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Gait and balance assessments as early indicators of frailty in patients with known peripheral artery disease

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Abstract

Background—Peripheral artery disease is associated with increased morbidity and mortality, and frailty syndrome may mediate the risk of these adverse health outcomes to predict intervention results. The aim of this study was to determine the association between motor performance impairments based on in-clinic gait and balance measurements with frailty at intermediate stages (pre-frailty) in peripheral artery disease patients.

Methods—Seventeen participants with peripheral artery disease (> 55 years) were recruited and frailty assessed using Fried criteria. Gait and balance were quantified using wearable sensor technologies in the clinical setting. Between-group differences in frailty were assessed using analysis of variance, and independent associations between gait and balance parameters with frailty were determined using logistic regression models.

Findings—Based on Fried index nine (53%) participants were pre-frail and eight (47%) were non-frail. Although no between group differences in demographics or clinical parameters was observed, gait parameters were worse among pre-frail compared to non-frail participants. The

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Author Contributions

Rebecca Thiede: data collection, data analysis, and writing

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Joseph L. Mills: study design, writing, and interpretation of findings

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Jane Mohler: writing, study design, and interpretation of findings

Bijan Najafi: study design, writing, and interpretation of findings

Conflicts of Interest

None

highest effect sizes for between group differences were observed in double support during habitual normal walking (effect size=1.86, $p<0.01$), speed variability during dual-task (effect size=1.26, $p=0.03$), and trunk sway during fast walking (effect size=1.43, $p=0.02$). No significant difference was observed in balance parameters ($p > 0.07$). The regression model using gait parameters demonstrated a high sensitivity and specificity in predicting pre-frailty.

Interpretation—A short 25-step sensor-based in-clinic overground gait test objectively identified pre-frailty independent of age. Double support was the most sensitive parameter in identifying pre-frail aging adults.

Keywords

Peripheral artery disease; locomotion; balance postural control; frailty; dual-task; wearable sensor technology

Introduction

Lower extremity peripheral artery disease (PAD) has an age-adjusted prevalence of nearly 12%, affecting 8 to 12 million Americans with the highest prevalence among older adults (1, 2). PAD is associated with reduced quality of life and increased morbidity and mortality in older adults (3). Recent advancements in both PAD treatment and prevention include aggressive risk factor management for prevention of cardiac and cerebrovascular complications, structured exercise therapy, endovascular approaches for revascularization, and less frequently, surgical interventions (4, 5). Although advancing age has been persistently associated with adverse health outcomes, predicting risk of adverse health conditions is challenging due to the heterogeneity of health status in older adults (6, 7). PAD patients, including those with carotid, aortic, and peripheral occlusive diseases, are generally considered a highly vulnerable population with a high prevalence of cramping, fatigue, and pain in lower extremities, and higher risk of cardiovascular morbidity and mortality compared to individuals without PAD and are susceptible to postoperative complications (8).

Frailty is an increasingly important geriatric syndrome that is characterized by low physiologic reserves, increased vulnerability to acute stressors, and overall functional decline (9), and has been linked to poor treatment outcomes and health conditions (10). Therefore, frailty can be useful in stratifying risk of adverse health outcomes in older adults with PAD. As a reflection of biologic, rather than chronologic age, frailty is predictive of adverse outcomes independent of old age or disability, and may explain the substantial heterogeneity of health status and surgical outcomes among the elderly patient population (9, 11). The necessity of making an initial distinction based on frailty status in the treatment of elderly with vascular disease was first indicated in 1996 (12). Further, frailty proved to independently predict postoperative complications, length of stay, mortality, and discharge to a skilled or assisted-living facility (9, 13). Recently, the ACS NSQIP®/AGS BEST PRACTICE GUIDELINES: Optimal Preoperative Assessment of the Geriatric Surgical Patient was published, recommending frailty measurement for all elders aged 65 and above undergoing surgical interventions (14).

Assessment of the five Cardiovascular Health Study (CHS) “Fried” frailty index criteria (unintentional weight loss, self-reported exhaustion, weakness (grip strength), slow walking speed, and low physical activity) is the most established approach for defining older adults as non-frail, pre-frail, or frail. Among these criteria, gait speed has been reported as one of the strongest predictors of adverse outcomes, such as mobility disability, falls, or hospitalization (13, 15, 16).

Advances in wearable technologies allow more precise measurement not only of gait speed, but also of other spatial and temporal gait variables and balance behaviors. These technologies are highly valid and practical and offer a promising, cost-effective way to analyze gait and balance parameters associated with frailty in the clinical setting (17-19). Using such technologies may facilitate identifying frailty in intermediate stages (i.e., pre-frailty) where its identification is more difficult using clinical or “eye-ball” judgments. Furthermore, routine frailty assessment could be incorporated in pre-surgical screening, per NSQIP guidelines. Although these practical methods exist to assess the decline in physical function due to frailty in older adults, no study to the best of our knowledge, has identified gait and balance deficits as markers of physical functional impairments in older frail PAD individuals in the clinical settings. Hence, the aim of the current study was to determine the association between motor performance impairments with frailty at intermediate stages in PAD patients. The specific aims were to: 1) compare gait and balance parameters among PAD patients with differing frailty status; and 2) determine sensitive gait and balance parameters to objectively diagnose pre-frailty in PAD patients. Wearable sensor technologies, could provide fast, in-clinic assessment of physical impairments, and therefore, the current study would provide results regarding in-clinic assessment of physical function in older population with PAD for the first time. Further, results from the current pilot study can be used to determine a better objective assessment method (balance versus gait) and identify sensitive parameters within each test for identifying pre-frailty in PAD patients to enhance preoperative clinical decision-making.

Methods

Participants

Aging adults (age ≥ 55 years) seen in the established outpatient clinic of an experienced vascular surgeon (JLM) with a clinical and hemodynamic diagnosis of PAD based on the 2011 ACCF/AHA criteria (Guideline Recommendations: A Report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines (20)), were recruited from the University of Arizona Division of Vascular and Endovascular Surgery between July 2012 and July 2014. Participants were excluded if they had any clinically significant medical or psychiatric condition (including dementia, or serious mental illness based on their medical history or the mini-mental state examination (MMSE) < 24), or laboratory abnormality that could, in the judgment of the investigators, interfere with the ability to participate in the study. PAD participants were excluded if they had known disorders associated with severe gait and balance deficits (including stroke or Parkinson's disease), recent surgery, an active foot ulcer, major foot deformity (e.g., Charcot neuroarthropathy), or major foot amputation. Furthermore, participants with major mobility

disorders (e.g., who were unable to walk a distance of 25 steps without walking assistance) or balance impairments (e.g., who were unable to perform balance trials as explained below) were also excluded. Ability of participants in performing gait and balance tests were assessed within the actual measurements, and those who failed to perform either tests were excluded. The study was approved by the University of Arizona Institutional Review Board. Written informed consent according to the principles expressed in the Declaration of Helsinki (21) was obtained from all subjects before participation. Participants were informed that they could withdraw from the study at any time without loss of benefits.

Frailty evaluation

The Fried index (9) was used as the “gold standard”. Individuals with three or more positive Fried criteria were considered “frail”, those with one or two Fried criteria were considered “pre-frail”, and those with none of Fried criteria were considered “non-frail”.

Ankle-Brachial Index (ABI) measurement and subjective questionnaires

Lower extremity blood flow was quantified via ABI determination in both legs using a 10MHz handheld Doppler as described previously (22). Subjective questionnaires included the SF-12 health survey (23), and the visual analog scale (VAS) for pain (24). SF-12 health survey was used to assess generic health status based on physical and mental components.

Objective assessment of gait and balance

Gait and postural balance were objectively assessed using validated wearable sensor technology. Three-dimensional acceleration and angular velocity of shins, thighs, and the trunk were measured using five wearable sensors, each of which included a tri-axial accelerometer and a tri-axial gyroscope (LEGSSys™ and BalanSens™—BioSensics LLC, Boston, MA), to derive gait and balance outcome measures using established methods previously reported (18, 25-27). Sensors were attached to the shin above the ankle, to the thigh above the knee, and to the lower back in the lumbar region. This wireless technology allows quantification of spatio-temporal parameters during overground walking in clinic.

Gait was assessed with a minimum of 25 steps under three conditions: 1) habitual overground normal walk (preferred speed); 2) dual-task overground walk; and 3) fast overground walk. The habitual normal walk consisted of patients walking at the normal pace at which they perform everyday activities. The dual-task walk consisted of patients counting backwards from 100 by one while walking, in order to observe the impact of an attention-demanding task on their walking habits (28). Counting is a rhythmic task and may highly interfere with another rhythmic task that has a different frequency such as walking (29, 30). The dual-task of counting backwards by “one” was chosen here, since it has been proven to be simpler and more appropriate for older adults (31). Lastly, the fast walk consisted of patients walking as fast as they comfortably could without jogging or falling. LEGSSys™ allows the extraction of over 30 different gait parameters. In this study, we measured gait speed, gait cycle time, stride length, double support, trunk sway during walking (i.e., anterior-posterior and medial-lateral trunk sway), speed variability, and mid-swing speed during gait steady state (see Table 1 for parameter definitions). Briefly, each sensor measures the angular velocity and acceleration of the segment. The stance and swing phase

was estimated by determining heel strike (when the foot first touches the floor) and toe-off (when it takes off) using angular velocity data from shins within each gait cycle (25). To compute the spatio-temporal gait parameters from the angular velocity of lower limbs, a mechanical model was used, and gait speed, gait cycle time, stride length, double support, speed variability, and mid-swing speed were estimated (25). Anterior-posterior and medial-lateral trunk sway parameters were calculated from trunk sensor data (25). All gait parameters were calculated for the steady state walking phase after removing the gait initiation phase. The initiation of steady state walking was estimated using the algorithm described in our previous work (32); steady-state walking was the first stride of the group of six strides with an standard deviation (SD) below the median SD of the all analyzed strides $\pm 6\%$. The 6% error was selected based on the sensitivity of the sensors (32).

Each participant performed two 30-second Romberg tests to assess balance using the wearable sensor technology described above. In each trial, participants stood upright with crossed arms and feet placed as close to each other as possible without touching. In the first trial, participants were instructed to keep their eyes open with no specified target. In the second trial, participants kept their eyes closed. The center of gravity (COG) was estimated following identical procedures reported in our earlier studies (26, 33). Briefly, two sensors, one attached to the right shin and one on the lumbar (two of the five sensors described above), were used to estimate three-dimensional angles of the ankle and hip joints. A two-link inverted-pendulum model of the human body was then used to calculate the COG from anterior-posterior and medial-lateral angles during body sways. The balance outcome measures included body sway parameters: COG_{AP} (anterior-posterior sway), COG_{ML} (medial-lateral sway), ankle sway, and hip sway (see Table 1 for parameter definitions).

Statistical analysis

Analysis of variance (ANOVA) and χ^2 tests were performed, respectively, to evaluate the differences in continuous and nominal demographic parameters between frailty groups. Gait and balance parameters were compared between the frailty groups, using separate ANOVAs. For between group comparison, effect size and 95% confidential interval were reported. Continuous variables were presented as mean (SD). Independent associations between each physical function parameter (balance or gait parameter) with frailty status was assessed using separate multivariate nominal logistic regression models, considering frailty status (pre-frail versus non-frail) as the dependent variable; independent variables included each gait and balance parameter in addition to age, body mass index (BMI), and gender. A final logistic model was constructed stepwise by adding related independent variables (gait and balance parameters) for which the p -value was less than 0.20 in the corresponding multivariate logistic regression model described above, as well as retaining any independent significant predictor ($p < 0.05$) from the previous multiple logistic model. When two or more parameters showed collinearity ($r > 0.90$), those with higher p -values were excluded. Sensitivity, specificity, area under curve (AUC) from receiver operating characteristic (ROC) curves, and parameter estimates and odds ratios were estimated for logistic regression models. All analyses were performed using JMP (Version 10, SAS Institute Inc., Cary, NC), and statistical significance was concluded when $p \leq 0.05$.

Results

Participants

Twenty individuals were screened, among whom 17 were deemed eligible to participate. All participants were living independently at the time of study entry. Three participants were ineligible due to an inability to safely perform gait and balance tests, and were likely frail. Of the 17 aging adults who participated in the pilot study, eight (47%) were non-frail, nine (53%) were pre-frail, and none were frail based on Fried criteria (Table 2). Mean (SD) age and BMI of participants were 74 (8) years and 26.8 (3.5) kg/m², respectively. Other sociodemographic information is reported in Table 2. The SF-12 physical health composite scale (PCS) was significantly lower by 29% in pre-frail compared to non-frail participants, while the SF-12 mental health composite scale (MCS) showed no significant difference between non-frail and pre-frail groups.

Differences in gait and balance parameters among frailty groups

Results from ANOVA demonstrated several differences in spatio-temporal gait parameters between non-frail and pre-frail groups. Specifically, gait speed and trunk sway during walking in the anterior-posterior and medial-lateral direction were 21%, 80%, and 47% larger, respectively, in the non-frail group compared to pre-frails among all walking conditions (Table 3). Gait cycle time and double support percentage were also 11% and 22% smaller in the non-frail group compared to the pre-frail group, respectively. Overall based on *p*-value and effect size values presented in Table 3, differences between parameters related to walking agility (gait speed and gait cycle time) among frailty groups were more pronounced in the dual-task condition. On the other hand, parameters related to the trunk sway during walking differed more between groups within the fast walking test.

The balance test results demonstrated greater sway among pre-frail compared to non-frail participants. On average among conditions, differences were observed in COG_{AP} sway (51%) and COG_{ML} (31%), due to significantly greater ankle (86%) and hip (43%) sway in the pre-frail group. None of the differences, however, were significantly different between two groups either in the eyes-open or in the eyes-closed conditions (*p* > 0.07).

Sensitivity and specificity of frailty prediction using gait parameters

Results from separate logistic regression models for each gait and balance parameter (in addition to demographic information) revealed that several gait parameters were significantly associated with frailty, including gait speed, gait cycle time, double support, anterior-posterior and medial-lateral sway, and mid-swing speed (Table 4). Of note, none of the balance parameters showed significant association with frailty based on logistic regression analysis (*p* > 0.11). In the final regression model using gait and balance parameters in addition to demographic information (i.e., age, BMI, and gender), only gait speed, double support, and medial-lateral sway among gait parameters were entered into the model. This model demonstrated a high sensitivity and specificity in predicting pre-frailty (Table 4 and Figure 1). Based on these models, specificity of pre-frailty prediction was improved by 163% when gait parameters were added to demographic information for predicting pre-frailty (Table 4 and Figure 1).

Discussion

Gait and balance parameters versus demographic information for identifying frailty

Our first observation was that three patients were ineligible for the study, because they were unable to safely perform gait and balance tests; many of these patients were likely frail. (Of note, these participants could not finish Fried walking test and, therefore, the frailty score was not determined.) This finding points to the need for a non-gait related frailty test for PAD patients, as the Fried index, which is the most commonly used test, requires gait assessment.

Socio-demographic characteristics of patients including age, BMI, gender, status of diabetes, ABI, and magnitude of pain were not significantly different between non-frail and pre-frail groups, suggesting that attempting to identify and distinguish pre-frail versus non-frail patients based on age and demographic information alone (the “eye-ball” test) may not be effective in every sample of PAD patients. These findings support the need for further classification of PAD patients based on more specific and objective frailty criteria.

Using age, BMI, and gender, pre-frailty was determined with an AUC of 0.67. On average among conditions the use of gait speed improved the pre-frailty prediction to an AUC of 0.81, which suggests that just measuring gait speed, as has been commonly done, might be sensitive for predicting pre-frailty in PAD patients. However, adding a 25-step instrumented walking test further improved the pre-frailty prediction by 41% to an optimized AUC of 1.00, suggesting the superiority of using a 25-step instrumented overground walking test. Among gait parameters, walking agility, double support percentage, and the trunk sway were noticeably different between frailty groups. Walking agility, as also measured by walking speed within the Fried index, represents the movement slowness feature of frailty. Differences in double support percentages suggest that pre-frail participants need more time for resting both feet on the floor while walking. This may represent a higher level of weakness or exhaustion in lower extremities for executing gait in pre-frail participants compared to non-frails. Weakness and exhaustion are also two important features of frailty, which are measured using hand grip strength and subjective questionnaires within the Fried index (9). Furthermore, previous studies demonstrated a smaller range of motion in upper extremities in frail and pre-frail compared to non-frail participants (34, 35). Accordingly, we observed less trunk sway of the trunk during walking, which may represent another frailty feature.

Although the degree of body sway was greater among the pre-frail group compared to the non-frail group, current results showed no significant difference in static quiet standing balance parameters between the two groups in our sample. This finding is consistent with previous work that identified body sway as an insensitive characterization of postural control to identify pre-frail participants from non-frail ones in a non-PAD sample (19). Another explanation could be the small sample size in our study.

Most sensitive gait parameters and walking conditions for identifying frailty

As is apparent from Tables 3, double support percentage was the only gait parameter that was significantly different between frailty groups in all three walking conditions and

provided the highest overall effect size (mean (SD) effect size of 1.65 (0.35) for double support parameter compared to mean (SD) effect size of 0.88 (0.32) for all other gait parameters). Previous work also demonstrated that double support is the most sensitive parameter for discriminating between frailty groups in non-PAD participants (34). For the first time, this observation was confirmed among PAD patients within the current study.

Previously, speed variability has been identified as a powerful prospective predictor of falls among older individuals (36, 37). The present study showed that speed variability differed between pre-frail and non-frail groups, especially within the dual-task walking condition. Therefore, these findings support the fact that among PAD patients, those who are pre-frail may be at a higher fall risk compared to non-frails. However, this hypothesis should be confirmed in a larger sample size. Except for gait variability, there was no substantial difference between conditions among gait parameters in identifying pre-frailty; the mean (SD) effect sizes were 0.99 (0.48), 1.04 (0.44), and 0.97 (0.40) for habitual normal, dual-task, and fast walking conditions, respectively.

Limitations and summary of findings

The study sample size was relatively small, and we also recruited aging adults (three PAD participants (18%) between 55 and 65 years old). Therefore, the current results, while encouraging, should be considered as a preliminary demonstration of the feasibility and proof of concept of gait alterations as an early indicator of frailty syndrome in PAD patients. Although the number of participants was limited, 53% of consecutively approached patients were pre-frail in our quaternary care vascular disease clinic, suggesting that pre-frailty is highly prevalent among patients with identified vascular problems. This reiterates the need for identifying patients that are pre-frail, whom may benefit from surgical intervention or exercise programs, in order to potentially decrease their vulnerability by changing their status from pre-frail to non-frail. Alternatively, identification of an unsuspected pre-frail state might lead to a more appropriate selection of less invasive management approaches with decreased attendant morbidity.

Conclusions

Risk stratification by frailty status has significant potential to meaningfully assist in optimizing ongoing management, selection of the most suitable mode of interventions, and optimizing clinical outcomes, as is recommended by the National Surgical Quality Improvement Program guidelines for older adults. The current study involved innovative wearable sensor technologies for measuring motor performance, and within our small pilot sample of PAD participants, we demonstrated the feasibility of an efficient gait and balance data collection in the inpatient clinical environment. Overall, results from the current study suggest that a short 25-step, in-clinic, sensor-based overground gait test objectively identified pre-frailty status independent of age. Double support was the most sensitive gait parameter in identifying pre-frail older adults. Additional studies are warranted to explore the associations of frailty and PAD, including whether endovascular and/or surgical approaches achieve better outcomes based on frailty status, as well as if revascularization combined with rehabilitation can reverse pre-frailty in those with PAD.

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Highlights

- Frailty mediate the risk of adverse health outcomes in peripheral artery disease
- We showed motor impairments at early stages of frailty in peripheral artery disease
- A 25-step sensor-based in-clinic gait test identified pre-frailty
- Double support is the most sensitive parameter in identifying pre-frailty

Figure 1.

Receiver operating characteristic (ROC) curves for predicting pre-frailty using demographic information and gait parameters within habitual normal walk condition. Similar results were obtained for dual-task and fast walk conditions. Area under curve (AUC) values are presented.

Table 1

Objective parameter definitions from gait and postural balance tests. A reference for calculation procedure is presented for each parameter.

Gait	Definition	Reference
Gait speed	Distance travelled divided by the walking duration	(25)
Stride length	Distance travelled by the same limb between two successive heel contacts (mean value across gait cycles)	(25)
Gait cycle time	Time interval starts when one foot makes contact with the ground and ends when that same foot contacts the ground again (mean value across gait cycles)	(25)
Double support	Duration of the initial and terminal double support (both feet in contact with the ground) as a percentage of the gait cycle time (mean value across gait cycles)	(25)
Anterior-posterior or medial-lateral trunk sway	Range of angular rotation of the trunk in the anterior-posterior or medial-lateral direction (mean value across gait cycles)	(25)
Speed variability	Coefficient of variation (SD divided by the mean) of gait speed among gait cycles	(25)
Mid-swing velocity	Peak values of shin angular velocity during the swing phase (mean value across gait cycles)	(25)

Balance	Definition	Reference
COG_{AP}	Range of COG sway in the anterior-posterior direction	(26)
COG_{ML}	Range of COG sway in the medial-lateral direction	(26)
Ankle sway	Product of range of ankle rotations in the anterior-posterior and medial-lateral direction	(33)
Hip sway	Product of range of hip rotations in the anterior-posterior and medial-lateral direction	(33)

SD: standard deviation

COG: center of gravity

AP: anterior-posterior

ML: medial-lateral

Table 2

Mean (SD or percentage) values of participant sociodemographic information.

	Non-frail	Pre-frail	95% CI (Lower)	95% CI (Upper)	<i>p</i> -value
Number (% of total)	8 (47%)	9 (53%)	-	-	-
Male (% of the group)	6 (75%)	4 (44%)	-1.8	0.3	0.20
Age, years (SD)	73.4 (9.9)	74.4 (7.5)	-5.1	4.0	0.80
Stature, cm (SD)	174.0 (10.1)	165.1 (7.7)	-0.2	9.1	0.06
Body mass, kg (SD)	80.5 (16.6)	74.1 (11.6)	-4.2	10.5	0.37
BMI, kg/m² (SD)	26.4 (4.1)	27.1 (3.1)	-2.2	1.5	0.71
ABI (SD)	0.88 (0.12)	0.79 (0.14)	0.0	0.1	0.17
DM (% of the group)	3 (38%)	3 (33%)	-1.1	0.9	0.86
VAS, 0-10 (SD)	0.7 (1.3)	1.4 (2.5)	-1.5	0.7	0.49
SF-12, MCS (SD)	59.8 (5.5)	60.4 (4.9)	-2.9	2.4	0.84
SF-12, PCS (SD)	44.5 (8.7)	31.8 (13.1)	0.6	12.2	0.03 [*]

CI: confidence interval

SD: standard deviation

BMI: body mass index

ABI: ankle-brachial index

DM: diabetes mellitus

VAS: visual analog scale

MCS: mental health composite scale

PCS: physical health composite scale

*
The symbol indicates a significant difference.

Table 3

ANOVA results for differences in gait parameters between non-frail and pre-frail groups. Mean (standard deviation) values are presented.

	Condition	Non-frail	Pre-frail	95% CI (Lower)	95% CI (Upper)	p-value	Effect Size
Gait speed (m/s)	Habitual walk	1.17 (0.23)	0.98 (0.17)	0.00	0.20	0.06	0.94
	Dual-task walk	1.16 (0.25)	0.93 (0.18)	0.01	0.19	0.04 *	1.06
	Fast walk	1.48 (0.33)	1.24 (0.28)	-0.03	0.24	0.11	0.78
Stride length (m)	Habitual walk	1.27 (0.27)	1.19 (0.19)	-0.08	0.16	0.55	0.34
	Dual-task walk	1.32 (0.28)	1.21 (0.18)	-0.05	0.12	0.39	0.47
	Fast walk	1.44 (0.29)	1.34 (0.24)	-0.07	0.14	0.47	0.38
Gait cycle time (s)	Habitual walk	1.12 (0.10)	1.21 (0.09)	-0.09	0.01	0.12	0.95
	Dual-task walk	1.15 (0.13)	1.32 (0.14)	-0.16	-0.01	0.03 *	1.26
	Fast walk	0.96 (0.10)	1.06 (0.11)	-0.11	0.01	0.11	0.95
Double support (%)	Habitual walk	22.71 (2.55)	28.25 (3.36)	-4.59	-0.80	<.01 *	1.86
	Dual-task walk	22.72 (3.56)	26.86 (3.63)	-3.72	-0.06	0.04 *	1.85
	Fast walk	19.34 (3.58)	23.84 (3.64)	-3.62	-0.36	0.02 *	1.25
Anterior-posterior sway (deg)	Habitual walk	8.23 (4.31)	5.03 (1.18)	0.01	3.19	0.05	1.01
	Dual-task walk	8.54 (5.28)	4.67 (0.78)	-0.16	4.18	0.06	1.03
	Fast walk	11.16 (5.05)	5.80 (1.63)	0.48	4.93	0.02 *	1.43
Medial-lateral sway (deg)	Habitual walk	6.75 (1.71)	4.77 (1.52)	0.15	1.82	0.02 *	1.22
	Dual-task walk	6.87 (2.18)	5.15 (1.54)	-0.19	1.75	0.10	0.91
	Fast walk	10.18 (3.73)	6.14 (1.86)	0.33	3.38	0.02 *	1.37
Speed variability (%)	Habitual walk	3.35 (1.70)	4.80 (2.59)	-1.94	0.49	0.30	0.66
	Dual-task walk	1.86 (0.78)	4.50 (2.87)	-2.73	-0.17	0.03 *	1.26
	Fast walk	3.10 (2.01)	3.92 (0.98)	-1.14	0.42	0.33	0.52
Mid-swing speed (deg/s)	Habitual walk	352.58 (44.32)	324.85 (42.29)	-8.53	36.26	0.15	0.64
	Dual-task walk	341.50 (47.27)	308.01 (44.86)	-2.72	40.58	0.16	0.73
	Fast walk	418.09 (61.29)	383.30 (51.46)	-11.12	45.10	0.21	0.61

CI: confidence intervals

* The symbol indicates a significant difference.

Table 4

Pre-frailty prediction using gait parameters and demographic variables in regression models.

	Condition	p-value [†]	Sensitivity	Specificity	AUC	Parameter Estimate (SE) [‡]	Odds Ratio
Gait speed + age + BMI + gender	Habitual walk	0.03 [*]	100%	63%	0.81	8.77 (4.92)	0.80
	Dual-task walk	0.02 [*]	78%	75%	0.82	7.80 (4.09)	1.52
	Fast walk	<.05 [*]	100%	63%	0.80	5.05 (3.36)	0.73
Gait cycle time + age + BMI + gender	Habitual walk	0.07	78%	88%	0.78	-10.40 (6.49)	1.11
	Dual-task walk	0.01 [*]	89%	75%	0.82	-13.45 (7.97)	0.83
	Fast walk	0.06	63%	88%	0.72	-10.25 (6.32)	1.34
Double support + age + BMI + gender	Habitual walk	<.001 [*]	78%	100%	0.92	-0.92 (0.46)	2.75
	Dual-task walk	0.02 [*]	78%	75%	0.81	-0.38 (0.20)	1.38
	Fast walk	0.02 [*]	63%	100%	0.80	0.72 (0.42)	3.50
Anterior-posterior sway + age + BMI + gender	Habitual walk	0.03 [*]	100%	63%	0.76	0.48 (0.30)	0.97
	Dual-task walk	0.02 [*]	100%	75%	0.81	0.52 (0.41)	0.99
	Fast walk	<.01 [*]	100%	63%	0.81	0.48 (0.30)	1.85
Medial-lateral sway + age + BMI + gender	Habitual walk	<.01 [*]	67%	100%	0.83	1.12 (0.58)	2.70
	Dual-task walk	0.06	100%	50%	0.74	0.60 (0.37)	0.63
	Fast walk	<.01 [*]	100%	63%	0.84	0.75 (0.40)	0.57
Mid-swing speed + age + BMI + gender	Habitual walk	0.09	67%	88%	0.76	0.03 (0.02)	1.46
	Dual-task walk	0.06	89%	75%	0.81	0.02 (0.01)	1.10
	Fast walk	0.04 [*]	75%	75%	0.70	0.02 (0.01)	1.24
Gait parameters[§] + age + BMI + gender	Habitual walk	-	100%	100%	1.00	-	-
	Dual-task walk	-	100%	100%	1.00	-	-
	Fast walk	-	100%	100%	1.00	-	-

Age + BMI + gender	Condition	p-value [‡]	Sensitivity	Specificity	AUC	Parameter Estimate (SE) [‡]	Odds Ratio
	-	-	100%	38%	0.67	-	0.55

BMI: body mass index
AUC: area under curve
SE: standard error

[‡] p-value for independent association of gait parameters with pre-frailty in logistic regression models
[‡] Parameter estimates are presented only for each gait parameter, not for demographic variables.
[¶] Included gait parameters: gait speed, double support, and medial-lateral sway.
* The symbol indicates a significant association.