s-STS ($r = 0.482$; $p = 0.007$). Inspiratory volume was also positively associated with the 6MWD ($r = 0.490$; $p = 0.006$) and 30s-STS ($r = 0.498$; $p = 0.005$). **Conclusion:** In hemodialysis patients, respiratory function and dynamic inspiratory muscle parameters are associated with exercise capacity and selected measures of peripheral muscle strength.

Keywords: Respiratory function tests. Exercise tolerance. Muscle strength. Kidney failure, chronic. Renal dialysis.

Resumo

Introdução: *Pacientes em hemodiálise podem apresentar uma ampla gama de sintomas e limitações funcionais que afetam negativamente suas capacidades físicas e atividades diárias.* ***Objetivo:*** *Investigar as relações entre função pulmonar, parâmetros da musculatura inspiratória, capacidade de exercício e força muscular periférica em pacientes em hemodiálise.* ***Métodos:*** *Trinta pacientes em hemodiálise participaram deste estudo transversal. A função respiratória foi avaliada por meio de espirometria, e o desempenho dinâmico da musculatura inspiratória foi mensurado com o dispositivo POWERbreathe K5 para avaliar o índice de força (S-index), o pico de fluxo inspiratório (PFI) e o volume inspiratório. A capacidade de exercício foi avaliada pelo teste de caminhada de seis minutos (TC6), e o desempenho funcional de membros inferiores foi avaliado pelo teste de sentar e levantar de 30 segundos (TSL-30s). A força muscular periférica foi determinada pela mensuração da força do bíceps braquial no membro superior dominante e do quadríceps em ambos os membros inferiores.* ***Resultados:*** *A idade média dos pacientes foi de 53,53 ± 11,53 anos. Observou-se correlação positiva significativa entre o volume expiratório forçado no primeiro segundo e tanto a distância percorrida no teste de caminhada de seis minutos (DTC6) (r = 0,489; p = 0,006) quanto o TSL-30s (r = 0,512; p = 0,004). A capacidade vital forçada apresentou correlação positiva com a DTC6 (r = 0,634; p < 0,001), o TSL-30s (r = 0,635; p < 0,001) e a força muscular do bíceps braquial (r = 0,430; p = 0,018). O S-index associou-se à DTC6 (r = 0,477; p = 0,008). O PFI associou-se à DTC6 (r = 0,465; p = 0,010) e ao TSL-30s (r = 0,482; p = 0,007). O volume inspiratório também apresentou associação positiva com o TC6M (r = 0,490; p = 0,006) e o TSL-30s (r = 0,498; p = 0,005).* ***Conclusão:*** *Em pacientes em hemodiálise, a função respiratória e os parâmetros dinâmicos da musculatura inspiratória estão associados à capacidade de exercício e a medidas selecionadas de força muscular periférica.*

Palavras-chave: *Testes de função respiratória. Tolerância ao exercício. Força muscular. Insuficiência renal crônica. Diálise renal.*

Introduction

Chronic kidney disease (CKD) is a progressive, irreversible condition that impairs kidney function due to structural damage to the kidneys. CKD is categorized into five stages based on glomerular filtration rate. Patients with end-stage CKD require renal replacement therapy to survive. Renal replacement therapies include peritoneal dialysis, hemodialysis, and kidney transplantation. Hemodialysis is the most commonly used treatment method worldwide.[1]

A decline in functional capacity and physical inactivity may occur in patients undergoing hemodialysis due to factors such as protein-energy wasting, metabolic acidosis, chronic inflammation, treatment-related fatigue, and hypotension.[2-4] In this population, pulmonary function, inspiratory muscle performance, exercise capacity, and peripheral muscle strength are among the primary affected functional parameters.[3,5,6] Hemodialysis patients have been shown to have lower spirometric values and reduced respiratory muscle strength compared to healthy individuals.[7,8] The causes of pulmonary dysfunction in this population include fluid overload, uremic myopathy, inflammation, malnutrition, and physical inactivity.[9]

In addition to pulmonary function, hemodialysis patients may exhibit a reduction in diaphragm thickness and inspiratory muscle weakness due to myopathic changes in skeletal muscles that affect respiratory muscles.[3,5,10] Low spirometric values and inspiratory muscle weakness have been linked to the severity of perceived dyspnea in hemodialysis patients.[5,11] Additionally, respiratory muscle weakness has been reported to be associated with reduced oxygen consumption capacity and more pronounced fatigue symptoms in hemodialysis patients. Low spirometric values and inspiratory muscle weakness have also been linked to the severity of perceived dyspnea in these patients.[11]

Given that symptoms such as dyspnea and fatigue can limit functional capacity,[12] assessing pulmonary function and inspiratory muscle performance in this population can provide valuable information for clinical interpretation. Compared to their healthy peers, exercise capacity in hemodialysis patients is significantly reduced and is considered one of the key indicators of functional limitation.[13] Severe fatigue, shortness of breath, and high levels of kinesiophobia are commonly observed in this patient group and have been reported as significant symptoms that accompany a decrease in exercise capacity.[3,14] It is also emphasized that exercise capacity may decrease in individuals undergoing long-term dialysis (defined as ≥ 5 years of hemodialysis)[14] and that this decrease may be associated with an increased risk of mortality.[2,4]

A decline in exercise capacity in hemodialysis patients is associated with not only physical function and symptom burden, but also survival. Therefore, it can be considered an important clinical indicator when determining the need for rehabilitation.

Patients with CKD commonly experience muscle mass loss, low muscle strength, and decreased physical performance. These effects may become more pronounced as the disease progresses, particularly in individuals undergoing hemodialysis. This is due to the accumulation of uremic toxins, increased protein breakdown, chronic inflammation, metabolic disorders, and the physiological burden imposed by the dialysis process.[4,15] A decrease in peripheral muscle strength is commonly reported in CKD population. This decrease is particularly pronounced in the lower extremity muscles of hemodialysis patients and is associated with limitations in functional capacity, mobility, and activities of daily living.[16] In addition, it has been shown that a decrease in peripheral muscle strength in hemodialysis patients is associated with all-cause mortality.[15] A decline in muscle performance of the upper extremities may be observed in hemodialysis patients. Impairments in hand grip strength, proximal muscle strength, and upper extremity function are important clinical indicators of activities of daily living and level of independence.[3,5,17] In patients receiving hemodialysis via an arteriovenous fistula rather than a catheter, the need to protect the affected extremity from trauma, pressure, and excessive strain, coupled with decreased use of the extremity, can lead to decreased daily activity and functional limitations.[18]

Although there are studies on pulmonary function, inspiratory muscle performance, exercise capacity, and peripheral muscle strength in hemodialysis patients, research examining the relationships among these parameters is limited. Previous studies have reported an association between respiratory muscle strength and pulmonary function and exercise capacity in hemodialysis patients.[6,19] However, rehabilitation approaches for hemodialysis patients primarily focus on aerobic and resistance exercises. Studies examining the relationship between pulmonary function, inspiratory muscle performance, and functional outcomes are limited.[20-22] Therefore, the aim of our study is to investigae the relationships between pulmonary function, inspiratory muscle parameters, exercise capacity, and peripheral muscle strength in hemodialysis patients.

Methods

This study was approved by the Başkent University Ethics Committee (KA24/416, date: 02/25/2025) and was funded by the Research Fund. The data presented in this study were obtained from the preliminary findings of an ongoing clinical trial registered under number NCT07094347.

A power analysis was performed using G*Power (version 3.1.9.7, Heinrich Heine University, Düsseldorf, Germany). A post hoc power analysis with effect sizes ranging from r = 0.417 to 0.635 and n = 30 participants yielded statistical power ranging from 70 to 99%. The type I error probability (α) was set at 0.05 for all hypothesis tests.[23]

The study was conducted at the Ümitköy Dialysis Center of Başkent University Hospital from March to June of 2025. Patients aged 18-65 who had received hemodialysis treatment for at least six months, three days a week for four hours per session, were included in the study. Those with severe communication and/or cognitive impairments, as well as those with uncontrolled cardiac, pulmonary, or other systemic diseases, were excluded.

Patients' sociodemographic and clinical characteristics were recorded. These characteristics included age, sex, body mass index (BMI), smoking status, exercise habits, dialysis duration, dialysis adequacy (expressed using Kt/V: a parameter representing the ratio of the product of urea clearance [K] and dialysis duration [t] to the urea distribution volume [V]),[24] hemoglobin level, and serum albumin level. Assessments were conducted prior to the scheduled hemodialysis session to minimize the acute effects of dialysis-related fatigue and changes in fluid balance on functional performance and pulmonary measurements.

Assessment of pulmonary functions

A spirometer (COSMED, Omnia, Rome, Italy) was used to assess pulmonary function. During the assessment, patients were seated in a chair with back support while undergoing a pulmonary function test. After placing a nose clip, patients were instructed to firmly seal the mouthpiece with their lips, breathe normally first, and then, immediately after maximum inspiration, exhale as quickly, forcefully, and completely as possible. The maneuver was continued until the patient could no longer

exhale, and it was repeated until at least three acceptable measurements were obtained. The test assessed forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), the FEV_1/FVC ratio used to evaluate airway obstruction, peak expiratory flow (PEF), and mean forced expiratory flow (FEF_{25-75}).[25] FEV_1 and FVC were recorded in liters (L), PEF and FEF_{25-75} in L/s, and the FEV_1/FVC ratio in percent (%). Additionally, FEV_1, FVC, and FEV_1/FVC values were expressed as a percentage of the expected values based on age, sex, height, and body weight (predicted%).[26]

Assessment of inspiratory muscle performance

Participants' dynamic inspiratory muscle performance was assessed using the POWERbreathe K5 device (HaB International Ltd., UK). During the assessment, patients were positioned in an upright seated position on a back-supported chair, instructed to relax their shoulders, and fitted with a nose clip. Patients were asked to perform a maximum, rapid, and deep inspiration through the mouthpiece following full expiration. Measurements were repeated until at least three acceptable maneuvers were obtained, and the highest value was recorded for analysis. The Strength Index (S-index) value, which represents the maximum dynamic inspiratory muscle force reached during the inspiratory maneuver, was recorded in cmH_2O using a measurement that allows for the evaluation of the dynamic pressure response generated during inspiration. In addition to the S-index value, the peak inspiratory flow (PIF, L/s) and the total air volume inhaled during inspiration (inspiratory volume, L) were also recorded.[27]

Exercise capacity assessment

Participants' exercise capacity was assessed using the 6-Minute Walk Test (6MWT) in accordance with the field test guidelines developed by the European Respiratory Society and the American Thoracic Society.[28] Participants rested for 10 minutes before the test. At the beginning and end of the test, heart rate, blood pressure, oxygen saturation, fatigue, and shortness of breath were recorded. The severity of fatigue and shortness of breath was assessed using the Modified Borg Scale (0 = no symptoms; 10 = most severe symptoms). A 30-meter straight corridor was used for the test, and participants were instructed to walk at a steady pace without running, without slowing down, and taking breaks as needed.

Participants were informed prior to the test that the total duration of rest periods during the test would be included in the 6-minute test duration. Participants were formally supported during the test and were not left alone. The test was repeated twice on the same day, 30 minutes apart, and the longest walking distance obtained from the two tests was recorded in meters (m) for analysis.[28] The distance covered was reported as the 6-minute walk distance (6MWD) in the results and discussion sections.

Peripheral muscle strength assessment

Muscle strength in the patients' upper and lower extremities was measured using a digital hand dynamometer (J-TECH Medical Commander Powertrack II, USA). Biceps brachii muscle strength was measured in the upper extremity area without a fistula, and quadriceps muscle strength was measured in both lower extremities. The biceps brachii muscle strength was measured with the patient seated, the elbow flexed to 90°, and the forearm in a neutral position. The dynamometer was placed on the proximal part of the styloid process.[29] Quadriceps muscle strength was measured with the patient sitting on the edge of the bed, the knee flexed at 90°, and the feet hanging freely without resting on any surface.[30] Three measurements were taken for each assessment (five seconds of maximum voluntary contraction followed by 30 seconds of rest), and the highest value was recorded in newtons (N).[31]

30-second sit-to-stand test

The 30-second sit-to-stand (30s-STS) test, which can be reliably administered to patients with CKD to assess lower extremity performance, was used.[2] The 30s-STS is recognized not only as a conventional measure of lower extremity muscle strength and endurance but also as a multidimensional performance indicator that comprehensively assesses neuromuscular control, dynamic stability, and functional strength.[32] During the test, patients were instructed to sit with their arms crossed over their shoulders and their backs against the chair, then to stand up and sit back down as quickly and continuously as possible for 30 seconds without using their upper extremities for support. The number of correct sit-to-stand repetitions completed by the end of the time period was recorded as the test score.[33]

Statistical analysis

The SPSS statistical software (v25.0, IBM Inc., Armonk, NY, USA) was used for data analysis. The normality of the variables was assessed using the Shapiro-Wilk test. Since the continuous variables were found to follow a normal distribution, descriptive statistics were presented as mean ± standard deviation. Categorical variables were expressed as counts and percentages. Pearson correlation analysis was used to examine the relationships between variables that followed a normal distribution.

Results

The study included 30 hemodialysis patients (12 women and 18 men) with a mean age of 53.53 ± 11.53 years and an average dialysis treatment duration of 10.23 ± 8.58 years. Twenty-nine of the participants were right-handed and one was left-handed. All participants had an arteriovenous fistula on their non-dominant upper limb. The patients' sociodemographic, clinical and functional characteristics are presented in Table 1.

Table 2 presents the correlations between pulmonary function parameters, respiratory muscle function parameters, exercise capacity, and peripheral muscle strength measurements. Statistically significant positive correlations was found between FEV_1 and 6MWD (r = 0.489; p = 0.006) and between FEV_1 and 30s-STS (r = 0.512; p = 0.004). FVC showed a statistically significant positive correlation with 6MWD (r = 0.635; p <0.001), 30s-STS (r = 0.512; p < 0.001), and biceps brachii muscle strength (r = 0.430; p = 0.018) showed a statistically significant positive correlation. The S-index and 6MWD (r = 0.477; p = 0.008) and 30s-STS score (r = 0.491; p = 0.006) showed a significant positive correlation. PIF showed a positive and significant correlation with 6MWD (r = 0.490; p = 0.006) and 30s-STS (r = 0.498; p = 0.005). The S-index, 6MWD (r = 0.490; p = 0.006), 30s-STS (r = 0.498; p = 0.005), biceps brachii muscle strength (r = 0.422; p = 0.020) and right lower extremity quadriceps muscle strength (r = 0.426; p = 0.019).

The correlations among the physical fitness parameters (6MWT, 30s-STS, and peripheral muscle strength) are presented in Table 3. A strong, positive, and statistically significant relationship was found between 6MWD and 30s-STS (r = 0.715; p < 0.001).

Table 1 - Clinical and functional characteristics of the patients

Characteristics	n = 30
Age (years)	53.53 ± 11.53
Body mass index (kg/m²)	26.55 ± 4.93
Dialysis duration (years)	10.23 ± 8.58
Dialysis adequacy (Kt/V)	1.56 ± 0.25
Hemoglobin (g/dL)	11.15 ± 1.30
Albumin (g/dL)	4.01 ± 0.61
Dominant arm	
Right-handed	29 (96.7%)
Left-handed	1 (3.3%)
Fistula located on the non-dominant limb	30 (100%)
Tobacco use	
Smokes	8 (26.7%)
Quit	7 (23.3%)
Does not use	15 (50.0%)
Pack-year	32.67 ± 15.82
Pulmonary functions parameters	
FVC (L)	2.70 ± 0.85
FVC (%predicted)	65.92 ± 15.39
FEV_1 (L)	2.01 ± 0.73
FEV_1 (%predicted)	60.80 ± 17.18
FEV_1/FVC	74.86 ± 13.36
FEV_1/FVC (%predicted)	91.80 ± 17.98
PEF (L)	3.14 ± 1.56
FEF_{25-75} (L/s)	2.00 ± 0.80
Inspiratory muscle functions parameters	
S-Index (cm H_2O)	52.35 ± 19.13
PIF (L/s)	2.98 ± 1.18
Inspiratory volume (L)	1.93 ± 0.60
Exercise capacity	
6-minute walk distance test (m)	363.90 ± 65.74
Peripheral muscle strength measurements	
Biceps brachii muscle strength (N)	52.90 ± 17.15
QFMS (Right) (N)	60.63 ± 18.83
QFMS (Left) (N)	54.61 ± 15.62
30-second sit-to-stand test (n)	7.56 ± 1.65

Note: Data are presented as mean ± standard deviation or n (%). FVC = forced vital capacity; FEV_1 = forced expiratory volume in the one second; PEF = peak expiratory flow; FEF_{25-75} = forced expiratory flow between 25 and 75% of FVC; S-index = Strength Index; PIF = peak inspiratory flow; 6MWD = 6-minute walk distance; QFMS = quadriceps femoris muscle strength; N = Newton.

Additionally, moderate, positive, and statistically significant correlations were found between 6MWD and right lower extremity qua-driceps muscle strength (r = 0.431; p = 0.017) and left lower extremity quadriceps muscle strength (r = 0.422; p = 0.020). A moderate, significant correlation was also found between 30s-STS and right lower extremity quadriceps muscle strength (r = 0.408; p = 0.025).

Table 2 - Relationships of pulmonary function and inspiratory muscle function parameters with exercise capacity and peripheral muscle strength

Parameters	6MWD (m)		30s-STS (n)		BBS (N)		RQS (N)		LQS (N)	
	r	p	r	p	r	p	r	p	r	p
FEV_1(L)	0.489[a]	**0.006**	0.512[a]	**0.004**	0.287	0.124	0.266	0.155	0.124	0.514
FEV_1(%)	0.417[a]	**0.034**	0.290	0.151	0.019	0.928	0.007	0.972	-0.069	0.739
FVC (L)	0.634[a]	**< 0.001**	0.635[a]	**< 0.001**	0.430[a]	**0.018**	0.339	0.067	0.261	0.163
FVC (%)	0.590[a]	**0.002**	0.456a	**0.019**	0.233	0.253	0.075	0.716	0.066	0.748
FEV_1/FVC	-0.181	0.338	-0.134	0.480	-0.232	0.217	-0.091	0.633	-0.220	0.243
FEV_1/FVC (%)	-0.235	0.249	-0.274	0.176	-0.431[a]	**0.028**	-0.164	0.423	-0.237	0.244
PEF (L)	0.297	0.111	0.208	0.270	0.157	0.409	0.282	0.132	0.083	0.664
FEF_{25-75}	0.296	0.113	0.320	0.085	0.208	0.270	0.215	0.254	0.095	0.616
S-index	0.477[a]	**0.008**	0.491[a]	**0.006**	0.257	0.171	0.180	0.342	0.204	0.279
PIF (L/s)	0.465[a]	**0.010**	0.482[a]	**0.007**	0.277	0.139	0.168	0.374	0.195	0.302
IV (L)	0.490[a]	**0.006**	0.498[a]	**0.005**	0.422[a]	**0.020**	0.426[a]	**0.019**	0.343	0.064

Note: Values are presented as correlation coefficients (r). 6MWD = 6-minute walk distance; 30s-STS = 30-second sit-to-stand test; BBS = biceps brachii strength; RQS = right quadriceps strength; LQS = left quadriceps strength; FEV_1 = forced expiratory volume in the one second; FVC = forced vital capacity; PEF = peak expiratory flow; FEF_{25-75} = forced expiratory flow between 25 and 75% of FVC; S-index = Strength Index (cmH_2O); PIF = peak inspiratory flow; IV = inspiratory volume; N = Newton. Bold text indicates statistical significance ($p < 0.05$). [a]Pearson test.

Table 3 - Relationship between individuals' respiratory physical fitness parameters

Parameters	6MWD (m)		30s-STS (n)		BBS (N)		RQS (N)		LQS (N)	
	r	p	r	p	r	p	r	p	r	p
6MWD(m)	1	–	0.715[a]	**< 0.001**	0.213	0.258	0.431[a]	**0.017**	0.422[a]	**0.020**
30s-STS (n)	0.715[a]	**< 0.001**	1	–	0.440[a]	**0.015**	0.408[a]	**0.025**	0.398[a]	**0.029**
BBS (N)	0.213	0.258	0.440[a]	**0.015**	1	–	0.443[a]	**0.014**	0.566[a]	**0.001**
RQS (N)	0.431[a]	**0.017**	0.408[a]	**0.025**	0.443[a]	**0.014**	1	–	0.789[a]	**< 0.001**
LQS (N)	0.422[a]	**0.020**	0.398[a]	**0.029**	0.566[a]	**0.001**	0.789[a]	**< 0.001**	1	–

Note: Values are presented as correlation coefficients (r). 6MWD = 6-minute walk distance; 30s-STS = 30-second sit-to-stand test; BBS = biceps brachii strength; RQS = right quadriceps strength; LQS = left quadriceps strength. Bold text indicates statistical significance ($p < 0.05$). [a]Pearson test.

Discussion

This study examined the relationship between respiratory function, dynamic inspiratory muscle parameters, exercise capacity, lower extremity functional performance, and peripheral muscle strength in hemodialysis patients. The study's most important findings are as follows: pulmonary function parameters (FEV_1 and predicted FEV_1) and inspiratory muscle performance parameters (S-index, PIF and inspiratory volume) were associated with 6MWD;

significant relationships were found between pulmonary function parameters (FEV_1, FVC, predicted FVC, S-index, PIF and inspiratory volume) and performance on the 30s-STS; predicted FEV_1/FVC, FVC and inspiratory volume were associated with biceps brachii muscle strength. Additionally, inspiratory volume was found to be associated with right quadriceps muscle strength.

Pulmonary function values of hemodialysis patients participating in our study revealed that the mean predicted values of FEV_1 and FVC were below the 75% threshold.[3] However, FEV_1/FVC ratio remained relatively preserved, indicating a pulmonary profile that suggests a restrictive pattern rather than an obstructive one among participants. Studies in hemodialysis patients have frequently reported decreased FVC and FEV_1 values, while FEV_1/FVC ratio remains relatively preserved; this finding may be consistent with restrictive-type pulmonary dysfunction.[5,34] Yuenyongchaiwat et al.[14] also demonstrated that restrictive-type pulmonary disorders are more common in patients receiving hemodialysis for five years or longer, and that FVC, FEV_1, predicted FVC, and predicted FEV_1 values were lower in the long-term hemodialysis group compared to those who had been on treatment for a shorter duration. In our study, the fact that the average duration of hemodialysis was over 10 years (10.23 ± 8.58) is an important clinical characteristic that should be considered when interpreting the observed decline in FVC and FEV_1 values. These findings suggest that a history of long-term hemodialysis may be a clinical characteristic that should be considered when interpreting declines in pulmonary function.

The S-index values, which indicate dynamic inspiratory muscle strength, were found to be approximately 52.35 ± 19.13 cmH_2O in our study, which is consistent with the values reported in similar hemodialysis cohorts (55.39 ± 19.14 cmH_2O).[11] In clinical assessment, values below approximately 80 cmH_2O in men and 70 cmH_2O in women are considered consistent with a decrease in inspiratory muscle strength.[35] Since inspiratory muscle measurements in our study were not analyzed separately by sex, the interpretation of the mean value obtained for female and male patients, respectively, is limited. However, because this value falls below the general threshold reported for both women and men, it suggests that inspiratory muscle performance may be low in the study sample.

The 6MWD value of 363.90 ± 65.74 m found in our study was close to the value of 373.04 ± 107.80 m reported for patients on hemodialysis for an average of 5.93 ± 4.96 years.[14] This similarity indicates that our participants' exercise capacity is comparable to previously reported hemodialysis data. Roshanravan et al.[15] have shown that in stage 2-4 CKD patients not receiving dialysis, 6MWD is approximately 30-39% lower than expected, and that a 6MWT distance below 350 m is associated with a higher risk of all-cause mortality. Since our study did not analyze the 6MWD by age, sex, and anthropometric characteristics, the interpretation of the obtained mean value is limited. However, the average 6MWD value is close to 350 m, a level clinically associated with low physical performance in CKD patients. Additionally, some patients may fall below this value when considering the standard deviation. Therefore, functional exercise capacity is a variable that should be clinically considered in our study sample.

The 30s-STS test has been reported to be a reliable and easily applicable method of assessing lower extremity functional performance in hemodialysis patients. Furthermore, it has been shown to be associated with exercise capacity, and twelve repetitions have been proposed as a cutoff value for identifying individuals with low exercise capacity.[2] With a mean of 7.56 ± 1.65 repetitions on the 30s-STS test, the lower extremity functional performance in our sample may be low, though this finding is limited when interpreted without considering factors such as age and sex. However, a study evaluating lower extremity strength in hemodialysis patients using a hand dynamometer reported right and left quadriceps strengths of 83.8 ± 43.2 and 82.0 ± 43.7 N, respectively.[36] These values suggest that the quadriceps strength in our sample may be relatively low.

We were unable to find comparable reference ranges in the literature for dominant biceps brachii muscle strength in hemodialysis patients that used the same measurement position and dynamometer protocol for this muscle group. Consequently, it is difficult to interpret these values based on a definitive cutoff point. Most studies have assessed upper extremity muscle performance in hemodialysis patients through handgrip strength.[13] One study also demonstrated that shoulder peripheral muscle strength and physical activity levels were lower compared to healthy controls.[3] Therefore, the assessment of biceps brachii muscle strength in our study contributes to the understanding of upper extremity function not only in terms of distal muscle performance or hand grip strength, but also in terms of proximal upper extremity muscle strength. Considering this clinical profile, the relationships identified between pulmonary function and

inspiratory muscle parameters on one hand, and exercise capacity and peripheral muscle strength on the other, suggest that functional impairment in hemodialysis patients requires a multidimensional assessment.

Significant correlations were found between 6MWD and pulmonary function test parameters: FEV_1, predicted FEV_1, FVC, and predicted FVC. This finding suggests that exercise capacity in hemodialysis patients may be associated with pulmonary function. Similarly, Posser et al.[19] reported that pulmonary function is associated with exercise capacity in hemodialysis patients. Faria et al.[37] demonstrated that exercise capacity, as evaluated by cardiopulmonary exercise testing and 6MWT, is associated with pulmonary function parameters in patients with stages 4-5 CKD who had not yet begun hemodialysis treatment. Mechanisms such as uremic myopathy, chronic inflammation, metabolic acidosis, changes in fluid balance, and cardiorespiratory involvement can affect pulmonary function and musculoskeletal performance in CKD.[38-41] This interplay may explain the physiological basis of the relationship between pulmonary function parameters and exercise capacity in hemodialysis patients. Specifically, the finding that spirometric parameters, such as FEV_1 and FVC, are associated with 6MWD suggests that exercise capacity is a multidimensional clinical outcome influenced by peripheral muscle performance, ventilatory capacity, and cardiopulmonary coordination. Taken together, these findings suggest that a decline in pulmonary function may be associated with decreased functional capacity beginning in the advanced stages of CKD, prior to hemodialysis. This relationship may also have clinical significance during hemodialysis. However, due to the cross-sectional and correlational design of our study, these relationships should not be interpreted causally. From a rehabilitation perspective, these results suggest that incorporating pulmonary function into comprehensive evaluations of exercise capacity in hemodialysis patients may be beneficial.

Previous studies have reported that, as with pulmonary function in hemodialysis patients, there may be a correlation between respiratory muscle strength and exercise capacity.[42-44] Dipp et al.[43] have demonstrated an association between maximum inspiratory pressure (MIP) values and 6MWD in hemodialysis patients. Similarly, Figueiredo et al.[6] found a positive association between respiratory muscle strength and 6MWD in hemodialysis patients, and Posser et al.[19] reported a positive correlation between 6MWD and MIP in their study of male hemodialysis patients. These studies suggest that inspiratory muscle strength may be associated with exercise capacity in hemodialysis patients. Similar to previous findings, our study identified significant associations between 6MWD and inspiratory muscle performance. These consistent findings suggest that inspiratory and peripheral muscles may be influenced by common mechanisms during hemodialysis. Factors such as uremic myopathy and inflammation may be one of the possible physiological mechanisms underlying this shared muscle involvement.[39,41] Additionally, decreased respiratory muscle strength can make it challenging to meet the increased ventilatory demands of exercise, which can lead to early fatigue and exercise intolerance.[7,45]

Unlike previous studies, we assessed inspiratory muscle performance not using MIP based on static pressure measurements, but using the S-index, a dynamic inspiratory pressure indicator, along with PIF and inspiratory volume responses during the maximum inspiratory maneuver. Our study demonstrates that the relationship between inspiratory muscle performance and exercise capacity in hemodialysis patients extends beyond static inspiratory pressure levels. Flow rate and volume responses during inspiration are also associated with exercise capacity. These findings suggest that inspiratory muscle performance should be considered when evaluating exercise capacity, and that incorporating respiratory muscle performance into comprehensive assessment frameworks could benefit clinical evaluations and the rehabilitation process.

We identified significant correlations between pulmonary function parameters and 30s-STS, which is a multidimensional test that assesses lower extremity muscle strength, endurance, balance, and coordination. It is a valid and reliable functional performance test in hemodialysis patients and is associated with exercise capacity.[3] This test measures the ability to perform repeated sit-to-stand movements over a short period. This comprehensive functional response requires not only lower extremity muscle performance, but also adequate ventilatory capacity. Thus, our findings that FEV_1, FVC, and predicted FVC values are associated with 30s-STS suggests that pulmonary function may relate to lower extremity functional performance.

We also observed significant correlations between 30s-STS and S-index, PIF, and inspiratory volume, which reflect inspiratory muscle performance. However, there are only a limited number of studies reporting that respiratory muscle strength may be associated with functional performance in hemodialysis patients.

Dipp et al.[43] demonstrated a relationship between MIP and MEP values and 30s-STS performance in patients with end-stage renal disease. Additionally, increases in respiratory muscle strength during inspiratory muscle training have been reported to be accompanied by improvements in functional capacity and performance on 30s-STS.[46] These findings suggest that respiratory muscle performance may be associated with performance in the lower extremities. Since systemic muscle impairment in hemodialysis patients affects both peripheral and respiratory muscles, individuals with better functional performance likely exhibit higher levels of dynamic inspiratory performance.

While the cross-sectional design of this study does not permit causal inferences, the observed associations imply that inspiratory muscle performance could be clinically significant when considered alongside functional capacity and peripheral muscle performance in hemodialysis patients. Unlike previous studies, we evaluated inspiratory muscle performance using not only the S-index, a measure of maximum dynamic inspiratory pressure, but also the PIF and inspiratory volume parameters, which reflect flow rate and volume responses during inspiration. These results imply that 30s-STS performance in hemodialysis patients may be related to inspiratory pressure levels and the dynamic flow and volume responses that occur during inspiration. A better understanding of these relationships could contribute to integrating inspiratory muscle performance into functional performance assessments and more comprehensive rehabilitation planning.

When examining the relationship between peripheral muscle strength and pulmonary function in hemodialysis patients, we found correlations between biceps brachii muscle strength and the percentage of the expected values for FVC and FEV_1/FVC. Upper extremity muscle performance in hemodialysis patients has mostly been assessed through handgrip strength, and it has been reported that this parameter is associated with FVC, maksimal volunter ventilasyon, and respiratory muscle strength.[5,13] However, we identified no studies evaluating the relationship between proximal upper extremity muscle strength, such as that of the biceps brachii, and pulmonary function or inspiratory muscle performance in a population with CKD; yet, biceps brachii muscle performance has been associated with FEV_1/FVC in patients with chronic obstructive pulmonary disease, a distinct chronic condition.[47]

This relationship has been explained by the fact that upper extremity muscles are not merely indicators of peripheral strength, but rather muscle groups that may interact with pulmonary load, thoracoabdominal coordination, and overall functional status.[47] In our study, no significant association was found between pulmonary function parameters and the strength of the right and left quadriceps femoris muscles. This can be explained by the fact that isometric quadriceps strength measurements reflect short-term, local maximal muscle strength, while spirometric parameters are more closely related to ventilatory mechanics and pulmonary volumes.

Therefore, the absence of a relationship between quadriceps strength and pulmonary function does not contradict the relationships found between 30s-STS performance and pulmonary parameters; because the 30s-STS is a more dynamic performance test that incorporates repetitive lower extremity movement, functional power, postural control, and cardiopulmonary response, it does not only reflect short-term and local maximal muscle strength. Similarly, a study of older adults reported that pulmonary function parameters were associated with walking distance, but not with quadriceps muscle strength.[48] These findings suggest that the relationship with pulmonary function may be more evident at the level of functional performance than in isolated muscle strength.

In our study, significant correlations were observed between inspiratory volume — a parameter of inspiratory muscle function — and biceps brachii and right quadriceps muscle strength. This finding suggests a possible relationship between the insoiratory volume response and certain aspects of peripheral muscle strength in hemodialysis patients. It has previously been reported that generalized muscle dysfunction is common in hemodialysis patients and that both peripheral muscle strength and respiratory muscle performance may be affected.[41] However, in our study, this relationship was observed only with the inspiratory volume parameter. No similar relationship was found with other inspiratory parameters, such as S-index and PIF. Therefore, the current finding should not be interpreted as indicating a general relationship between peripheral and inspiratory muscle performance. The limited number of studies that directly examine the relationship between inspiratory volume and peripheral muscle strength in hemodialysis patients makes it difficult to discuss this finding in a comparative context.

Future studies with larger sample sizes and multivariate analyses are needed to evaluate the relationship between inspiratory volume response and peripheral muscle strength and functional performance.

From a clinical perspective, the associations identified in our study suggest that functional limitations in hemodialysis patients should be interpreted in conjunction with pulmonary function and inspiratory muscle performance. Our finding that parameters such as FEV_1, FVC, S-index, PIF, and inspiratory volume are associated with 6MWD and 30s-STS performance supports the idea that functional capacity is a multidimensional clinical outcome influenced by ventilatory capacity, inspiratory muscle performance, peripheral muscle function, and overall physical performance. Thus, a functional assessment of hemodialysis patients that considers pulmonary function, inspiratory muscle performance, exercise capacity, lower extremity functional performance, and peripheral muscle strength together may provide a more comprehensive clinical interpretation. From a rehabilitation planning perspective, these findings underscore the importance of comprehensive approaches that evaluate respiratory and musculoskeletal system parameters together. However, due to the cross-sectional design of the study, these results should be interpreted as clinically meaningful associations rather than evidence of causation or therapeutic effects.

Limitations

This study has several limitations. First, the relatively small sample size may limit the statistical power and generalizability of the findings. Second, the cross-sectional design does not permit causal inferences about the relationships between respiratory parameters, exercise capacity, and peripheral muscle strength. Third, the absence of a healthy control group limits our ability to interpret differences in pulmonary and functional findings compared to those of individuals not undergoing hemodialysis. Fourth, the analyses are based on bivariate correlations; no multivariate analysis was conducted to adjust for potential confounding variables, such as age, sex, BMI, dialysis duration, hemoglobin, albumin, smoking status, and physical activity level. Therefore, the observed relationships should be interpreted with caution, as these clinical and demographic factors may have influenced respiratory function, inspiratory muscle performance, peripheral muscle strength and exercise capacity.

Finally, multiple correlation analyses were performed, increasing the risk of false-positive findings. For these reasons, the findings should be interpreted as exploratory. Future studies with larger sample sizes, control groups, longitudinal or interventional designs, multivariate analyses, and appropriate controls for multiple comparisons are needed to clarify the independent and clinically meaningful relationships among these parameters in patients undergoing hemodialysis.

Conclusion

In patients undergoing hemodialysis, pulmonary function and dynamic inspiratory muscle performance have been found to be associated with exercise capacity, lower extremity functional performance, and peripheral muscle strength. These findings suggest that respiratory parameters may help provide a more comprehensive understanding of the multidimensional nature of functional limitations in this patient group. However, due to the cross-sectional design of the study, the results should be interpreted as clinically meaningful associations rather than evidence of causality or therapeutic effects.

Author contribution

ND and YKG were responsible for the investigation. ND and YKG were responsible for data curation, project administration, formal analysis, writing the original draft, and writing - review and editing. ND, YKG, and TÇ were responsible for conceptualization and methodology. All authors approved the final version of the manuscript.

Data availability statement

Data are available upon reasonable request from the corresponding author.

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