BMC Geriatrics

RESEARCH

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Cross-sectional assessment of the Tinetti performance-oriented mobility tool for screening physical frailty syndrome in older adults

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Abstract

Background Physical-functional fitness (PFF) assessments have become crucial tools for identifying physical frailty syndrome (PFS) in older adults, helping guide preventive and interventional strategies.

Purpose This study aimed to evaluate the predictive value of performance-based PFF tests for detecting PFS among community-dwelling older adults in Tehran, Iran. Additionally, it sought to compare PFF variables between PFS groups to assess the applicability of these tests as practical screening tools in clinical and community settings.

Methods Data were collected from 161 participants (91 males, 56.5%; 70 females, 43.5%), including sociodemographic, anthropometric, medical history, PFF, and PFS assessments.

Results Frail participants exhibited significantly lower scores in various PFF tests, including the Tinetti balance, walking, and total score components, physical activity levels (PAL), mean hand grip strength (MGS), 30-s arm curl (30 s-AC), 30 s-chair stand (30 s-CS), Standing Stork Balance (SSB), and back stretch (BST) tests ($p < 0.001$). Frail individuals also had lower levels of education, shorter stature, and higher BMI compared to non-frail/pre-frail participants, highlighting broader vulnerabilities. Logistic regression analyses showed that all PFF tests, including Tinetti balance and walking components, MGS, 30 s-AC, 30 s-CS, were significant protective factors against FS. However, ROC curve analysis revealed optimal cutoff points for PFS identification, with PAL and MGS demonstrating the highest sensitivity and specificity for predicting PFS. The all components of Tinetti scale also proved to be strong predictors of FS.

Conclusion Our findings demonstrate that, regardless of age, sex, education level, stature, and fall incidence, PFF assessments remain critical for identifying older adults at risk for PFS. The study highlights the predictive strength of key variables, such as PAL, MGS, and the Tinetti-POMA components, offering novel insights into the role of these tests in improving PFS screening accuracy. These results underscore the importance of integrating PFF assessments into routine clinical and community-based health evaluations, enabling early detection and timely interventions to promote healthier aging trajectories.

Keywords Frailty syndrome, Health risk assessment, Fatigue, Accidental falls, Muscle weakness

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Background

The global demographic shift toward an aging population presents a considerable challenge for healthcare systems, as the growing proportion of older adults necessitates the provision of adequate and specialized care [1]. Frailty syndrome (FS) among older adults is a critical health concern that has gained substantial attention in geriatric research and healthcare [2]. The FS is theoretically defined as a clinically recognizable condition of heightened vulnerability, resulting from age-related declines in reserve and function across multiple physiological systems, thereby impairing the ability to cope with everyday or acute stressors [3].

Among the various methods for assessing FS in older adults, the Physical FS (PFS) model proposed by Fried and collaborators stands out as one of the most widely recognized and utilized frameworks [4]. This model conceptualizes PFS as a biological syndrome characterized by the presence of three or more of the following criteria: unintentional weight loss, self-reported exhaustion, weakness, slow walking speed, and low physical activity levels (PAL). Individuals meeting one or two of these criteria are classified as pre-frail, while those with none are considered robust [5]. The PFS emphasizes the physical components of frailty and has been instrumental in advancing research and clinical practices aimed at identifying at-risk individuals and guiding targeted interventions to mitigate its impacts [6].

A recent longitudinal study demonstrated that older-frail participants incurred an average total healthcare resource cost of €2,476 per year, compared to €2,056 per year for pre-frail individuals and €1,217 per year for non-frail individuals [7]. The FS is, therefore, a condition of major interest for public health and has become a key focus for reshaping outdated healthcare systems that are unable to adequately address the clinical needs of aging populations [8]. Governments and policymakers must develop strategies and policies to address the challenges associated with FS in the context of an increasingly aging population [9]. Consequently, there is a growing emphasis on promoting healthy aging and encouraging preventive healthcare measures to improve the overall well-being of older adults [10]. Early identification of PFS using low-cost and quick-to-administer tests facilitates the implementation of preventive strategies, which can enhance overall well-being and support individuals in maintaining their independence [10, 11].

Considering that PFS is estimated to affect 4–59.1% of individuals over 60 years of age [9], there is clear need for interventions to help this population lead an active and healthy life [12]. Additionally, aging is associated with a higher risk of musculoskeletal disorders, cognitive declines (such as fear of movement), and reduced functional performance, all of which contribute to a more sedentary lifestyle among older adults [13–15]. This decline in PAL related to aging leads to changes in body composition, such as increased fat percentage, and a reduction in muscle strength, flexibility, endurance, and agility, which in turn elevates the risk of developing FS [15]. While the health implications of PFS are well documented, the specific physical declines most responsible for its onset remain unclear [16]. As physical functional capacities deteriorate, individuals become more vulnerable to stressors, leading to frailty [3]. It is well documented that poor balance, motor control issues, and a decrease in overall functional performance contribute significantly to frailty onset [17, 18]. However scientific information regards the cut-points from there the various components of physical-functional fitness status lead to the frailty syndrome is rare.

A study conducted by Furtado and collaborators investigated the association between PFS and PFF in institutionalized older women, providing sensitivity, specificity, cutoff points, and predictive values for Timed Up and Go test in identifying frail individuals [19]. In the same direction, a study conducted by Sachi and colleagues examined PFF and PFS using the Short Physical Performance Battery, the Late-Life Function and Disability Instrument-Function component, and the FS to predict adverse outcomes older adults [20]. Their results indicated that the both tests exhibited similar effectiveness in predicting adverse outcomes, including PFS, hospitalization and falls [19, 20].

As highlighted by clinical guidance statements and current frailty prevention clinical practice guidelines [21, 22], there is ongoing research exploring the association between PFF tests and PFS. However, the results remain inconclusive. In this sense, the study addresses a critical gap in FS screening by evaluating the predictive value of PFF tests that are practical, widely used in community settings, and feasible for older adults [23]. While traditional frailty assessments, are time-intensive and resource-demanding, fitness-based tests [24, 25]. These tests not only assess key FS domains such balance, upper and lower strengh and resistance, but also align with the multifaceted nature of PFP [26], as noted in prior research emphasizing the predictive validity of such measures.

The Single-Leg Stance Test, upper body flexibility, strength tests, and the Tinetti Performance-Oriented Mobility Assessment (POMA) are widely used tools that provide valuable insights into various aspects of senior PFF [27]. Among these, the POMA is particularly notable for its dual focus on both balance and gait, which are critical components of PFF and are closely linked to FS [23, 28]. Chosen for its ease of administration, well-documented reliability, and predictive validity in assessing fall risk and functional decline, the POMA appers to be a the ideal tool for evaluating frailty in community-dwelling older adults [29]. Furthermore, the POMA enables a detailed assessment of performance-based mobility, aligning well with key markers of PFP, making it an effective measure for identifying individuals at risk of functional decline and falls [30].

Therefore, the aim of this study is to investigate the screening value of specific senior physical-functional fitness tests and their association with FS. Our research team hypothesize that the Tinetti POMA score can effectively differentiate between frail and non-frail older adults.

Methods

Study design

This cross-sectional study aimed to examine the association between senior PFF tests and PFS in community-dwelling older adults. Specifically, the focus was to evaluate the screening potential of a series of PFF tests in predicting frailty, as defined by the PFS criteria. The study followed the guidelines provided by the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) to ensure transparency and comprehensive reporting of observational studies [31].

Participants and settings

Data were recorded for 161 community-dwelling older adults living in urban area in Tehran, 56.5% of whom were male (91 individuals) and 43.5% were female (70 individuals).

Selection criteria of participants

Participants were eligible for inclusion if they were male or female aged 60 years or older, were willing to participate in the study, were able to ambulate with or without the use of an assistive device, and could provide informed consent [19, 32]. Exclusion criteria included individuals residing in nursing homes, those who were hospitalized or bedridden, or those receiving nursing home-level care at home at the time of enrollment. Additionally, participants with a diagnosis of neurological, orthopedic, or visual disorders (e.g., Parkinson's disease, knee replacement, or macular degeneration) that directly impaired mobility were excluded [27]. Volunteers with any major medical conditions that could interfere with safe and successful testing were also excluded.

Ethical statement

The study protocol was approved by the Ethical Committee of the Sport Sciences Research Institute of Iran (number code: IR.SSRC.REC.1401.025) and was conducted in accordance with the guidelines for research involving human participants as outlined in the Declaration of Helsinki [33].

Sample size calculation and enrollment

The sample size calculation for this study was based on the study conducted by Furtado and collaborators [19]. Using this assumptions, a significance level (alpha) of 0.05, and a desired power of 0.80, the sample size required for adequate statistical power was determined [34]. Using the TwinPower function from the stats model's library, the calculated sample size required per group was approximately 64 participants. Therefore, the total sample size required for the study was estimated to be 128 participants, accounting for both groups. To ensure robustness and account for potential dropouts (30%), an additional 30% was added to the original sample size of 128, resulting in a final sample size of 161 community-dwelling older adults. This sample size exceeds the minimum requirement, ensuring sufficient power to detect significant differences and correlations between PFF tests and PFS indicators.

Outcome measures

The assessment of all variables indicators was supervised by the principal investigator (MH) and carried out by an independent specialist on the research team. This specialist was extensively trained and had over five years of experience working with older adults. To ensure consistency in data collection, a single evaluator was responsible for gathering data from all participants. Sociodemographic, anthropometric, and medical history variables were treated as covariates, while PFF variables were considered independent variables. The PFS combined score were entered as dependent variables.

Co-variates

Sociodemographic status

Information on chronological age (continuous variable), marital state (assessed as a four categories variable: single, married, widowed, and divorced), and level of education (elementary school or less, middle school, high school, university education) was collected for each participant.

Medical history screen

The medical history screen included an assessment of participants' smoking status, categorized as either positive or negative. Additionally, visual health was evaluated and classified into three categories: no eyesight problems, poor eyesight, or the use of eyeglasses. Hearing health was similarly assessed and categorized as no hearing problems, poor hearing, or the use of hearing aids.

Dependent variable

Physical Frailty Syndrome (PFS)

Frailty was assessed using the PFS protocolol. Older ndividuals were classified as frail if they met three or more of the following components: weakness, slowness, low PAL levels, shrinking, and exhaustion [4]. Weakness was measured using grip strength, adjusted for gender and body mass index. Slowness was determined by the 8-foot up-and-go test, adjusted for gender and height. The low PAL levels was evaluated using the short version of the Minnesota Leisure Time Activity Questionnaire [4], with adjustments for gender. Shrinking was defined as self-reported unintentional weight loss of more than 10 pounds in the past year, unrelated to dieting or exercise. Exhaustion was identified based on responses to two items from the CES-D scale related to energy and effort, with scores of "2" or "3" indicating exhaustion [35]. The prevalence of each of the five frailty components was calculated to create a continuous PF composite score ranging from 0 to 5 points, with higher values indicating greater frailty. Additional details of the PFS protocol are provided in Appendix 1.

Independent variables

Physical functional fitness status

Tinetti Performance Oriented Mobility Assessment (POMA) is a tool used to assess gait and balance in older adults, consisting of two components: gait and balance. The gait evaluation section is scored out of 12 points, while the balance evaluation section is scored out of 16 points. The combined total score, with a maximum of 28 points, provides an overall measure of functional mobility, where higher scores indicate better function [36]. In the gait portion, participants are asked to walk a 25-foot distance in each direction, with the evaluator evaluating factors such as hesitation, step length, step height, leg distance, step symmetry, and step continuity. The balance portion involves assessing the participant's ability to maintain balance in various positions, including sitting, standing, standing up from a chair, standing balance with chest tapping, 360-degree rotation, and standing with eyes closed. The POMA has been shown to have good reliability (ICC = 0.75–0.97) in older adult populations [30].

Standing stork balance test

The Standing Stork Balance (SSB) test was used to assess static balance in participants. To perform the test, participants were instructed to stand on their non-dominant leg, with the opposite foot placed against the inside of the supporting knee and both hands resting on the hips [37]. The timer was started when the heel of the supporting foot was lifted from the floor, and the time spent in this position was recorded [29]. The test ended if one or both hands were removed from the hips, the supporting foot shifted, or the foot on the opposite knee lost contact with the knee [38]. The SSB test is considered a reliable measure of balance [39]. If a participant was unable to complete the test due to poor balance, they received a score of zero seconds.

Mean hand grip test

Mean Hand grip strength (MGS) was measured using a hand dynamometer model T.K.K.5401 (Takei Kiki Kogyo, Tokyo, Japan) [40]. The measurement protocol involved the participant holding their arm extended and close to the body, with the dynamometer facing outward. The participant was then instructed to apply a strong and continuous force against the dynamometer handle for approximately 3 s. Each participant performed the test twice, with a one-minute rest between attempts. The highest value (in kg) from the two attempts was used for analysis [41]. The MGS test has been shown to be a highly reliable measure in older adults, with an intraclass correlation coefficient (ICC) ranging from 0.96 to 0.98 [42].

Anthropometric

Anthropometric data were collected following the standardized procedures described by Lohan and collaborators [43]. Body mass was measured using a portable scale (Seca®, model 770, Germany) with a precision of 0.1 kg, and height was determined using a portable stadiometer (Seca Bodymeter®, model 208, Germany) with a precision of 0.1 cm. Body mass index (BMI) was then calculated using the formula: BMI = weight (kg) / height^2 (m^2).

Back scratch test

Upper body flexibility was assessed using the back scratch test (BST). Participants stood with their legs apart at shoulder width and were instructed to reach one arm over the shoulder and the other up the middle of the back [44]. The distance between the extended middle fingers was measured in centimeters, with the result recorded as either positive, zero, or negative, depending on whether the fingers touched or overlapped. This test evaluates the flexibility of the shoulder and upper back region in elderly individuals [45].

The 30 s chair-stand test

Lower body strength was assessed using the 30-s chair-stand (30-sCS) test. Participants were instructed to stand up and sit back down from an armless chair (approximately 43 cm in height) as many times as possible within 30 s, while keeping their arms crossed at chest level with wrists resting against their chest [46]. The total number of times the participant successfully stood up during the 30 s was recorded as the outcome. The 30-sCS test is considered a reliable and valid measure of lower body strength in community-dwelling older adults, with reported reliability coefficients (ICC) ranging from 0.97 to 0.98 [47].

The 30 s arm curl test

Upper body strength was assessed using the 30-s arm curl (30-sAC) test. Participants were asked to perform as many repetitions of elbow flexion and extension as possible within 30 s, while seated and holding a 2.3 kg dumbbell in one hand [48]. The total number of repetitions for each arm was recorded. The 30-s arm curl test is considered a reliable and valid measure of upper body strength in generally active, community-dwelling older adults, with reported reliability coefficients (ICC) ranging from 0.88 to 0.99 [49].

Levels of Physical Activity (PA)

The PAL were assessed using the International PA Questionnaire-Short Form (IPAQ-SF), which measures the average weekly minutes spent on vigorous and moderate-intensity PA, walking, and sitting. Activity levels were calculated by assigning MET values: 8.0 for vigorous activities, 4.0 for moderate activities, and 3.3 for walking [50]. Total PA scores were categorized as high, moderate, or low, and sitting time was recorded in minutes per day. This standardized tool helps assess PA behavior in diverse populations and was used to explore the relationship between PA and frailty syndrome in this study [51]. MET is the standard unit used in the IPAQ scoring protocol, several studies however, have reported IPAQ outcomes in kcal/week instead of MET, demonstrating that kcal is an acceptable alternative for expressing physical activity data [52, 53]. Reporting in kcal/week allows for an intuitive understanding of energy expenditure for both researchers and practitioners working in the field of physical frailty in older adults, aligning with our study's clinical application.

Statistical analysis

The normal distribution of the data was assessed using the Shapiro–Wilk test. Descriptive data are presented as mean (M) ± standard deviation (SD) with 95% confidence intervals. Comparisons between frail subgroups were conducted using the Student's t-test, with a significance level set at 0.05. Effect sizes (Cohens *d'*) with 95% confidence intervals were calculated for t-test comparisons, where values < 0.2 were considered small, < 0.5 medium, and > 0.8 large [54]. Associations between the PFP total score and PFF indicators were evaluated using Spearman's correlation with the strength of the relationships classified as trivial (r < 0.1), small (r = 0.1–0.3), moderate (r = 0.3–0.5), strong (r = 0.5–0.7), and robust (r 0.7–0.9) [55]. Logistic regression models were used to identify the significance of PFF variables as risk factors for FS. To enhance the robustness of our findings, we incorporated adjustment variables in the both correlations models that demonstrated significant differences in the comparison between frailty subgroups. Additionally, the predictive performance of PFF test scores for FS was assessed using receiver operating characteristic (ROC) curves to determine the optimal cut-off values for each PFF variable. Data analysis was performed using SPSS for Windows, version 26.0 (SPSS Inc., Chicago, IL, USA).

Results

The data presented in Table 1 summarizes the general characteristics of paricipants. Significant differences were observed between these groups in sociodemographic, anthropometric, medical history, and PFF variables. Frail individuals were older than non-frail/pre-frail individuals, and had lower educational levels ($p = 0.001$). Adittionally, frail participants had a significantly lower height ($p = 0.008$) and higher BMI ($p = 0.027$) compared to the non-frail/pre-frail subgroup. Regarding medical history, frail individuals had a higher incidence of falling ($p = 0.001$). Participants in the frail subgroup exhibited significantly worse PFF indicators in all variables ($p < 0.001$). In terms of PFS indicators, frail participants exhibited lower performance on the all tests ($p = 0.001$). Effect size calculations indicated medium to large differences between groups in most variables, with Cohen's d values ranging from 0.35 to 1.26, highlighting the significant functional and physical disparities between frail and non/pre-frails individuals.

Table 2 presents the Spearman correlations between the PFS total score and various indicators of PFF. A significant negative correlation was found between PFS and HGS (r = −0.702, $p < 0.001$), were found. Similarly, PAL levels of IPAQ (r = −0.681, $p < 0.001$), and Tinneti POMA-balance (r = −0.515, $p < 0.001$); Tinneti POMA-walking, r = −0.523, $p < 0.001$) showed moderate to strong negative correlations with PFP total score. Furthermore, the Tinneti-POMA combined score also displayed a significant negative correlation with PFS (r = −0.586, $p < 0.001$). Additionally, lower performance on the 30-sAC (r = −0.521, $p < 0.001$) and 30-sCS tests (r = −0.579, $p < 0.001$) were associated with higher PFS scores. The SSB test also showed a moderate negative correlation with PFS (r = −0.629, $p < 0.001$). In contrast, the BST showed a small positive correlation with PFS (r = 0.282, $p < 0.001$).

The adjusted logistic regression analysis revealed significant associations between several PFF variables and the risk of PFS, even after controlling for age, sex,

Table 1 Characterization of the total sample study population and comparison by frailty for sociodemographic, anthropometric, medical history, frailty and physical-functional fitness status

	Total sample (n = 161, 100%)	Non-frail and pre-frail (n = 85, 53%)	Frail (n = 76, 47%)	p-value	Cohens d' Effect size [95% CI]
Sociodemographic					
Age (years, Mean ± SD)	68.01 ± 6.88	64.79 ± 4.43	71.61 ± 7.35	0.001*	−1.14 [−1.45—0.83]
Sex (n, %)				0.004*	
Male	91 (56.5%)	57 (67.1%)	34 (44.7%)		
Female	70 (43.5%)	28 (32.9%)	42 (55.3%)		
Marital State (n, %)				0.007*	
Single	1 (0.6%)	1 (1.2%)	0 (0%)		
Married	129 (80.1%)	75 (88.2%)	54 (71.1%)		
Widowed	28 (17.4%)	7 (8.2%)	21 (27.6%)		
Divorced	3 (1.9%)	2 (2.4%)	1 (1.3%)		
Level of education (Degree; M 1;3)	1 (1; 3)	2 (1; 3)	1 (1; 1.75)	0.001*	
Anthropometric (*M ± SD*)					
Weight (kg)	69.87 ± 11.46	69.67 ± 11.06	70.10 ± 11.96	0.813	−0.04 [−0.35–0.27]
Height (centimeters)	1.63 ± 0.09	1.65 ± 0.08	1.61 ± 0.10	0.008*	0.44 [0.13–0.76]
BMI (kg.m^{-2}) Mean ± SD)	26.27 ± 4.49	25.53 ± 3.95	27.09 ± 4.92	0.027*	−0.35 [−0.66—0.04]
Medical History screen					
Smoking (n, %)				0.663	
Yes	32 (19.9%)	18 (21.2%)	14 (18.4%)		
No	129 (80.9%)	67 (78.8%)	62 (81.6%)		
Eyesight problems (n, %)				0.074	
No problem	81 (50.3%)	47 (55.3%)	34 (44.7%)		
Poor eyesight	43 (26.7%)	24 (28.2%)	19 (25.0%)		
Eye glasses	37 (23.0%)	14 (16.5%)	23 (30.3%)		
Hearing problems (n, %)				0.212	
No problem	123 (76.4%)	68 (80.0%)	55 (72.4%)		
Poor hearing	35 (21.7%)	17 (20.0%)	18 (23.7%)		
Hearing aids	3 (1.9%)	0 (0%)	3 (3.9%)		
Falling incidence (n, %)	43 (26.7%)	12 (14.1%)	31 (40.8%)	0.001*	
Physical Frailty Screen (n, %)				0.001*	
Weakness	89 (55.3%)	28 (32.9%)	61 (80.3%)		
Slowness	71 (44.1%)	16 18.8%)	55 72.4%)		
Poor energy	80 (49.7%)	14 (16.5%)	66 (86.8%)		
Shrinking	80 (49.7%)	25 (29.4%)	55 (72.4%)		
Low PAL (Man < 383 women < 270)	49 (30.4%)	2 (2.4%)	47 (61.8%)		
Physical-Functional Fitness status (M ± SD)					
IPAQ (Kcal.week^{-1}, Mean ± SD)	985.26 ± 909.11	1434.66 ± 1344.76	482.64 ± 477.31	0.001*	0.92[0.61–1.24]
Hand grip strength test (kg, Mean ± SD)	25.01 ± 10.29	30.21 ± 9.40	19.20 ± 7.87	0.001*	1.26[0.95–1.58]
Tinetti POMA-balance (points)	11.58 ± 3.89	13.08 ± 3.22	9.89 ± 3.90	0.001*	0.90[0.59–1.21]
Tinetti POMA-walking (points)	7.97 ± 3.09	9.18 ± 2.65	6.62 ± 3.01	0.001*	0.91[0.59–1.22]
Tinetti POMA total score	19.55 ± 6.37	22.26 ± 5.09	16.51 ± 6.32	0.001*	1.01[0.70–1.32]
30-s arm curl (reps per time)	13.27 ± 3.17	14.34 ± 3.58	12.07 ± 2.09	< 0.001*	0.76[0.45–1.08]
30-s chair stand (reps per time)	10.41 ± 4.10	12 ± 3.98	8.63 ± 3.47	< 0.001*	0.90[0.59–1.21]
Standing Stork balance test (per time)	12.58 ± 12.66	17.97 ± 13.73	6.56 ± 7.82	< 0.001*	1.01[0.70–1.32]
Back scratch test (centimeters)	16.15 ± 13.28	12.71 ± 9.32	19.95 ± 15.81	< 0.001*	−0.57[−0.88—0.25]

M ± SD Mean ± Standard Deviation, *BMI* Body Massa Index, *Kg* Kilograms, *PAL* Physical Activity levels, *IPAQ* International Physical Activity Questionnaire, *POMA* Tinetti Performance Oriented Mobility Assessment

Table 2 Correlations between Physical Frailty Phenotype total score and Indicators of Physical- Functional Fitness ($n = 161$)

Physical-Functional Fitness indicators	*r*	*p-value*
Body mass Index (kg.m^{-2})	0.191	0.015
Hand grip strength test (kg)	−0.702	0.001
IPAQ (Kcal.week-1)	−0.681	0.001
Tinetti POMA-balance (points)	−0.515	0.001
Tinetti POMA-walking (points)	−0.523	0.001
Tinetti POMA total score	−0.586	0.001
30-s arm curl (reps per time)	−0.521	< 0.001
30-s chair stand (reps per time)	−0.579	< 0.001
Standing Stork balance test (per time)	−0.629	< 0.001
Back scratch test (centimeters)	0.282	< 0.001

r = Spearman Correlation coefficient, p = Significance (2-tailed), *IPAQ* International Physical Activity Questionnaire, *s* seconds, *POMA* Performance Oriented Mobility Assessment

$p < 0.001$), with the adjusted model explaining 32% of FS variance.

Interestingly, BMI remained positively associated with PFS risk after adjustments (OR = 1.078, 95% CI: 1.002–1.161, $p = 0.035$), highlighting its role in PFF decline. Conversely, better BST, indicated a protective effect against FS (OR = 1.043, 95% CI: 1.015–1.073, $p = 0.005$). Overall, these adjusted models demonstrated robust predictive strengths, with Nagelkerke R^2 values ranging from 12.0% to 40.2% and predictive accuracy between 61.3% and 73.9%, emphasizing the critical role of PFF tests in frailty assessment. Table 3.

The predictive performance of PFF tests for FS was evaluated using ROC analysis. Figure 1 showed that, the Tinetti POMA-balance showed a cutoff of ≤ 12.5 (AUC of 0.752 [95% CI: 0.677–0.826]). Similarly, the Tinetti POMA-walking had a cutoff of ≤ 8.5 (AUC of 0.738 [95% CI: 0.662–0.814]). The Tinetti total score cutoff of ≤ 19.5 yielded higher predictive performance (AUC = 0.779 [95% CI: 0.708–0.850]). The PAL by IPAQ demonstrated excellent predictive accuracy with a cutoff of ≤ 440.50 kcal/week (AUC = 0.847 [95% CI: 0.787–0.907]). In contrast, HGS test (cutoff ≤ 26.80 kg) achieved an AUC of 0.808 (95% CI: 0.741–0.874).

Table 3 Regression analysis of risk Factors for Physical Frailty Syndrome Based on Physical-functional Fitness Variables ($n = 161$)

Variables	Adjusted Coefficient (B)	p-value	R^2 (Nagelkerke)	Adjusted Odds Ratio (Exp(B))	95% Confidence Interval for Exp(B)
Tinetti POMA-balance (points)	−0.220	0.002	0.245	0.803	0.726–0.888
Tinetti POMA-walking (points)	−0.290	0.001	0.252	0.748	0.656–0.853
Tinetti POMA combined score	−0.165	0.001	0.305	0.848	0.786–0.914
IPAQ (Kcal.week^{-1})	−0.002	0.001	0.402	0.998	0.997–0.999
Mean hand grip strength (kg)	−0.130	0.001	0.385	0.878	0.835–0.921
BMI (kg.m^{-2})	0.075	0.035	0.051	1.078	1.002–1.161
30-s arm curl (reps per time)	−0.280	< 0.001	0.198	0.756	0.656–0.871
30-s chair stand (reps per time)	−0.220	< 0.001	0.235	0.802	0.728–0.884
Standing Stork balance test (per time)	−0.100	< 0.001	0.320	0.905	0.865–0.947
Back scratch test (centimeters)	0.042	0.005	0.120	1.043	1.015–1.073

Adjusted Logistic Regression controlling for age, sex, education, height, and fall Incidence; p = Significance (2-tailed), *IPAQ* International Physical Activity Questionnaire, *s* seconds, *POMA* Performance Oriented Mobility Assessment

educational level, height, and fall incidence. Lower scores on the Tinetti-POMA balance (OR = 0.803, 95% CI: 0.726–0.888, $p = 0.002$) and walking component (OR = 0.748, 95% CI: 0.656–0.853, $p = 0.001$) remained strongly associated with higher PFS risk, with the combined Tinetti score showing an adjusted OR of 0.848 (95% CI: 0.786–0.914, $p = 0.001$). The PAL levels demonstrated the strongest protective association (OR = 0.998, 95% CI: 0.997–0.999, $p = 0.001$), explaining 40.2% of PFS variability and predicting 72% of cases.

Among the strength-based tests, decreased MCS (OR = 0.878, 95% CI: 0.835–0.921, $p = 0.001$), 30-sAC (OR = 0.756, 95% CI: 0.656–0.871, $p < 0.001$), and 30-s CS (OR = 0.802, 95% CI: 0.728–0.884, $p < 0.001$) were significantly associated with PFS risk, confirming their predictive value. Poor static balance (SSB), emerged as another significant predictor (OR = 0.905, 95% CI: 0.865–0.947,

A BMI cutoff of ≥ 27.30 kg/m^2 with an AUC of 0.615 (95% CI: 0.526–0.704) provided a moderate predictive capacity. The measures of PFF showed varied predictive power: the 30-sAC (cutoff ≤ 11.5) and AUC of 0.714 (95% CI: 0.635–0.794). The 30-s CS (cutoff ≤ 10.5) demonstrated slightly higher sensitivity and specificity (AUC = 0.745 [95% CI: 0.668–0.822]). The stork balance test (cutoff of ≤ 8.70 s, and an AUC of 0.800 [95% CI: 0.732–0.869]), and the BST (cutoff ≥ 11.5 cm) showed lower sensitivity and specificity, with an AUC of 0.629

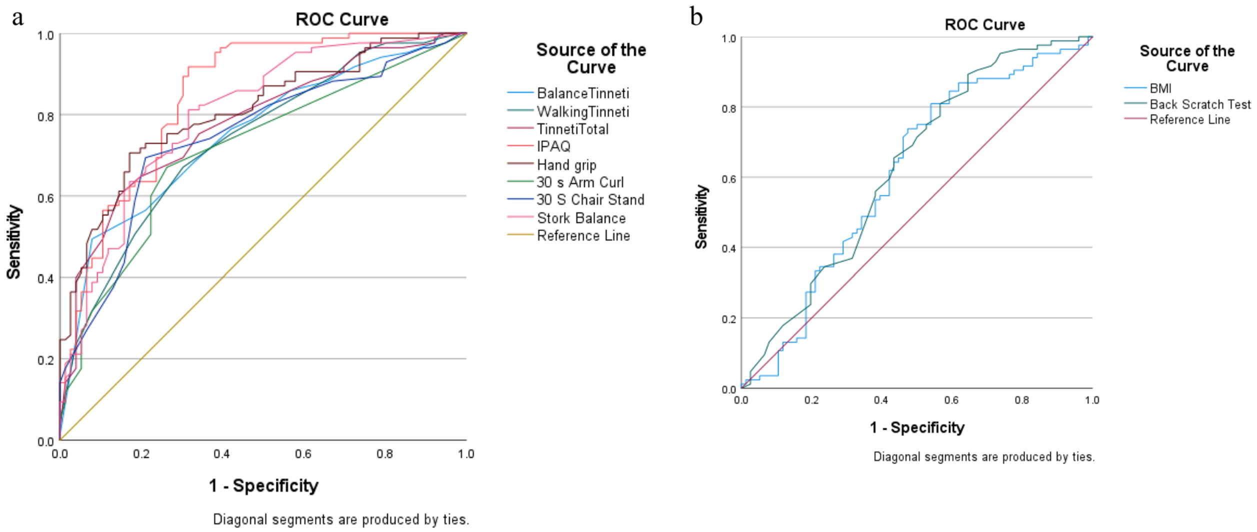

Fig. 1 **a** & **b**, Receiver operating characteristic (ROC) curves for physical-functional fitness scores and frailty phenotype among participants. The straight line shows the reference line, which was approximated by the ROC curve plotted on sensitivity (true positive rate) over 1-specificity (false positive rate) for the physical-functional fitness

(95% CI: 0.542–0.717). In summary, IPAQ and SSB test exhibiting the highest predictive accuracy.

Discussion

Main results

The current study aimed to evaluate the association between senior PFF test scores and PFS among older adults. Frail participants demonstrated significantly lower scores across all PFF assessments, indicating compromised functional capacities. Additionally, frail individuals were found to have lower levels of education, shorter stature, and higher BMI compared to their non-frail/pre-frail counterparts, highlighting a broader profile of vulnerability within this group. Logistic regression analyses further emphasized the protective role of PFF tests against PFS. Moreover, the ROC curve analysis determined optimal cutoff points for predicting PFS, with the PAL and MGS showing the highest sensitivity and specificity. All components of the Tinetti-POMA scale also demonstrated strong predictive value, underscoring their importance in assessing frailty and guiding interventions in older adults.

Comparison of frailty subgroups

Frail participants exhibited significantly lower scores in a range of all PFF tests compared to non-frail and pre-frail individuals. These results highlight the substantial functional impairments associated with PFS, aligning with previous studies that show frail individuals generally experience diminished strength, balance, walking speed, PA, instrumental and independent daily life activities [19, 28, 56].

In particular, balance and muscle strength emerged as a keys markers in distinguishing frail individuals, as it is closely linked to an increased risk of falls, a common consequence of PFS. Our findings further support this association, as frail individuals exhibited significantly poorer static and dynamic balance compared to non-frail individuals. The SSB test, which assesses static balance, revealed frail participants experiencing difficulty in maintaining balance for prolonged periods, which could have direct implications for fall risk in this population. Similarly, the Tinetti components, which evaluate both dynamic balance and gait, proved to be highly sensitive to frailty [57], reinforcing the idea that balance-related dysfunction is one of the earliest and most prominent signs of PFS in older adults.

In addition to balance, muscle strength emerged as another key distinguishing factor. The MGS, 30 s-AC and 30 s-CS, which assess upper and lower body strength, were significantly lower in frail participants. Muscle strength is essential for performing everyday activities, and its decline is a hallmark of frailty [58]. Our results, which show a significant difference in strength between frail and non-frail individuals, further emphasize the critical role of maintaining muscle mass and strength in preventing or delaying frailty. These findings are consistent with previous research, which has identified strength as one of the most important physical indicators of frailty [59].

Additionally, frail individuals were found to have lower educational levels, shorter stature, and higher BMI than their non-frail counterparts, emphasizing the broader spectrum of vulnerabilities associated with frailty, as also reported in similar research [60].

Interestingly, our study also identified that frail participants were shorter in stature compared to their counterparts, which to our knowledge, has not been extensively discussed in frailty research. Shorter stature has been linked to PFS in previous studies [60, 61]. This observation supports the idea that short stature may confer a greater susceptibility to functional decline due to factors like muscle loss and reduced capacity to handle physical stressors [62]. Our results also indicated that higher BMI was significantly associated with PFS, which is consistent with the body of literature suggesting that elevated BMI in older adults is linked to increased frailty risk [63]. High BMI is often associated with metabolic changes and joint degeneration [23, 64], both of which contribute to functional decline and frailty, reinforcing the relevance of BMI as a factor in PFS assessment [65]. The inclusion of both stature and BMI in our models provides a broader understanding of the physical and functional dimensions of PFS [66], emphasizing the importance of considering multiple physical factors when assessing frailty risk in older adults.

Associations with PFS and PFF

The results of regression analyses in this study highlighted several key associations between PFF tests and FS. Notably, all the PFF variables were identified as significant protective factors against PFS. These findings align with a growing body of research that emphasizes the importance of balance and strength in the context of frailty [19, 28, 56]. However, the Tinetti-POMA test, which assesses both balance and gait, proved to be particularly significant in this study, with all its components (balance, walking, and combined scores) demonstrating strong protective associations with PFS. This aligns with recent studies that have highlighted the Tinetti test as a reliable tool for detecting frailty and fall risk in older adults [57]. Previous research has consistently found that impairments in balance and walking ability are central features of PFS [67, 68], and our study supports these conclusions by demonstrating that poor performance in these domains is significantly linked to higher frailty risk.

Similarly, MCS, which has been identified as one of the most reliable markers of frailty in older adults, was significantly associated with frailty in this study. This is consistent with findings from recent studies, which have shown that MCS test alone is a strong predictor of PFS and related adverse outcomes, such as disability and hospitalization [55]. The 30 s-AC and 30 s-CS tests, which assess upper and lower body strength, also emerged as significant protective factors against PFS due to their direct relationship with muscular function. This relationship is particularly relevant to daily life tasks that require effective neuromuscular actions, and deterioration in these functions leads to a frail condition [69, 70], as weakened muscle strength impairs the ability to perform essential activities of daily life and increased the risk os falls.

ROC curve prediction

Finally, the ROC curve analysis provided valuable insights into the predictive power of various PFF tests for PFS. Among the tests, PAL, as measured by the IPAQ, and MGS exhibited the highest sensitivity and specificity, with the optimal cutoff points identified as $\leq$ 440.50 kcal/week and $\leq$ 26.80 kg, respectively. This finding underscores the critical role of PA and muscular strength in predicting frailty, reinforcing the established relationship between these factors and functional decline in older adults [71].

The MGS emerged as a good predictor of PFS in our study. This threshold aligns closely with recommendations from the Asian Working Group for Sarcopenia (AWGS) for diagnosing PFS in men [72]. While normative studies in Europe report peak grip strength values of 43–49 kg and weakness thresholds ranging from 29–32 kg [73], findings in Western populations, such as the United States and Europe [74, 75], suggest slightly higher thresholds for handgrip strength, often exceeding 30 kg for men. These regional differences likely reflect variations in genetic, dietary, and lifestyle factors [75]. Additionally, studies from Asian countries, such as Japan and China, reveal similar cut-off values for MGS and 30 s-CS, demonstrating a level of regional consistency in these measures [76]. These findings support the use of MGS as a globally recognized and practical tool for frailty evaluation, while underscoring the importance of tailoring cut-off points to specific populations to ensure accurate and context-appropriate assessments.

Indeed, studies have shown that recognizing these regional and population-specific differences can enhance the accuracy and effectiveness of health interventions. A 20-year longitudinal study examining PA patterns in older adults found that consistent PA significantly reduced the risk of frailty by preventing chronic conditions, which are key risk factors for frailty. Additionally, frailty is more prevalent among older adults who engage in insufficient PA and spend excessive time in sedentary behavior [77], and PAL appears as a critical factor in maintaining functionality and quality of life in older age [23]. Prolonged sedentary activities, such as extended periods of television viewing, sitting while reading, and limited engagement in social or recreational activities, contribute to reduced energy expenditure and weakened musculoskeletal health. The resulting decline in strength, balance, and overall physical resilience increases susceptibility to falls and functional impairments. In urban environments like Tehran, lifestyle factors such as high traffic congestion, limited green spaces, and a preference for car-based transportation further exacerbate sedentary behavior. These patterns are reflected in the identified IPAQ cut-off point of ≤ 440.50 $kcal.week^{-1}$, which aligns with the distinct characteristics of Tehran's predominantly urban population, where sedentary behavior is prevalent, and PAL are notably lower than in rural areas. This low energy expenditure underscores the challenges posed by urbanization, including limited recreational opportunities and lifestyle patterns marked by prolonged sedentary behavior [78]; and highlights the need for tailored intervention strategies to promote active lifestyles and mitigate frailty risk in urban communities. Such localized thresholds are crucial for accurately identifying individuals at risk for frailty and implementing strategies to address the unique needs of urban communities.

Notably, the BMI cut-off in our study (≥ 27.30 kg/m^2) is higher than thresholds typically reported in Asian populations (e.g., ≥ 25 kg/m^2), reflecting differences in obesity prevalence and health risk profiles. In Asian populations, a BMI threshold of ≥ 25 kg/m^2 is frequently used to define obesity-related health risks, as seen in countries like Japan and China. This reflects a lower obesity prevalence compared to Western populations and the recognition that health risks associated with BMI can occur at lower thresholds in Asian populations [73, 75]. Inconsistently, the cut-off in our study (≥ 27.30 kg/m^2) is higher, which could reflect urban lifestyle factors specific to Tehran, such as diet and activity patterns, contributing to greater prevalence of higher BMIs.

In this study the Tinetti components, alongside other PFF tests such as the 30 s-AC, 30 s-CS, and SSB, were all shown to be strong predictors of PFS. Using similar analyses, Furtado and their colleagues identified dynamic-balance test, as a significant predictor of PFS. These findings align with our study, emphasizing the importance of balance assessments as part of PFS evaluation. Moreover, a recent study employing advanced technologies to predict falls demonstrated that objective measures of gait, balance, and PA parameters could effectively identify prefrailty and classify frailty levels [79]. The 30 s-CS demonstrated its relevance in PFS screening, aligning with findings from a large cohort study by Guralnik et al., which highlighted its utility in epidemiologic research [80]. However, the cut-off value of ≤ 10.5 repetitions identified in our study is notably lower than thresholds reported for predicting sarcopenia in the older Japanese population [76]. This discrepancy underscores the need for further research to explore population-specific variations and refine cut-off points to enhance global applicability. Especially, the Tinetti POMA total score emerged as a robust tool in this study, with a cut-off point of ≤ 19.5 for frailty classification. This threshold aligns with prior research, such as Faber et al. [81], which identified comparable benchmarks for frailty detection in European older adults [81]. These consistent findings highlight the cross-context applicability of Tinetti POMA as a reliable measure for frailty screening across diverse populations [81].

Strengths and limitations

This study offers several key strengths. First, it provides valuable cutoff points, offering actionable thresholds for PFS detection. These results suggest that the Tinetti-POMA could serve as a novel and effective tool for identifying PFS, broadening the range of practical instruments available for clinical and research use. Additionally, the study employs validated instruments, such as the PAL and MCS measures, which enhance the credibility and reproducibility of its findings. Furthermore, it introduces new insights into the role of stature as a potential marker of PFS, adding a novel perspective to the assessment of physical fitness and frailty relationships.

Despite these strengths, the study has certain limitations. The cross-sectional design restricts the ability to establish causal relationships between PFF and PFS, underlining the need for longitudinal studies to better understand these dynamics. The study's focus on elderly individuals from Tehran limits the generalizability of the findings to other cultural and geographic contexts.

Practical applications

The findings have direct implications for geriatric healthcare. The validated PFF assessments used in this study, provide practical tools for identifying older adults at higher risk of PFS. Integrating these measures into routine clinical evaluations enables healthcare providers to implement early interventions tailored to individual needs, promoting physical resilience and healthier aging. Community-based exercise programs and rehabilitation initiatives focusing on balance, strength, and endurance could be particularly effective in reducing PFS prevalence. Additionally, these tools can guide the design of personalized care plans that address the physical and functional health challenges associated with aging.

Future insights

Future research should address the limitations of this study by employing longitudinal designs to establish causal relationships between PFF and PFS. Expanding the scope to include diverse populations across various cultural and geographic settings would enhance the generalizability of the findings. Incorporating objective measures of PAL, such as accelerometers or wearable devices, could improve the accuracy of PAL assessments. Further investigation into the effectiveness of specific interventions—such as tailored exercise programs, nutritional support, and multi-component approaches—would offer valuable strategies for preventing and managing frailty. Randomized controlled trials could provide robust evidence for these interventions. Additionally, exploring the genetic and molecular underpinnings of the PFF–PFS relationship may identify novel therapeutic targets, advancing personalized approaches to geriatric care.

Conclusion

This study highlights the critical role of specific PFF assessments in screening for PFS. Among these, the Tinetti-POMA emerged as a promising tool for frailty detection due to its ease of administration, low cost, and capacity to provide valuable insights into balance and gait—key components of PFS assessment. The identification of optimal cutoff points enhances the clinical utility of these assessments, facilitating timely and targeted interventions. Moreover, the findings introduce novel markers, such as stature, which offer fresh perspectives on PFS risk. These results underscore the importance of exploring and integrating such accessible and validated tools into routine geriatric evaluations, aiming to improve health outcomes and quality of life for older adults.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-025-05858-0.

Additional file 1

Acknowledgements

The co-author Guilherme Furtado thanks the National funding by FCT- Foundation for Science and Technology, P.I., through the institutional scientific employment program-contract (CEECINST/00077/2021).

Authors' contributions

M.H.1 and M.H.4 conceived the study. M.H.1 collected the data. M.H.4, M.S. and P.N. supervised the data collection. M.H.4, M.H.1, H.M., and G.E.F. analyzed the data. M.H.4 and G.E.F. performed the statistical analysis. M.H.1, M.H.4 and G.E.F. wrote the main manuscript. All authors reviewed and approved the manuscript.

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Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. "no external financial support".

Data availability

Sequence data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki), and was also approved by the institutional review board of Sport Sciences Research Institute of Iran (IR.SSRC.REC.1401.025). Signed informed consent to participate in the study was obtained from all participants.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Received: 22 June 2024 Accepted: 12 March 2025
Published online: 29 March 2025

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