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Gait characteristics and their associations with clinical outcomes in patients with chronic obstructive pulmonary disease

Masahiro Iwakura[a,b,*], Kazuki Okura[b], Kazuyuki Shibata[a,b], Atsuyoshi Kawagoshi[a], Keiyu Sugawara[a], Hitomi Takahashi[a], Takanobu Shioya[b], Masahiko Wakasa[b]

[a] Department of Rehabilitation, Akita City Hospital, 4-30 Kawamoto Matsuoka-cho, Akita City, Akita, 010-0933 Japan
[b] Department of Physical Therapy, Akita University Graduate School of Health Sciences, 1-1 Hondo 1-chome, Akita City, Akita, 010-8543 Japan

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ABSTRACT

Background: Abnormalities of spatiotemporal gait parameters are frequently observed in chronic obstructive pulmonary disease (COPD). However, associations of gait parameters with clinical outcomes and their implementation into clinical practice have not been established.
Research question: To investigate gait abnormalities and their association with clinical outcomes of COPD.
Methods: This study included 34 male outpatients with COPD and 16 community-dwelling healthy men aged ≥65 years. The subjects underwent a ten-metre walk test wearing an accelerometer. Data on gait speed, step length, cadence, walk ratio, acceleration magnitude, and standard deviation of step time (step time SD) were collected. Forced expiratory volume in 1-second, modified Medical Research Council dyspnoea score, six-minute walk distance (6MWD), quadriceps muscle strength (QMVC), and physical activity (daily steps and time spent in moderate to vigorous physical activity per day) were measured in the COPD group as clinical outcomes of COPD. We tested group differences in gait parameters, associations between gait parameters and COPD clinical outcomes, and predictive capability of gait parameters for reductions in 6MWD, QMVC, and daily steps in COPD.
Results: All gait parameters except walk ratio deteriorated in COPD. Step time SD and gait speed were significant independent predictors of 6MWD in COPD ($B = -0.440$, $p = 0.001$, $B = 0.339$, $p = 0.007$, respectively). Step length was a significant independent predictor of QMVC ($B = -0.609$, $p < 0.001$) and daily steps ($B = -0.453$, $p = 0.006$). Step length was a significant predictor of muscle weakness and physical inactivity, and step time SD was significant in predicting poor 6MWD in COPD.
Significance: Significant associations between gait abnormalities measured by an accelerometer and deficits in extra-pulmonary features of COPD were observed. An accelerometer-based gait analysis could be an alternative approach to assessing gait abnormalities and screening of functional decline in COPD.

1. Introduction

Gait abnormalities are often observed in chronic obstructive pulmonary disease (COPD) [1–5]. Previous studies have revealed that a reduction in gait speed is a strong indicator of poor exercise capacity (6-minute walk distance [6MWD] ≤350 m) [6] and short-term mortality [7,8]. Gait speed is also significantly associated with important clinical outcomes of COPD [9]. Gait speed measurement shows excellent reliability in COPD [10,11] and responds strongly to pulmonary rehabilitation [12]. The importance of gait speed measurement has thus been increasingly recognized in COPD.

Gait is a complex movement that can be assessed not only by gait speed but also by numerous spatiotemporal parameters [13]. Guidelines for assessment of gait published by The Biomathics and Canadian Gait Consortium Initiative recommend the evaluation of the variability of spatiotemporal parameters such as stride length and swing time in the elderly [13]. Indeed, a recently published systematic review has demonstrated that COPD patients exhibit altered walking patterns compared to healthy elderly individuals [14]. These altered patterns were more evident in COPD patients with severe airflow limitations and

Abbreviations: COPD, chronic obstructive pulmonary disease; 6MWD, 6-minute walk distance; 6MWT, 6-minute walk test; ATS, American Thoracic Society; FEV_1, forced expiratory volume in 1-second; MV-PA, the time spent in moderate to vigorous physical activity per day; BMI, body mass index; QMVC, quadriceps isometric maximum voluntary contraction (kg) to body mass index ($kg \cdot m^{-2}$) ratio; mMRC, modified medical research council; step time SD, standard deviation of step time; R, acceleration magnitude; SDWT, short distance walking test

* Corresponding author at: Department of Rehabilitation, Akita City Hospital, 4-30 Kawamoto Matsuoka-cho, Akita City, Akita 010-0933 Japan.
E-mail address: m.iwa.phys.ther@gmail.com (M. Iwakura).

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history of falls, and might explain why the prevalence of falls is higher in these patients [1].

However, previous studies have had some limitations. First, the associations between spatiotemporal parameters and clinical outcomes of COPD remain to be clarified. Second, all previous studies used gait-analysing systems [1–5] that were expensive and/or required ample space; thus, it is not feasible for clinicians to conduct gait analysis using these systems and obtain results applicable to interventions. Therefore, we aimed (i) to investigate spatiotemporal parameters of gait in patients with COPD using an accelerometer-based gait analysing system; (ii) to identify associations of spatiotemporal parameters of gait with clinical outcomes in COPD; and (iii) to test the capability of each gait parameter to predict poor exercise capacity, lower muscle weakness, and physical inactivity in COPD patients.

2. Materials and methods

2.1. Study design

A cross-sectional study design was used for this study. All subjects underwent a ten-metre walking test, pulmonary function test, the 6-minute walk test (6MWT), and physical activity assessment. COPD patients also underwent muscle strength assessment and completed a questionnaire. This study was performed in conformity with the Declaration of Helsinki and was reviewed and approved by the Ethics Committee of Akita City Hospital, 2015 (accepted No. 19).

2.2. Subjects

Male COPD patients with no exacerbations in the previous 3-months were enrolled in this study. All patients met the following criteria: age ≥65 years, diagnosis of COPD according to international guidelines [15], and the ability to provide written informed consent. The exclusion criteria were as follows: diagnosis of dementia or other mental disorders, inability to communicate, use of any walking aid, use of medication(s) that may affect walking ability, neurological or musculoskeletal conditions that limit mobility, and patients on long-term oxygen therapy. Age-matched male controls with normal spirometry (forced expiratory volume in 1-second [FEV_1]) ≥80% predicted, FEV_1/forced vital capacity ≥0.7) were recruited at a local community centre. The exclusion criterion was absence of health problems that could affect mobility.

2.3. Accelerometer

A tri-axial accelerometer system (Mimamori-gait system, LSI Medience Corporation, Japan) [16,17] was used to measure acceleration signals during gait and to calculate gait parameters (Fig. 1A). The accelerometer (weight: 80 g) was 80 mm long, 60 mm high, and 20 mm wide. The sampling rate was 100 Hz. The accelerometer included a wired remote push button controller able to record events, and allowed the examiner to extract acceleration signals between one event and the next [18]. Acceleration signals and event marker were analysed and gait parameters were calculated using the accelerometer's analysis software on a personal computer [16–18].

2.4. Ten-metre walk test with an accelerometer

Participants wore the accelerometer on their lower back around the third lumbar vertebra, which was defined and marked using an intercristal line by palpation of the iliac crests in accordance with Chakraverty's method [19]. Next, the accelerometer was fixed to a belt around the level of the subject's third lumbar vertebra (Fig. 1 B). The ten-metre walk test was performed as previously described [20]. Two cones were placed 14 m apart, and two lines were drawn 2 m after the first cone and 2 m before the final cone. Participants were instructed to "walk at a comfortable/normal pace" from one cone to the other. Examiners activated the control button once when the participant's first foot completely crossed over the first line and again after crossing the second line. One trained investigator obtained all measurements, and each test was performed twice for each subject with a 5 to 10-second break between trials. The faster of the two trials was used to analyse acceleration signals (Fig. 1C). The following gait parameters were obtained: gait speed ($m \cdot s^{-1}$), step length (m), cadence ($step \cdot min^{-1}$), walk ratio ($mm \cdot (steps \cdot min^{-1})^{-1}$), acceleration magnitude during walking (g), and the standard deviation of step time (step time SD) (s). The walk ratio was calculated as follows [21]: Walk ratio = step length (mm)/cadence ($steps \cdot min^{-1}$). Test-retest reliability of gait parameter measurements was excellent and measurement error of each gait parameter was acceptable (see Supplementary Material 1).

2.5. Clinical outcomes of chronic obstructive pulmonary disease

Airflow limitation was assessed by FEV_1 and described as a percentage of predicted value using previously published reference values [22]. The Global Initiative for Chronic Obstructive Lung Disease (GOLD) classification was used to define severity of airflow limitations as follows: GOLD 1-mild: $FEV_1 \geq 80\%$ predicted; GOLD 2-moderate: $50\% \leq FEV_1 < 80\%$ predicted; GOLD 3-severe: $30\% \leq FEV_1 < 50\%$ predicted; GOLD 4-very severe: $FEV_1 < 30\%$ predicted. The 6MWD was measured as an indicator of functional exercise capacity and was performed according to the European Respiratory Society/ATS technical standards [23]. Physical activity was measured using an accelerometer-based activity monitor (Lifecorder, Suzuken Co., LTD., Japan) [24]. We obtained activity data across at least five weekdays. The subject's average daily steps and time spent in moderate to vigorous physical activity per day (MV-PA) were calculated to define physical activity levels. For quadriceps muscle strength data, we measured quadriceps isometric maximum voluntary contraction (kg) to body mass index (BMI) ($kg \cdot m^{-2}$) ratio (QMVC) using a isometric dynamometer (Hydromusculator GT-160, OG Wellness Technologies Co., LTD, Japan) [25]. Dyspnoea was measured using the modified Medical Research Council (mMRC) dyspnoea scale.

2.6. Statistical analysis

Statistical analyses were performed using SPSS software (IBM SPSS Statistics (version 22.0 for Windows), IBM, United States). The assumption of normality was assessed by the Shapiro-Wilk test. For all analyses, a p-value < 0.05 was considered significant.

Independent samples *t*-tests were used to determine between-group differences for continuous variables. Subgroup comparison of demographics and gait parameters was performed to test differences between COPD patients with GOLD stage 1–2, COPD with GOLD stage 3–4, and controls (details are shown in Supplementary Material 2). Pearson's correlations and Spearman's rank correlations were used to determine the correlations between each gait parameter and clinical outcomes in the COPD group. The gait parameters that had significant correlation with 6MWD, QMVC, and daily steps were then entered into a step-wise multivariate liner regression model to identify the independent gait parameters influencing clinical outcomes. Age and FEV_1 were also included in all multivariate regression models to adjust for age and disease severity.

The capability of each gait parameter to predict poor exercise capacity (6MWD < 350 m) [6], muscle weakness (QMVC < 120%) [25], and physical inactivity (daily steps < 5000 $steps \cdot day^{-1}$) [26] were evaluated using the C-statistic (area under the curve [AUC]) of the logistic model.

Power analysis was performed with the program G*Power 3.1 for a correlation analysis with an α of 0.05, power of 0.80, and expected correlation between each gait parameter and outcome measures to be 0.5 [9]. The calculated sample size was 29, and considering a possible

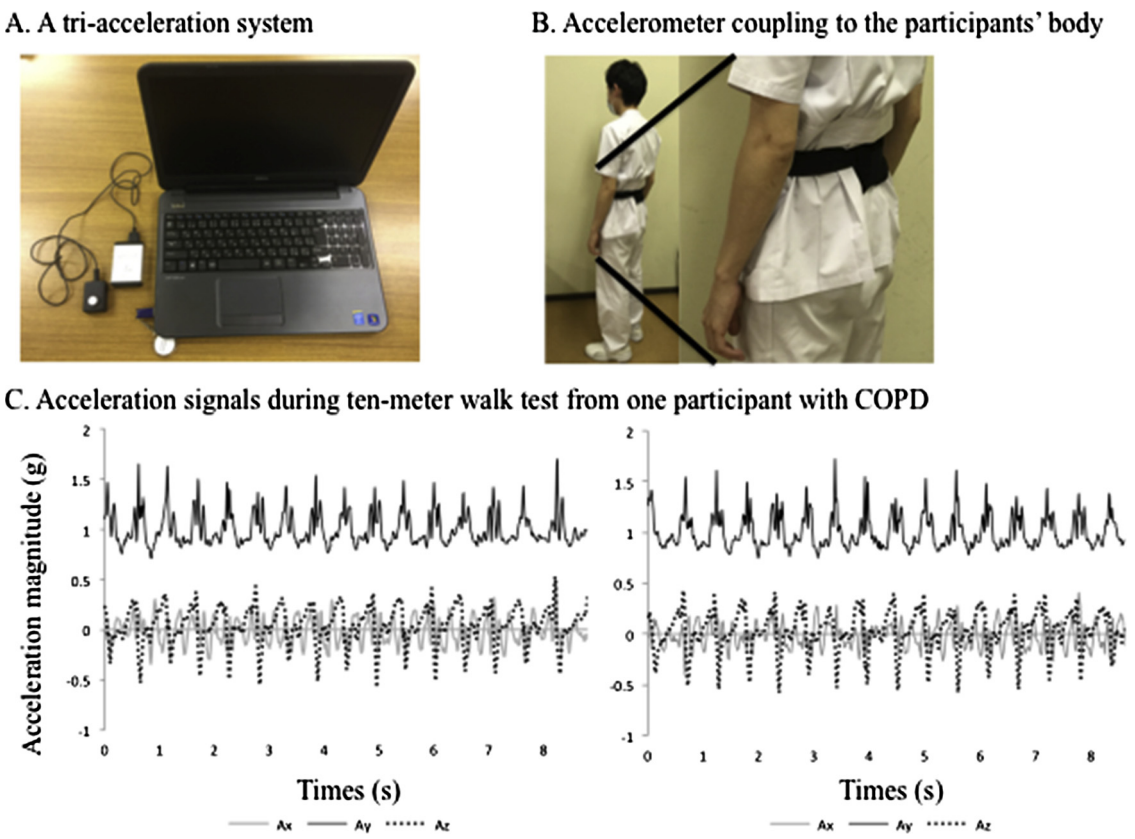

Fig. 1. Description of a tri-accelerometer system.
A. A tri-accelerometer system includes a tri-accelerometer, a wired remote control, and a personal computer with accelerometer's analysis software. B. The accelerometer was fixed to a belt around the level of the subject's third lumbar vertebra. The level of third lumbar vertebra was defined and marked using intercristal line by palpation of the iliac crests. C. Acceleration signals during a ten-metre walk test from one participant with COPD on day 1 (left side) and day 2 (right side) were described. Ax, Ay, and Az represents mediolateral, anterioposterior, and vertical acceleration of the subject's trunk during the test.

Table 1
Demographics and gait parameters in the COPD group and control group.

Variables	COPD	Control	Mean differences (95% CI)	P-value
Age, years	71 (8)	72 (6)	−2 (−6, 3)	0.489
Height, cm	166.4 (5.2)	163.7 (7.2)	2.7 (−0.9, 6.9)	0.135
Weight, kg	60.2 (7.5)	61.2 (9.2)	−1.0 (−5.9, 3.9)	0.673
BMI, $kg \cdot m^{-2}$	21.8 (2.8)	22.8 (2.3)	−1.0 (−2.6, 0.6)	0.217
FEV_1, % predicted	57 (28)*	102 (19)	−45 (−66, −34)	< 0.001
GOLD stage, 1/2/3/4	8/10/10/6	N.A.	N.A.	N.A.
mMRC dyspnea scale	1 (1, 2)	N.A.	N.A.	N.A.
6MWD, m	437 (152)*	529 (127)	−92 (−180, −4)	0.041
QMVC, %	195 (62)	N.A.	N.A.	N.A.
Daily steps, $steps \cdot day^{-1}$	4669 3030)*	7865 (4787)	−3196 (−5434, −959)	0.006
MV-PA, $steps \cdot day^{-1}$	14.9 (16)*	75.2 (34.9)	−60.3 (−74.7, -46.0)	< 0.001
Gait speed, $m \cdot s^{-1}$	1.09 (0.22)*	1.53 (0.23)	−0.44 (−0.58, −0.31)	< 0.001
Step length, m	0.60 (0.08)*	0.71 (0.09)	−0.11 (−0.16, −0.06)	< 0.001
Cadence, $steps \cdot min^{-1}$	109 (10)*	129 (7)	−20 (−26, −15)	< 0.001
Walk ratio, $mm \cdot (steps \cdot min^{-1})^{-1}$	5.53 (0.69)	5.50 (0.65)	0.03 (−0.38, 0.45)	0.883
Acceleration magnitude, g^{+}	0.23 (0.08)*	0.40 (0.11)	−0.17 (−0.23, −0.11)	< 0.001
Step time SD, s	0.03 (0.01)*	0.01 (0.01)	0.01 (0.00, 0.02)	0.001

Definitions: GOLD stage, the Global Initiative for Chronic Obstructive Lung Disease classification of severity of airflow limitation; BMI, body mass index; FEV_1, forced expiratory volume in 1 s; mMRC, modified Medical Research Council; 6MWD, 6-min walk distance; QMVC, quadriceps isometric maximum voluntary contraction (kg) to BMI ($kg \cdot m^{-2}$) ratio; MV-PA, time spent in moderate to vigorous physical activity per day. GOLD stage categorizes airflow limitation into the following four stages; GOLD 1 - mild: $FEV_1 \geqq 80\%$ predicted, GOLD 2-moderate: $50\% \leq FEV_1 < 80\%$ predicted, GOLD 3 - severe: $30\% \leq FEV_1 < 50\%$ predicted, GOLD 4 - very severe: $FEV_1 < 30\%$ predicted. Data are presented as mean (SD) or median (25, 75 percentile) unless otherwise indicated.
*, $p < 0.05$; +, $g \fallingdotseq 9.8\ m/s^2$.

Table 2
Correlations between gait parameters and other outcomes in COPD.

Variable	Age	FEV_1	mMRC	6MWD	QMVC	Daily steps	MV-PA
Gait speed	−0.336	0.216	−0.461*	0.598*	0.499*	0.548*	0.469*
Step length	−0.377*	−0.145	−0.529*	0.591*	0.605*	0.572*	0.391*
Cadence	−0.135	0.129	−0.222	0.400*	0.221	0.336*	0.427*
Walk ratio	−0.286	0.138	−0.382*	0.304*	0.493*	0.362*	0.105
Acceleration magnitude	−0.101	0.260	−0.320	0.489*	0.329	0.365*	0.429*
Step time SD	0.340*	−0.136	0.446*	−0.628*	−0.444*	−0.473*	−0.310
Age	1.000	0.007	0.211	−0.370*	−0.312	−0.441*	−0.128
FEV_1	0.007	1.000	−0.422*	0.508*	0.174	0.059	0.106

Definitions: FEV_1, forced expiratory volume in 1 s; mMRC, modified Medical Research Council; 6MWD, 6-min walk distance; QMVC, quadriceps isometric maximum voluntary contraction (kg) to BMI (kg/m^2) ratio; MV-PA, time spent in moderate to vigorous physical activity per day.
* $p < 0.05$.

15% dropout rate, the final sample size was selected to be 34.

3. Results

All variables followed normal distribution ($p > 0.05$). Baseline demographics for the 34 COPD patients and 16 controls are shown in Table 1 and Supplementary Material 2. Seven (21%) of 34 COPD patients had poor exercise capacity, 5 (15%) exhibited muscle weakness, and 20 (59%) were physically inactive.

Gait speed, step length, cadence, and acceleration magnitude were significantly lower in COPD patients than in controls, while step time SD was significantly higher in COPD patients (Table 1). Subgroup analysis showed that there was no significant difference between gait parameters in COPD patients with GOLD stage 1–2 and GOLD stage 3–4 (Supplementary Material 2).

Correlations between gait parameters and other outcomes in COPD are shown in Table 2. Numerous significant correlations between gait parameters and clinical outcomes were found except between gait parameters and FEV_1.

Step time SD, FEV_1, and gait speed were significant determinants of 6MWD ($p = 0.001$, $p = 0.002$, and $p = 0.007$). Only step length was a significant determinant of QMVC and daily steps ($p < 0.001$ and $p = 0.006$) (Table 3).

Predictive capability of gait speed, step length, and step time SD for poor exercise capacity (6MWD < 350 m), muscle weakness (QMVC < 120%), and physical inactivity (daily steps < 5000 steps·day^{-1}) are described in Table 4. Gait speed and step length were significant in predicting poor 6MWD ($p = 0.041$ and $p = 0.013$, respectively), lower QMVC ($p = 0.009$ and $p = 0.002$, respectively), and decreased daily steps ($p = 0.009$ and $p = 0.002$, respectively). Whereas, step time SD was significant only in predicting poor 6MWD ($p = 0.004$). Table 5 shows the cut-off values used for predicting poor 6MWD, QMVC, and decreased daily steps.

Table 3
Predictors of 6MWD, QMVC, and daily steps in COPD.

Dependent variables	Predictors	β	t-value	P-value
6MWD	Step time SD	−0.440*	−3.820	0.001
	FEV_1	0.375*	3.478	0.002
	Gait speed	0.339*	2.900	0.007
	Adjusted R^2	0.636*		
QMVC	Step length	0.609*	4.247	< 0.001
	Adjusted R^2	0.352*		
Daily steps	Step length	0.453*	2.936	0.006
	Step time SD	−0.282	−1.829	0.077
	Adjusted R^2	0.354*		

Definitions: BMI, body mass index; FEV_1, forced expiratory volume in 1 s; 6MWD, 6-min walk distance; QMVC, quadriceps isometric maximum voluntary contraction (kg) to BMI (kg/m^2) ratio. This table shows the results of multivariable regression analysis using, 6MWD, QMVC, Daily steps as the dependent variables. Each analysis included gait parameters that had significant associations with each dependent variable in simple regression analyses, age, and FEV_1 as predictors.
* $p < 0.05$.

4. Discussion

The present study measured in gait parameters in patients with COPD compared to healthy counterparts using tri-accelerometer-based gait analysis. Correlation analyses and multivariate regression models identified independent associations between gait speed, step length, and step time SD and 6MWD, QMVC, and daily steps in COPD. Step length showed the highest predictive ability for muscle weakness and reduced daily steps, while step time SD showed the highest ability to predict poor 6MWD among the six gait parameters tested. Our results suggested that an accelerometer-based gait analysis could be used to screen for deficits in extra-pulmonary features of patients with COPD. Moreover, accelerometer-based gait analysis is inexpensive, unlike 3-dimensional motion analysis and pressure walkway systems, and requires only a small and lightweight accelerometer with a controller device and a personal computer. The acceleration system required < 5 min to measure and calculate the target gait parameters. Therefore, accelerometer-based gait analysis could be an alternative to gait analysis methods currently used in the routine clinical setting.

All gait parameters except the walk ratio were deteriorated in patients with COPD when these were measured using an accelerometer. Gait speed, step length, cadence, and acceleration magnitude were significantly lower in the COPD group than in controls, and COPD patients walked with greater step time SD compared to healthy controls. These results were similar to a recent systematic review of gait analysis in COPD that demonstrated abnormalities of spatiotemporal gait parameters and variability of these parameters in COPD [14]. In contrast, there was no significant difference in walk ratio or ratio of step length and cadence between the two groups. This may be explained by the fact that both step length and cadence are lower in COPD patients than in controls [4,5], and thus the ratio of step length and cadence remained unchanged. Our results revealed that accelerometer-based gait analysis is also feasible to identify abnormalities of spatiotemporal parameters of gait in COPD, and support the presence of gait alterations in COPD [14].

Correlation analysis and the multivariate regression model identified step time SD, gait speed, and FEV_1 as independent predictors of 6MWD. Gait speed measured by the short distance walking test (SDWT) [11,12] and airflow limitation [27] are well established predictors of 6MWD in patients with COPD. Variability of gait parameters during 6MWT has been associated with 6MWD in COPD patients [5]. Variability of gait is a possible contributor to increasing energy expenditure while walking [28], and this may have a greater impact on patients with COPD due to airflow limitations and extra-pulmonary abnormalities than on healthy elderly individuals. This may be one possible explanation why step time SD measured by SDWT had the strongest

Table 4
Predictions of poor 6MWD, low QMVC, and reduced daily steps.

	Poor 6MWD (6WMD < 350 m)	Low QMVC (QMVC < 120%)	Reduced Daily Steps (Daily steps < 5000 steps·day^{-1})
Gait speed	0.75 (0.55, 0.96)*	0.87 (0.64, 1.00)*	0.77 (0.61, 0.93)*
Step length	0.81 (0.64, 0.99)*	0.94 (0.82, 1.00)*	0.82 (0.66, 0.97)*
Step time SD	0.86 (0.70, 1.00)*	0.77 (0.57, 0.97)	0.69 (0.52, 0.87)

Definition of abbreviations: BMI, body mass index; 6MWD, 6-min walk distance; QMVC, quadriceps isometric maximum voluntary contraction (kg) to BMI (kg·m^{-2}) ratio; AUC, area under the curve. Data are presented as AUC (95%CI).
* $p < 0.05$.

association with 6MWD in this study. Our results indicated the importance of assessment of gait variability in COPD.

Our correlation analyses identified significant associations between gait parameters (gait speed, step length, step time SD, and walk ratio) and QMVC, and the multivariate regression model identified an independent association of step length with QMVC in patients with COPD. Although previous studies did not find any significant association of gait parameters with lower muscle strength [4,5], this could be an artefact of the different methods used for measuring muscle strength and gait analysis. Medical Research Council grades (MRC: 0, no movement; 5, normal muscle strength) have been used to measure lower limb muscle strength [4], but these might not be sufficiently sensitive to test the association of gait and lower limb muscle strength. Spatiotemporal gait parameters assessed using a self-paced treadmill 6MWT [5], showed that muscle endurance may be more crucial than muscle strength to maintain gait speed during the 6MWT. A significant association between gait parameters and QMVC was found in this study.

Step length had the strongest independent association with QMVC among the six gait parameters evaluated. Step length showed a significant correlation with QMVC (r = 0.605). Conversely, cadence was not significantly correlated with QMVC. Previous studies have shown that the strength of knee extension was associated with step length in older adults [29]. Changes in step length while walking had a greater influence on muscle function than step frequency using three-dimensional gait analysis [30]. These studies suggest that step length is strongly associated with lower muscle strength rather than with step frequency, and a similar trend may be evident in the COPD population. Furthermore, gait speed is mainly determined by step length and cadence [31]. Cadence may weaken the strength of association of gait speed with QMVC. Consequently, the strength of correlation between gait speed and QMVC was lower than that between step length and QMVC. Our results suggest that step length may be a better marker of lower muscle weakness than gait speed in COPD.

The present study found that step length was a significant independent predictor of daily steps. A previous literature review reported that gait speed is associated with daily steps in COPD [9], whereas, in our study, gait speed was not identified as an independent predictor of daily steps in multivariate regression analysis. A longitudinal study, which investigated the changes in walking parameters over a 4-year period in a Japanese community-dwelling for the elderly, revealed that participants' gait speed and step length but not cadence at their preferred speed were significantly decreased with ageing [32]. Changes in step length have a greater impact on muscle function than changes in step frequency while walking [30]. Step length might better reflect the alterations in gait compared with gait speed and cadence and may explain why the multivariate regression model identified step length as an independent predictor of daily steps.

Conversely, there was a non-significant and very weak association between gait parameters and FEV_1 in the COPD group. Our subgroup analysis demonstrated that COPD patients with severe/very severe airflow limitation had similar gait characteristics as patients with mild/moderate airflow limitations, which was in line with previous studies [4]. A possible explanation for the weak association between gait parameters and FEV_1 could be that gait parameters when tested along a short walkway are not influenced by pulmonary functions, since SDWT may be insufficient to increase ventilatory responses while walking short distances [33]. Indeed, as revealed by a previous literature review, gait speed measured by SDWT was not associated with spirometric parameters [9]. Speed reductions measured by SDWT were related to balance impairment rather than other determinants of gait parameters like pulmonary and cardiovascular function [4]. Spatiotemporal gait parameters measured by the SDWT were not associated with pulmonary function in this study. Thus, we suggest that the SDWT should be used for screening extra-pulmonary features, while another simple screening tool for pulmonary function is required.

This is the first study to demonstrate the predictive ability of gait speed, step length, and step time SD for poor 6MWD (< 350 m), low QMVC (< 120%), and reduced daily steps (< 5000 steps·day^{-1}) in patients with COPD. These cut-off values are not intended to predict exact measures of 6MWD, QMVC, and daily steps or to replace these measures. Instead, a combination of these values may provide a simple and inexpensive, but more accurate screening test than gait speed alone for poor 6MWD, low QMVC, and reduced daily steps. The usual gait speed of 0.94 m·s^{-1} for predicting poor 6MWD and 0.87 m·s^{-1} for QMVC is similar to the previously reported threshold of 0.9 m·s^{-1} for poor 6MWD in COPD patients [11]. These results support the notion that the usual gait speed of approximately 0.9 m·s^{-1} may be a key threshold for predicting extra-pulmonary dysfunction in COPD.

The main limitation of this study was its cross-sectional study design; therefore, a causal relationship between gait abnormalities and extra-pulmonary dysfunction could not be established. Further studies are required to investigate the longitudinal association between

Table 5
Cut off point of for predicting reductions in 6MWD, QMVC, and daily steps.

Variables	Predictors	Cut off point	Sensitivity	Specificity	Positive predictive value	Negative predictive value
6MWD	Gait speed, m·s^{-1}	0.94	89	56	57	89
	Step length, m	0.60	70	86	86	70
	Step time SD, s	0.04	71	93	71	93
QMVC	Gait speed, m·s^{-1}	0.87	100	80	80	100
	Step length, m	0.51	100	80	80	100
Daily steps	Gait speed, m·s^{-1}	0.98	100	50	50	100
	Step length, m	0.63	79	85	85	79

Definitions: BMI, body mass index; 6MWD, 6-min walk distance; QMVC, quadriceps isometric maximum voluntary contraction (kg) to BMI (kg·m^{-2}) ratio. Sensitivity, specificity, positive predictive value, and negative predictive value are presented as percentage.

deterioration in gait and decline in extra-pulmonary features in COPD. Second, our study included only males due to lack of female patients with COPD in Japan. Thus, whether our results could be interpreted in female patients with COPD should be examined by future research. Third, the accelerometer coupling to the subjects' body was based on palpation and repeatability of the coupling is unclear. However, we used the intercristal line defined by palpation of the iliac crests, which had been previously validated to identify the level of third lumbar vertebra. Test-retest reliability and measurement error of the accelerometer-based gait analysis were within acceptable levels. Thus, we believe that the reliability of the gait parameter measurement is retained.

5. Conclusions

Accelerometer-based gait analysis is able to identify gait abnormalities of COPD and could be used as a simple screening test of poor exercise capacity, reduced muscle weakness, and physical inactivity in COPD. The combination of gait speed, step length, and step time SD is accurate in detecting poor 6MWD, low QMVC, and reduced daily steps, which may help clinicians evaluate the need for further assessment of exercise capacity, muscle strength, and physical activity in the routine clinical care of patients with COPD.

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Declaration of Competing Interest

None.

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Appendix A. Supplementary data

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