Journal of
Clinical Medicine

MDPI

Article

Pulmonary Function, Walking Capacity, and Balance in Patients with Chronic Ischemic Stroke: A Cross-Sectional Study

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Abstract

Background: Respiratory dysfunction is common after stroke, but its relationship with chronic phase walking capacity and balance is unclear. We explored associations between spirometry and walking and balance performance. **Methods:** In this exploratory cross-sectional study, 27 outpatients with chronic ischemic stroke underwent spirometry, including peak expiratory flow (PEF); six-minute walk test (6MWT) and Berg Balance Scale (BBS) data were available for 25. We used Spearman correlations (Bonferroni $\alpha = 0.005$), rank-based partial correlations, and linear regression. **Results:** PEF correlated with 6MWT distance ($\rho = 0.568$, 95% confidence interval [0.21, 0.82], $p = 0.003$; B = 23.92 m per L/s, $R^2 = 0.297$). The association persisted after adjustment for age, body mass index, and time since stroke (partial r = 0.558, $p = 0.007$), although adjusted analyses did not meet the Bonferroni threshold. In 13 participants with high-quality spirometry, the correlation was similar in size but not significant ($\rho = 0.360$, $p = 0.226$). No other parameter correlated with 6MWT distance, and none with BBS scores. **Conclusions:** Higher PEF was associated with longer walking distance in this small exploratory sample, but effort-dependent measurement error and confounding by motor impairment cannot be excluded. PEF should not replace functional assessment; larger studies are needed.

Keywords: stroke; spirometry; postural balance; walk test; respiratory function tests

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Academic Editors: Maria-Arantzazu Ruescas-Nicolau, Marco Iosa and María Luz Sánchez-Sánchez

Received: 21 October 2026
Revised: 9 November 2026
Accepted: 11 November 2026
Published: 12 November 2026

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1. Introduction

Stroke is one of the leading causes of mortality and morbidity worldwide and is an important neurological disease that can lead to varying degrees of impairment in motor, sensory, cognitive, and cardiopulmonary function [1,2]. Functional impairments occurring after stroke are not limited to the acute period but may also negatively affect individuals' mobility, physical activity levels, and independence in the chronic period [2]. Therefore, identifying the physiological factors underlying these persistent functional impairments in the chronic phase of stroke is important for a better understanding of individuals' functional status.

The cardiopulmonary system may also be affected after stroke, with various changes occurring in respiratory muscle strength, ventilatory functions, and trunk control [3–5]. Pulmonary function and respiratory muscle performance have been reported to be associated with trunk control in patients with stroke [3,4]. These findings suggest that respiratory

function may be important after stroke not only for assessing respiratory status but also for determining functional capacity. Spirometry is a fundamental method that enables the objective assessment of pulmonary function through parameters such as forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), the FEV_1/FVC ratio, and peak expiratory flow (PEF) [6,7].

Walking capacity is an important indicator of functional independence after stroke. The six-minute walk test (6MWT) is a widely used assessment tool for evaluating functional walking capacity and submaximal exercise capacity. It has been reported that the 6MWT is widely used in individuals after stroke and that test performance may vary depending on the protocol applied [8]. In patients with chronic stroke, 6MWT distance has been reported to be weakly associated with inspiratory reserve volume and peak inspiratory flow, but not with PEF [9]. Balance is another important component of functional performance after stroke. Balance impairments may contribute to reduced walking performance, increased risk of falls, and dependence in activities of daily living. The Berg Balance Scale (BBS) is a widely used, valid, and reliable clinical assessment tool for evaluating balance performance after stroke [10]. The possible relationship between respiratory function and both balance and gait may be explained by the role of respiratory and trunk muscles in both ventilatory and postural control processes. Previous studies have reported that some respiratory parameters are associated with balance and walking performance after stroke [3,4,11]. A substantial proportion of the studies examining these relationships have included patients with stroke in the acute or subacute phase.

The existing literature indicates that respiratory function after stroke may be associated with functional outcomes such as walking and balance. However, evidence in chronic stroke is limited and inconsistent: studies in chronic stroke have reported no association between 6MWT distance and PEF [9,12], one study in subacute stroke reported an association between percent-predicted PEF and balance [13], and few studies have evaluated several spirometric parameters together with both walking capacity and balance in the same chronic sample. Accordingly, the aim of this exploratory study was to investigate the relationships between spirometric parameters (FVC, FEV_1, FEV_1/FVC, $FEF_{25–75\%}$, and PEF) and 6MWT distance and BBS scores in patients with chronic ischemic stroke. We hypothesized that spirometric parameters would be positively associated with 6MWT distance and BBS scores.

2. Materials & Methods

2.1. Study Design and Setting

This cross-sectional, non-interventional, correlational study was conducted at the Stroke Unit of Istanbul Aydın University Medicalpark Florya Hospital between December 2024 and April 2025. The study was registered at ClinicalTrials.gov (NCT06758791) and is reported in accordance with the STROBE statement for cross-sectional studies [14]. Patients were recruited consecutively among the outpatients who attended the stroke unit during the study period. The study was approved by the Istanbul Beykent University Non-Interventional Clinical Research Ethics Committee (meeting no: 2024/8, 10 September 2024; approval letter dated 20 November 2024, document no: E-45778635-050.99-168517) and was conducted in accordance with the ethical principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to data collection.

2.2. Participants

Twenty-seven consecutive outpatients with chronic ischemic stroke who attended the Stroke Unit were included in the study. Inclusion criteria were: (1) first-ever stroke, (2) age ≥18 years, (3) ischemic stroke subtype, (4) at least 6 months elapsed since stroke onset, (5) modified Rankin Scale score ≤3, (6) ability to communicate and follow instructions,

and (7) willingness to participate. Exclusion criteria were: (1) hemispatial neglect, (2) psychiatric disease, (3) any pre-existing respiratory problem prior to stroke, (4) orthopedic, neurological, or cardiopulmonary conditions contraindicating the study protocols, and (5) diagnosis of sarcopenia. Eligibility was determined by the treating physician (İHU) from the patient's history and medical records, including the absence of pre-existing respiratory disease and sarcopenia; no additional tests were performed to screen for these conditions. Eligible patients were referred to the physiotherapists for assessment. Screening logs were not kept; therefore, the number of patients screened or excluded is not available.

2.3. Outcome Measures

Demographic and anthropometric characteristics (age, sex, height, weight, body mass index [BMI], time since stroke) were recorded for all participants.

2.3.1. Pulmonary Function Testing

Spirometric measurements were obtained in accordance with American Thoracic Society/European Respiratory Society (ATS/ERS) standards [6,15]. Forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), FEV_1/FVC ratio, forced expiratory flow between 25% and 75% of FVC ($FEF_{25–75\%}$), peak expiratory flow (PEF), and peak inspiratory flow (PIF) were recorded. Each participant performed three forced expiratory manoeuvres, and the best manoeuvre was selected for analysis; all spirometric parameters, including PEF, were recorded from this single manoeuvre. Percent predicted and z-score values for FVC, FEV_1, FEV_1/FVC%, and $FEF_{25–75\%}$ were computed by the spirometry system software using the Global Lung Function Initiative (GLI-2012) multi-ethnic reference equations [16]; reference-based normalization was not available for PEF or PIF under the system configuration used in this study. Spirometry was performed with a COSMED Quark PFT system (COSMED, Rome, Italy; 28 mm turbine flowmeter). Participants were tested in the seated position, wearing a nose clip and using disposable mouthpieces; none had facial palsy preventing an adequate lip seal. Each participant received standardized verbal instructions and performed one practice manoeuvre before testing. The device software assigned an acceptability/repeatability quality grade (A–F) according to the 2019 ATS/ERS criteria [6]; this grade is based on FEV_1 and FVC only. Because PEF was taken from the selected best manoeuvre, it was not necessarily the highest PEF among the three attempts. No PEF-specific acceptability or repeatability criteria were applied, and within-session PEF reproducibility could not be assessed because only the best manoeuvre was stored.

2.3.2. Six-Minute Walk Test (6MWT)

Functional exercise capacity was assessed using the 6MWT, performed along a flat, 30 m corridor under the supervision of a physiotherapist, following the ATS guidelines [17] with the modifications described below. Before the test, the corridor and turning points were shown to the participants, but no practice walk was performed. Participants were instructed to walk as far as possible in 6 min and were allowed to rest during the test; the timer was not stopped during rests. Six participants used walking aids (one cane, five tripod canes) during the test. Heart rate and oxygen saturation (measured with a finger pulse oximeter) and Borg rating of perceived exertion were monitored before and after the test for safety but were not recorded. The total distance covered (in meters) was recorded.

2.3.3. Berg Balance Scale (BBS)

Balance performance was evaluated using the BBS, a 14-item performance-based measure assessing the ability to maintain balance during postural changes and functional tasks, originally described by Berg et al. [18] and validated in patients with stroke [10,19].

Each item is scored from 0 (unable to perform) to 4 (normal performance), yielding a total score ranging from 0 (dependent) to 56 (independent).

2.4. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics (version 22.0; IBM Corp., Armonk, NY, USA); percentile bootstrap confidence intervals were additionally computed in Python 3.13 (NumPy 2.5, SciPy 1.18). The normality of data distribution was assessed using the Shapiro–Wilk test, given the sample size ($n < 50$). Normally distributed continuous variables are presented as mean ± standard deviation, and non-normally distributed variables as median (first–third quartile). Categorical variables are presented as frequencies and percentages.

Primary analyses were performed on complete cases ($n = 27$ for spirometric parameters; $n = 25$ for analyses involving the 6MWT or the BBS). In the initial dataset, the two missing 6MWT and BBS values had been replaced by the sample mean; as mean substitution can bias associations, the primary analyses did not use imputed values, and the results with mean-substituted data ($n = 27$) are reported only as a sensitivity analysis.

Associations between spirometric parameters (FVC, FEV_1, FEV_1/FVC, $FEF_{25–75\%}$, and PEF) and the two functional outcomes (6MWT distance and BBS score) were examined using Spearman's rank correlation coefficient for all pairs, because PEF and BMI deviated from a normal distribution and 6MWT distance was borderline. Ninety-five percent confidence intervals were obtained by the percentile bootstrap method: participants were resampled with replacement, the statistic was recalculated in each resample, and the 2.5th and 97.5th percentiles of the resulting distribution were taken as the confidence limits (5000 resamples for correlations and regression coefficients; 3000 resamples for the partial correlations). The ten correlations (5 spirometric parameters × 2 outcomes) were defined as the primary analyses and were judged against a Bonferroni-adjusted threshold of $\alpha = 0.05/10 = 0.005$. All other analyses (partial correlations, regression models, and sensitivity analyses) were considered exploratory, were not corrected for multiplicity, and are interpreted accordingly. Spearman-type (rank-based) partial correlations were calculated by first converting each variable to ranks (average ranks for ties); the ranked spirometric and outcome variables were then each regressed on the ranked covariates, and the Pearson correlation between the two sets of residuals was computed ($df = n - 2 - k$, i.e., 20 with three covariates). Partial correlations adjusted for age, BMI, and time since stroke; in a second model, they adjusted for age, sex, and height. Hierarchical linear regression was used to model 6MWT distance: Model 1 included PEF; Model 2 added age, sex, and height; Model 3 added BMI and time since stroke; and Model 4 included PEF and BBS score; the additional variance explained by PEF beyond BBS (ΔR^2) was calculated as the difference between the R^2 of Model 4 and the R^2 of a model containing BBS score alone. Residual normality (Shapiro–Wilk test), multicollinearity (variance inflation factors), and influential observations (Cook's distance, threshold $4/n$) were checked, and bootstrap confidence intervals were additionally calculated for the simple regression.

Five sensitivity analyses were performed: (1) exclusion of the influential observation identified by Cook's distance; (2) restriction to participants with a device-generated quality grade of A–C (ATS/ERS 2019 criteria) for both FEV_1 and FVC, and to those with an FEV_1 grade of A–C; (3) repetition of the correlations using GLI-2012 z-scores for FVC, FEV_1, FEV_1/FVC, and $FEF_{25-75\%}$ (reference values were not available for PEF); (4) re-analysis of the mean-substituted dataset ($n = 27$) used in the initial analysis; and (5) expression of 6MWT distance as a percentage of the predicted value for healthy adults, calculated with the reference equations of Enright and Sherrill [20]. Peak inspiratory flow (PIF) was recorded but not analyzed, because it could be measured in only 8 of 27 participants. No a

priori sample size calculation was performed; the sample comprised consecutive patients presenting during the study period. For $n = 25$, the minimum detectable correlation with 80% power was $|r| = 0.54$ at $\alpha = 0.05$ and $|r| = 0.65$ at $\alpha = 0.005$. A two-sided p value < 0.05 was considered statistically significant, except where the Bonferroni-adjusted threshold is stated.

3. Results

A total of 27 patients with chronic ischemic stroke (7 women, 20 men; 25.9% and 74.1%, respectively) were included; mean age was 61.1 ± 12.1 years (range, 33–84) and mean time since stroke onset was 15.3 ± 6.7 months. Six participants (22.2%) used a walking aid (one cane, five tripod canes). Six-minute walk test and Berg Balance Scale data were available for 25 participants. Participant characteristics are presented in Table 1.

Table 1. Participant characteristics of patients with chronic ischemic stroke ($n = 27$ unless stated otherwise).

Characteristic	Value
Age, years	61.1 ± 12.1
Sex, female/male, *n* (%)	7 (25.9)/20 (74.1)
Height, cm	169.6 ± 7.4
Body weight, kg	75.0 (70.0–82.5) [a]
Body mass index, kg/m^2	26.0 (24.3–29.2) [a]
Time since stroke, months	15.3 ± 6.7
Walking aid use, *n* (%)	6 (22.2)
Six-minute walk distance, m ($n = 25$)	249.4 ± 77.1
Berg Balance Scale score ($n = 25$)	31.8 ± 9.5
FVC, L	3.18 ± 0.77
FVC z-score	−1.34 ± 0.85
FEV_1, L	2.29 ± 0.66
FEV_1 z-score	−1.65 ± 1.06
FEV_1/FVC, %	71.6 ± 10.6
FEV_1/FVC z-score	−0.81 ± 1.31
$FEF_{25–75\%}$, L/s	2.06 ± 0.94
$FEF_{25–75\%}$ z-score	−0.77 ± 1.05
PEF, L/s	3.01 (2.31–5.26) [a]
PEF, L/min	181 (139–315) [a]
FEV_1/FVC below the lower limit of normal ($z < -1.645$), *n* (%)	9 (33.3)

Data are presented as mean ± SD, or as [a] median (first–third quartile) for variables that deviated from a normal distribution (Shapiro–Wilk $p < 0.05$). Z-scores were calculated by the device software using the GLI-2012 reference equations; reference values are not available for PEF. Six-minute walk test and Berg Balance Scale data were available for 25 of 27 participants. Peak inspiratory flow was recorded (>0 L/s) in only 8 participants and was not analyzed. BMI, body mass index; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 s; $FEF_{25–75\%}$, forced expiratory flow between 25% and 75% of FVC; PEF, peak expiratory flow; SD, standard deviation.

According to the device-generated quality grades (ATS/ERS 2019 criteria), FEV_1 was graded A in 17, C in 1, D in 1, and E in 8 of the 27 participants, and FVC was graded A in 17, C in 3, and E in 7 participants. Fifteen participants had a grade of A–C for both FEV_1 and FVC, whereas 12 had a grade of D or E for at least one of them. Because only the best of three manoeuvres was recorded, within-session reproducibility of PEF could not be assessed. Peak inspiratory flow (PIF) could be recorded (>0 L/s) in only 8 of 27 participants and was therefore not analyzed.

Six-minute walk test and Berg Balance Scale data were available for 25 participants, and correlations with these outcomes were therefore based on $n = 25$. Spearman's rank correlation coefficient was used for all analyses, because PEF and body mass index deviated from a normal distribution and 6MWT distance was borderline (Shapiro–Wilk $p = 0.019$,

0.020 and 0.053, respectively). PEF was positively correlated with 6MWT distance (ρ = 0.568, 95% bootstrap CI [0.21, 0.82], $p = 0.003$), which met the Bonferroni-adjusted threshold for the ten primary correlations (α = 0.005; Table 2). No other spirometric parameter was significantly correlated with 6MWT distance (all $p \geq 0.098$); FEV_1 (ρ = 0.338, $p = 0.098$) and FEV_1/FVC (ρ = 0.318, $p = 0.121$) showed weak-to-moderate associations that were not statistically significant. BBS scores were not significantly correlated with any spirometric parameter (all $p > 0.08$; PEF: ρ = 0.352, $p = 0.084$). 6MWT distance and BBS score were strongly correlated with each other (ρ = 0.786, $p < 0.001$).

Table 2. Spearman correlations (with 95% bootstrap confidence intervals) between spirometric parameters and functional outcomes in patients with chronic ischemic stroke ($n = 25$).

Pulmonary Parameter	6MWT Distance, ρ [95% CI], *p*	BBS Score, ρ [95% CI], *p*
FVC, L	0.164 [−0.256, 0.524], $p = 0.434$	0.192 [−0.243, 0.579], $p = 0.357$
FEV_1, L	0.338 [−0.044, 0.648], $p = 0.098$	0.264 [−0.132, 0.613], $p = 0.202$
FEV_1/FVC%	0.318 [−0.061, 0.642], $p = 0.121$	0.117 [−0.291, 0.506], $p = 0.578$
$FEF_{25–75\%}$, L/s	0.236 [−0.133, 0.532], $p = 0.257$	0.107 [−0.314, 0.488], $p = 0.612$
PEF, L/s	0.568 [0.206, 0.817], $p = 0.003$ *	0.352 [−0.049, 0.653], $p = 0.084$

ρ, Spearman's rank correlation coefficient; CI, percentile bootstrap confidence interval (5000 resamples); 6MWT, six-minute walk test; BBS, Berg Balance Scale; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 s; $FEF_{25–75\%}$, forced expiratory flow between 25% and 75% of FVC; PEF, peak expiratory flow. * Significant after Bonferroni correction for 10 primary correlations (α = 0.05/10 = 0.005).

Because PEF and 6MWT distance were not normally distributed, partial correlations were calculated on ranks, adjusting for age, body mass index, and time since stroke (df = 20). The association between PEF and 6MWT distance persisted (r = 0.558, 95% bootstrap CI [0.17, 0.84], $p = 0.007$), but did not reach the Bonferroni-adjusted threshold used for the primary analysis (α = 0.005); it is therefore interpreted as exploratory. No other spirometric parameter showed a partial correlation whose confidence interval excluded zero (Table 3). In a further model adjusting for age, sex, and height instead, the PEF–6MWT association was similar (r = 0.645, $p = 0.001$).

Table 3. Rank-based partial correlations (with 95% bootstrap confidence intervals) between spirometric parameters and functional outcomes, adjusted for age, BMI, and time since stroke ($n = 25$, df = 20).

Pulmonary Parameter	6MWT Distance, r [95% CI], *p*	BBS Score, r [95% CI], *p*
FVC	0.322 [−0.118, 0.683], $p = 0.144$	0.372 [−0.163, 0.701], $p = 0.088$
FEV_1	0.386 [−0.066, 0.716], $p = 0.076$	0.408 [−0.077, 0.714], $p = 0.060$
FEV_1/FVC%	0.183 [−0.243, 0.591], $p = 0.414$	0.097 [−0.287, 0.534], $p = 0.669$
$FEF_{25–75\%}$	0.161 [−0.289, 0.546], $p = 0.475$	0.161 [−0.363, 0.608], $p = 0.473$
PEF	0.558 [0.167, 0.835], $p = 0.007$ *	0.415 [−0.046, 0.745], $p = 0.055$

r, rank-based (Spearman-type) partial correlation coefficient; CI, percentile bootstrap confidence interval (3000 resamples); other abbreviations as in Table 2. These analyses are exploratory and are reported without additional correction for multiple comparisons. * $p < 0.05$; this association did not meet the Bonferroni-adjusted threshold (α = 0.05/10 = 0.005).

Simple linear regression showed that PEF predicted 6MWT distance (B = 23.92 m per 1 L/s, 95% CI [8.04, 39.81], β = 0.545, t(23) = 3.12, $p = 0.005$; bootstrap 95% CI [11.84, 38.42]), explaining 29.7% of the variance ($R^2 = 0.297$, adjusted $R^2 = 0.266$; F(1,23) = 9.70, $p = 0.005$; Model 1 in Table 4). Because the residuals deviated from normality (Shapiro–Wilk $p = 0.032$), bootstrap confidence intervals are also reported. In hierarchical models,

adding age, sex, and height (Model 2) and then body mass index and time since stroke (Model 3) did not materially change the PEF coefficient (B = 26.50, 95% CI [7.01, 45.98], $p = 0.010$; and B = 28.02, 95% CI [4.67, 51.36], $p = 0.021$, respectively), and none of the added covariates was a significant predictor. Age, sex, and height alone explained 3.8% of the variance in 6MWT distance, and PEF explained an additional 27.6% ($\Delta R^2 = 0.276$, $p = 0.010$). However, with 25 participants and up to seven predictors these models are imprecise (adjusted $R^2 = 0.176$ and 0.096 for Models 2 and 3; overall F-test $p = 0.096$ and 0.259) and should be regarded as exploratory. When BBS score was added (Model 4), the PEF coefficient was reduced by almost half (B = 13.16, 95% CI [2.83, 23.49], $p = 0.015$), and PEF explained an additional 7.9% of the variance beyond BBS alone (BBS-only model: $R^2 = 0.671$, adjusted $R^2 = 0.657$; Model 4: $R^2 = 0.750$; $\Delta R^2 = 0.079$, $p = 0.015$), indicating that part of the PEF–6MWT association is shared with general motor and balance capacity. Variance inflation factors were below 3.0 in all models.

Table 4. Hierarchical linear regression models predicting six-minute walk distance ($n = 25$).

Model/Predictor	B	95% CI	β	*p*
Model 1				
Constant	159.62	94.06 to 225.18	—	<0.001
PEF, L/s	23.92	8.04 to 39.81	0.545	0.005
Model 2				
Constant	217.73	−793.73 to 1229.20	—	0.658
PEF, L/s	26.50	7.01 to 45.98	0.603	0.010
Age, years	0.65	−2.58 to 3.89	0.104	0.677
Male sex (vs. female)	−14.84	−119.91 to 90.23	−0.088	0.771
Height, cm	−0.57	−6.34 to 5.20	−0.055	0.838
Model 3				
Constant	259.86	−969.99 to 1489.71	—	0.662
PEF, L/s	28.02	4.67 to 51.36	0.638	0.021
Age, years	0.71	−2.72 to 4.14	0.113	0.670
Male sex (vs. female)	−15.76	−133.66 to 102.14	−0.094	0.782
Height, cm	−0.88	−7.40 to 5.65	−0.085	0.781
BMI, kg/m^2	0.66	−8.57 to 9.90	0.035	0.882
Time since stroke, months	−1.08	−6.86 to 4.70	−0.097	0.700
Model 4				
Constant	14.68	−47.50 to 76.85	—	0.629
PEF, L/s	13.16	2.83 to 23.49	0.300	0.015
BBS score, points	5.83	3.92 to 7.74	0.717	<0.001

Model fit: Model 1, $R^2 = 0.297$, adjusted $R^2 = 0.266$, $F(1,23) = 9.70$, $p = 0.005$; Model 2, $R^2 = 0.314$, adjusted $R^2 = 0.176$, $F(4,20) = 2.29$, $p = 0.096$; Model 3, $R^2 = 0.322$, adjusted $R^2 = 0.096$, $F(6,18) = 1.42$, $p = 0.259$; Model 4, $R^2 = 0.750$, adjusted $R^2 = 0.728$, $F(2,22) = 33.04$, $p < 0.001$. For reference, the BBS-only model had $R^2 = 0.671$, adjusted $R^2 = 0.657$, $F(1,23) = 46.9$, $p < 0.001$; ΔR^2 for adding PEF to BBS = 0.750 − 0.671 = 0.079. B, unstandardized coefficient; CI, confidence interval; β, standardized coefficient; BBS, Berg Balance Scale. All models are exploratory.

Regression diagnostics identified one influential observation (Cook's distance = 0.32, above the $4/n$ threshold of 0.16): an 84-year-old participant whose walking distance (39 m) was disproportionately low relative to his PEF (1.95 L/s). After excluding this participant ($n = 24$), the association remained (Spearman's $\rho = 0.529$, $p = 0.008$; B = 19.48, 95% CI [5.57, 33.38], $R^2 = 0.277$, $p = 0.008$). In a further sensitivity analysis that used the mean-substituted dataset of the original analysis ($n = 27$), the correlation was similar ($\rho = 0.546$, $p = 0.003$).

In a sensitivity analysis restricted to the 13 participants with 6MWT data and a quality grade of A–C for both FEV_1 and FVC, the PEF–6MWT association had a similar magnitude but was not statistically significant as a rank correlation ($\rho = 0.360$, 95% bootstrap CI [−0.27, 0.91], $p = 0.226$; linear regression B = 19.28, 95% CI [1.15, 37.42], $p = 0.039$, $R^2 = 0.332$). In the 16 participants with an FEV_1 grade of A–C, the correlation was $\rho = 0.499$ ($p = 0.049$; B = 18.08, 95% CI [3.36, 32.80], $p = 0.020$). Participants who did not meet the A–C criteria for both FEV_1 and FVC had a lower median PEF than those who did (2.93 vs. 4.42 L/s, n = 27), but not a shorter median 6MWT distance (289 vs. 248 m, $n = 25$). The effect sizes in these subgroups were similar to that of the full sample, but the subgroups were small and underpowered, and a contribution of variable expiratory effort to the PEF values cannot be excluded. When 6MWT distance was expressed as a percentage of the predicted value (mean 46.9 ± 15.5% of predicted), the correlation with PEF was weaker and not statistically significant ($\rho = 0.364$, $p = 0.073$).

To examine whether the observed associations were influenced by age, sex, or height, correlations were repeated using GLI-2012 z-scores for FVC, FEV_1, FEV_1/FVC, and $FEF_{25–75\%}$ (reference values were not available for PEF). None of the z-scores was significantly correlated with 6MWT distance (all $p \geq 0.124$) or BBS score (all $p \geq 0.197$), a pattern similar to that observed for absolute values (Table 5). Because PEF could not be standardized, this analysis does not allow conclusions about the specificity of the PEF association.

Table 5. Spearman correlations (with 95% bootstrap confidence intervals) between GLI-2012 z-scores of spirometric parameters and functional outcomes ($n = 25$).

Pulmonary Parameter (z-Score)	6MWT Distance, ρ [95% CI], *p*	BBS Score, ρ [95% CI], *p*
FVC	0.251 [−0.107, 0.537], $p = 0.227$	0.267 [−0.146, 0.606], $p = 0.197$
FEV_1	0.316 [−0.065, 0.622], $p = 0.124$	0.238 [−0.162, 0.571], $p = 0.252$
FEV_1/FVC	0.287 [−0.129, 0.654], $p = 0.164$	0.123 [−0.290, 0.496], $p = 0.559$
$FEF_{25–75\%}$	0.229 [−0.191, 0.591], $p = 0.272$	0.129 [−0.331, 0.530], $p = 0.539$

ρ, Spearman's rank correlation coefficient; CI, percentile bootstrap confidence interval (5000 resamples); 6MWT, six-minute walk test; BBS, Berg Balance Scale; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 s; $FEF_{25–75\%}$, forced expiratory flow between 25% and 75% of FVC. Z-scores were calculated by the device software using the GLI-2012 reference equations [16]. Reference values for PEF are not available.

4. Discussion

In this exploratory study of people with chronic ischemic stroke, PEF was the only one of five spirometric parameters significantly associated with 6MWT distance ($\rho = 0.568$, $p = 0.003$; Bonferroni-adjusted $\alpha = 0.005$). Each 1 L/s higher PEF corresponded to about 24 m longer walking distance, but the confidence interval was wide (95% CI, 8.0–39.8 m), and the rank correlation was not significant in the small subgroup with high-quality spirometry, although its magnitude was similar. FVC, FEV_1, FEV_1/FVC, and $FEF_{25–75\%}$ were not significantly associated with 6MWT distance, and no spirometric parameter was significantly associated with BBS scores.

After stroke, loss of cortical motor control, inadequate activation of trunk and respiratory muscles on the hemiparetic side, chest wall asymmetry, and reduced diaphragmatic mo-

bility may adversely affect respiratory mechanics. These neuromuscular and biomechanical changes may lead to reductions in respiratory muscle strength, lung volumes, and expiratory flows, thereby making it more difficult to meet the increased ventilatory demand during physical activity and potentially limiting functional activities such as walking [21–23]. In this context, our study examined the relationships of spirometric parameters with functional walking capacity, as well as their possible relationships with balance performance. Because spirometric parameters describe different volume, time, and flow components of forced expiration, respiratory impairment after stroke may not be reflected in each parameter in the same manner. FVC represents the total volume of air exhaled during forced expiration; FEV_1 represents the volume exhaled in 1 s; FEV_1/FVC represents the ratio used in the assessment of airflow obstruction; and $FEF_{25–75\%}$ represents the mean expiratory flow during the middle half of the FVC. PEF, on the other hand, is the highest flow achieved at the beginning of forced expiration and is markedly influenced by the initial lung volume, airway characteristics, the quality of the start of the maneuver, and voluntary effort [6,21,24].

The literature is not consistent regarding which of these respiratory parameters is associated with walking capacity. Lista-Paz et al. reported that, in individuals with chronic stroke, 6MWT distance was weakly associated with inspiratory reserve volume and peak inspiratory flow, but showed no significant association with PEF [9]. In another small study of patients with chronic hemiplegia, no association was found between the 6MWT and PEF [12]. One meta-analysis reported that respiratory muscle training improved respiratory muscle strength, FVC, FEV_1, and the 6MWT, but had no significant effect on PEF [23], whereas another review reported that respiratory muscle training increased PEF and FEV_1 but did not significantly affect exercise capacity [25]. In our study, a positive and moderate correlation was found between 6MWT distance and PEF, whereas no relationship was observed between the 6MWT and the other spirometric parameters. Since our study had a cross-sectional and correlational design, it does not claim causality; the results of respiratory muscle training studies and other findings in the literature also suggest that the relationship between PEF and walking capacity may not be generalizable to all stroke populations. The limited number of studies directly examining this relationship highlights the need for larger-sample studies that include different stages of stroke and varying clinical characteristics.

Several explanations may account for the finding that only PEF was associated with 6MWT distance. First, PEF is the spirometric parameter most dependent on voluntary effort and on the quality of the start of the forced manoeuvre; it may therefore partly reflect the general ability to mobilize effort and motor control, which also determines walking performance. Second, PEF is influenced by expiratory muscle strength, which may be reduced after stroke, particularly on the paretic side [21–23]. Third, volume-based parameters (FVC, FEV_1) and the FEV_1/FVC ratio depend largely on lung size and airway mechanics, and ventilatory capacity may not be the main constraint on walking in ambulatory patients with chronic stroke; in our sample, 6MWT distance was on average less than half of the predicted value for healthy adults (46.9%), which suggests that motor impairment rather than ventilatory capacity limited walking. Fourth, when BBS score was included in the regression model, the PEF coefficient was reduced by almost half, indicating that part of the PEF–6MWT association is shared with overall motor and balance status. Finally, FEV_1 and FEV_1/FVC showed correlations of similar direction and moderate size ($\rho = 0.34$ and 0.32) that did not reach significance; with 25 participants, only correlations of $|\rho| \geq 0.54$ could be detected with 80% power at $\alpha = 0.05$. The apparent specificity of PEF should therefore be interpreted with caution.

The association persisted after excluding the influential observation ($\rho = 0.529$, $p = 0.008$), after adjustment for age, BMI, and time since stroke (rank-based partial $r = 0.558$), and after adjustment for age, sex, and height ($r = 0.645$; $B = 26.50$ m per L/s).

However, the adjusted analyses did not meet the Bonferroni threshold defined for the primary analyses and are exploratory, and the regression models, with up to seven predictors for 25 participants, had limited precision. The association was also attenuated when BBS score was added to the regression model and when 6MWT distance was expressed as a percentage of the predicted value ($\rho = 0.364$, $p = 0.073$). Residual confounding by anthropometric characteristics and motor impairment therefore cannot be excluded. In the 13 participants with a quality grade of A–C for both FEV_1 and FVC, the rank correlation was similar in size but not significant ($\rho = 0.360$, $p = 0.226$); this subgroup was too small to draw conclusions. Participants with lower-quality tests had lower PEF but not shorter walking distances, which does not support the simple explanation that poor-quality tests merely identified the weakest walkers, although submaximal effort in some participants cannot be excluded. Therefore, rather than concluding that PEF is an independent determinant of the 6MWT, it is more appropriate to conclude that higher PEF values may be associated with longer walking distances. From a clinical perspective, PEF is a quick, inexpensive, and widely available measure. Our findings suggest that it could be explored as an additional measure alongside established walking tests such as the 6MWT, but not as a replacement for direct functional assessment; whether PEF adds information beyond established assessments must be tested in larger studies with quality-controlled spirometry and reference-normalized PEF.

The findings in the literature regarding the relationship between pulmonary function and balance do not fully overlap with those of our study. Guo et al. reported that percent-predicted PEF was significantly associated with the BBS in patients with subacute stroke [13]. Similarly, another study showed that lower BBS scores were associated with weaker respiratory muscle strength and poorer pulmonary function [26]. While the aforementioned studies included larger samples, our study included only 25 participants with BBS data, in whom only correlations of at least 0.54 could be detected with 80% power; the absence of significant associations with BBS may therefore reflect insufficient power and should not be interpreted as evidence of no association. In addition, this discrepancy may be explained by the multifactorial nature of balance performance. While the BBS evaluates the ability to perform functional balance tasks of daily living [10,19], spirometry primarily measures the volume and flow characteristics of the respiratory system [6,7]. Although both functions involve the trunk muscles, balance is likely influenced by additional factors such as lower-extremity motor control, sensory integrity, muscle strength, spasticity, and cognitive processes, which were not assessed in the present study; this interpretation is speculative. It has been reported that the cardiovascular response occurring during the 6MWT may not be explained solely by aerobic demand; rather, the test is a multifactorial performance measure influenced not only by aerobic and pulmonary capacity but also by additional demands such as motor control, balance requirements, and feelings of insecurity during walking [27]. Indeed, the strong relationship found between the BBS and the 6MWT in our study may indicate that balance performance is more closely related to walking capacity than pulmonary function.

This study has several limitations. First, its exploratory, cross-sectional design and small sample (27 participants, 25 with 6MWT and BBS data) preclude conclusions about causality or direction. No a priori sample size calculation was performed, only correlations of $|r| \geq 0.54$ could be detected with 80% power, and the wide confidence intervals indicate considerable imprecision; non-significant findings, particularly for BBS, may therefore reflect insufficient power. Many analyses were performed, and only the ten primary correlations were corrected for multiplicity. Second, the quality of spirometry was suboptimal: 12 of 27 participants had a device-generated quality grade of D or E for FEV_1 or FVC. PEF is strongly effort-dependent, within-session reproducibility of PEF could not be assessed because only the best result

was recorded, and PEF was relatively low compared with FEV_1 in several participants (median PEF/FEV_1 ratio 1.26 s^{-1} in those who did not meet the A–C criteria for both FEV_1 and FVC vs. 1.75 s^{-1} in the others), which may indicate submaximal or slowly initiated expiratory effort. All spirometric parameters were taken from a single best manoeuvre, and the device-generated quality grades reflect the acceptability and repeatability of FEV_1 and FVC only; they do not establish the reliability of the PEF measurements. PEF-specific technical acceptability and repeatability could not be assessed, which is a methodological limitation. PEF could not be expressed as percent predicted or z-score, and PIF could be measured in only 8 participants. Third, important potential confounders were not measured or not analyzed: stroke severity (e.g., NIHSS), lesion side and location, paretic side, the distribution of modified Rankin Scale scores within the eligible range (≤3), lower-extremity motor function, trunk control, spasticity, physical activity level, cognitive status, and smoking history. These data could not be retrieved retrospectively for the present report. Although pre-existing respiratory disease was an exclusion criterion, it was assessed from history and records only, and 9 participants (33.3%) had an FEV_1/FVC ratio below the lower limit of normal. Maximal respiratory pressures (MIP/MEP) were not measured because the device was not available in our hospital, so respiratory muscle strength could not be evaluated directly. Fourth, the 6MWT and BBS data of two participants could not be retrieved. The missing-data mechanism could not be determined; therefore, the primary analyses were conducted using complete cases ($n = 25$). No screening log was kept, so the number of eligible patients and the potential for selection bias are unknown; participants were consecutive outpatients of a single stroke unit, and most were men (74%). Fifth, heart rate, oxygen saturation, and perceived exertion were monitored during the 6MWT for safety but were not recorded, so ventilatory limitation during the test could not be examined; six participants used walking aids, and no practice walk was performed. Finally, there was no healthy control group, so we cannot determine how much of the observed spirometric impairment (e.g., mean FEV_1 z-score −1.65) is attributable to stroke rather than to age, sex, or other factors, or whether the PEF–walking association is specific to people with stroke. GLI-2012 z-scores allowed comparison with population reference values (none was available for PEF) but do not replace a matched control group. Our findings therefore need confirmation in larger studies.

5. Conclusions

In conclusion, in this small exploratory study of people with chronic ischemic stroke, higher PEF was associated with longer 6MWT distance, whereas FVC, FEV_1, FEV_1/FVC, and $FEF_{25–75\%}$ were not significantly associated with walking distance, and no spirometric parameter was significantly associated with balance. Although the association persisted after adjustment for selected demographic and clinical variables, the exploratory nature of these analyses, the small sample size, and the potential for residual confounding prevent conclusions regarding the independent contribution of PEF to walking capacity. The association was attenuated after accounting for BBS score or expressing 6MWT distance as percent predicted, and it was not significant in the small subgroup with the highest-quality spirometry. Because PEF is effort-dependent and could not be standardized against reference values, residual confounding and measurement error cannot be excluded, and PEF should not be used as a substitute for the 6MWT or as a stand-alone indicator of functional capacity. Because of the cross-sectional design, these findings indicate an association and do not show that better pulmonary function leads to better walking performance. The absence of a significant association with BBS should not be taken as evidence that no relationship exists. Future studies should include larger samples, spirometry with strict quality control and reproducibility assessment, reference-normalized PEF, direct measurement of respi-

ratory muscle strength (MIP/MEP), and assessment of stroke severity, trunk control, and lower-extremity motor function.

Author Contributions: Substantial contributions to the conception and design of the work (İ.H.U. and S.A.), performing clinical and neurological assessments (İ.H.U.), performing outcome measurements (D.K.A. and B.A.), analysis of data (S.A.), interpretation of data for the work (İ.H.U., D.K.A., S.A. and B.A.), drafting the work or revising it critically for important intellectual content (İ.H.U., D.K.A., S.A. and B.A.), final approval of the version to be published (İ.H.U., D.K.A., S.A. and B.A.). All authors have read and agreed to the published version of the manuscript.

Funding: The authors received no financial support for the research, authorship, and/or publication of this article.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and was approved by the Istanbul Beykent University Non-Interventional Clinical Research Ethics Committee (meeting no: 2024/8, 10 September 2024; approval letter dated 20 November 2024, document no: E-45778635-050.99-168517). The study was registered at ClinicalTrials.gov (NCT06758791).

Informed Consent Statement: Written informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on reasonable request from the corresponding author. The data are not publicly available because of privacy and ethical restrictions.

Acknowledgments: The authors are grateful to all patients and their families for their participation and cooperation throughout the study. We would also like to express our sincere appreciation to Istanbul Aydın University Medicalpark Florya Hospital for their valuable support and contributions to this research.

Conflicts of Interest: The authors declare no conflicts of interest.

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