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ORIGINAL ARTICLE

Utilizing Lower Limb Phase Angle as a Functional Prognostic Indicator for Patients in Convalescent Rehabilitation Wards

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Objectives: This study aimed to investigate whether lower limb phase angle (LL-PA) at admission predicts functional outcomes in patients undergoing rehabilitation. **Methods**: In this retrospective study, we measured the LL-PA of 256 patients (mean age 74.09±12.86 years) admitted to a convalescent rehabilitation ward upon arrival. The primary outcomes at discharge were motor Functional Independence Measure (FIM) scores and walking independence. The secondary outcomes included a 10-m walking speed and Timed Up-and-Go test result. **Results**: The LL-PA independently predicted discharge motor FIM scores (β=0.323, P <0.001) and walking independence (odds ratio=3.302, 95% confidence interval: 1.714–6.360). The sex-specific cut-off value for predicting walking independence was 3.050° for men (sensitivity, 0.804; specificity, 0.853) and 2.650° for women (sensitivity, 0.769; specificity, 0.812). **Conclusions**: LL-PA at admission is a significant predictor of functional outcomes in patients undergoing rehabilitation, with potential utility in early prognostic assessments.

Key Words: bioelectrical impedance analysis; convalescent rehabilitation; functional independence measure; phase angle; prognostic prediction

INTRODUCTION

Predicting functional outcomes in older adult patients in convalescent rehabilitation hospitals is crucial for developing effective intervention strategies and for discharge planning.[1] Traditionally, factors such as age, disease severity, and Functional Independence Measure (FIM) scores at admission have been used as prognostic indicators. However, these indicators do not adequately reflect the body composition and muscle quality of patients.

Recently, phase angle (PA) measurements using bioelectrical impedance analysis (BIA) has gained attention as a novel assessment tool.[2,3] PA reflects cell membrane integrity and function, with lower values associated with decreased muscle mass, malnutrition, and functional decline.[4,5] Notably, lower-limb PA (LL-PA) has shown strong correlations between walking ability and lower-limb muscle strength,[6,7] indicating its potential utility in the functional assessment of older adults.

However, in patients undergoing rehabilitation, several important problems regarding the clinical significance of LL-PA remain unresolved. First, the relationship between LL-PA values at admission and functional independence or walking ability at discharge remains unclear. Second, the utility of LL-PA as an independent predictor compared with conventional prognostic factors is uncertain. Third, sex-specific evaluation criteria for LL-PA have not been established. Therefore, to address these problems in the present study, we aimed to analyze the relationship between LL-PA and functional indicators in patients admitted to a convalescent

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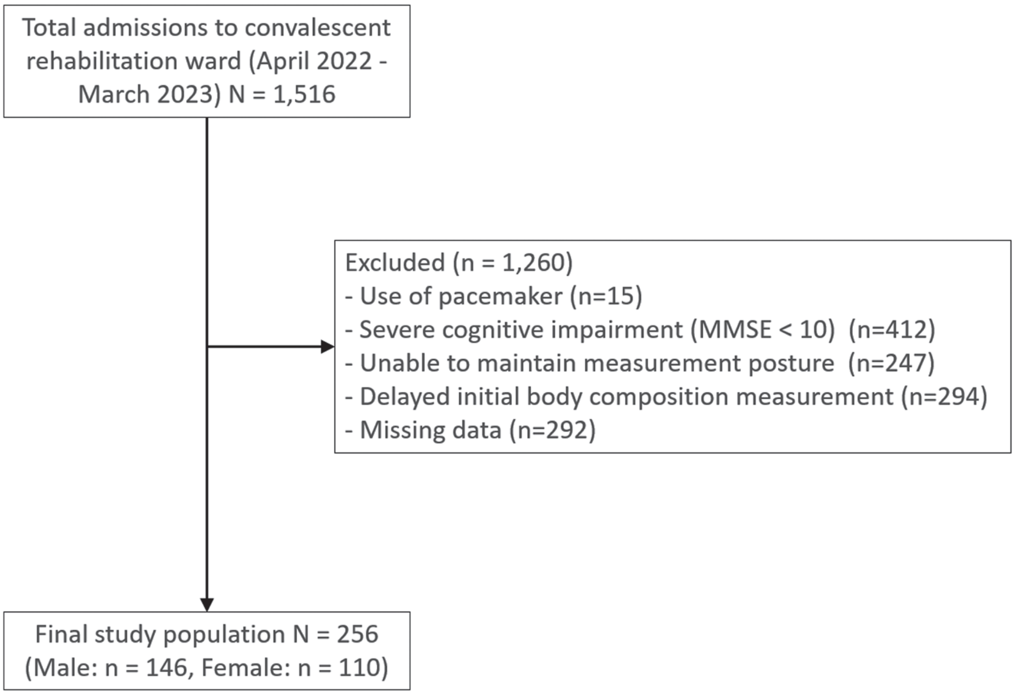

Fig. 1. Flowchart of participant selection process.

rehabilitation hospital and to verify the utility of LL-PA as a functional prognostic indicator.

MATERIALS AND METHODS

Study Design and Participants

This retrospective observational study was conducted in the convalescent rehabilitation ward of Tamus Urayasu Hospital. For patients admitted between April 2022 and March 2023, the following inclusion criteria were used: (1) first-time admission to a convalescent rehabilitation ward, (2) ability to maintain a stable standing position (defined as the ability to stand independently for at least 30 s without support) during BIA measurements, (3) completion of all outcome measurements at both admission and discharge, and (4) BIA measurements conducted within 4 weeks of admission. Of a total of 1516 patients, 1260 patients were excluded. First, 15 patients using pacemakers were excluded because of safety concerns. Among the remaining 1501 patients, 412 patients with severe cognitive impairment [Mini-Mental State Examination (MMSE) <10 points] were excluded because we considered that cognitive impairment, consciousness disorder, or severe higher brain dysfunction may have significantly affected the reliability of measurements and rehabilitation outcomes. Of the 1089 remaining patients, 247 were excluded because they were unable to maintain the required standing position for BIA measurements. Among the 842 eligible patients, 294 were excluded because their initial body composition measurements were not conducted within 4 weeks of admission. Finally, 292 patients were excluded because of missing outcome data, resulting in a final study population of 256 patients. All BIA measurements were performed in the morning before any rehabilitation activities to ensure standardized conditions.

A total of 256 patients (146 men and 110 women) were included in the analysis (**Fig. 1**). Primary diagnoses included cerebrovascular disease (n=114, 44.5%), orthopedic conditions (n=76, 29.7%), and disuse syndrome (n=66, 25.8%). This study was approved by the Ethics Committee of Tamus Urayasu Hospital (approval number: 2023001). Because this was a non-invasive retrospective observational study using only medical record data, we employed an opt-out methodology instead of obtaining written informed consent. Information about the study was publicly disclosed on our institution's website and in the hospital, providing patients with the opportunity to refuse participation. This procedure was conducted in accordance with the Japanese Ethical Guidelines for Medical and Health Research Involving Human Subjects.

Measurements

Body Composition Assessment

Body composition was measured using a multifrequency bioelectrical impedance analyzer (TANITA 780A; TANITA, Tokyo, Japan). The patients achieved stable medical conditions and maintained a standing position. Their measurements were taken under standardized conditions: in the morning after a minimum of 2 h of fasting, post-urination, at room temperature 22–26 °C, and when wearing light hospital clothing. The patients stood barefoot on the electrode plates while holding hand electrodes. LL-PA was calculated from the reactance and resistance values obtained at 50 kHz.

Functional Assessment

FIM was assessed at admission and discharge and consisted of 13 motor items (91 points) and 5 cognitive items (35 points), totaling 18 items (126 points).[8] The motor FIM score was primarily used in the analysis. Walking independence at discharge was defined as a FIM walking score of 6 or above (independent indoor walking), whereas a score of 5 or below was considered dependent.

Physical function was evaluated using the 10-m walk and the Timed Up-and-Go (TUG) test. The 10-m walk test was performed at a comfortable speed following Bohannon's method.[7] The TUG test measures the time taken to stand up from a chair, walk 3 m, turn around, walk back, and sit down, according to Podsiadlo and Richardson's protocol.[9]

Nutritional Status and Cognitive Function Assessment

Nutritional status was evaluated using the Controlling Nutritional Status (CONUT) score, which was calculated using serum albumin, total cholesterol, and lymphocyte count. The CONUT score ranges from 0 to 12, with higher scores indicating poorer nutritional status.[10] Cognitive function was assessed using MMSE, which evaluates orientation, memory, calculation, language function, and other cognitive domains using a 30-point scale.[11]

Rehabilitation Program

Our convalescent rehabilitation ward provided standardized rehabilitation programs 7 days a week. Comprehensive rehabilitation, including physical, occupational, and speech therapy, was provided at an average of 7.57 ± 0.70 units (approximately 2.5 h) per day, with each unit lasting 20 min. Physical therapy included basic movement gait, balance training, and muscle-strengthening exercises. Occupational therapy focuses on the activities of daily living, upper limb function, and cognitive training. Speech therapy, including swallowing rehabilitation, articulation, and higher brain function training, was provided when necessary.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for Social Sciences version 27.0 (IBM, Armonk, NY, USA), with a statistical significance level of 5%. Dummy variables were created for cerebrovascular disease and disuse syndrome for the primary diagnosis, with orthopedic conditions as the reference. Pearson's correlation coefficients were used to examine the relationships between LL-PA and various assessment items for men and women.[12] Multiple regression analysis was performed using the discharge motor FIM score as a dependent variable and LL-PA as an independent variable, adjusting for age, sex, body mass index, primary diagnosis, length of stay, admission motor FIM score, and MMSE using the forced entry method.[13] Logistic regression analysis was performed using walking independence at discharge as the dependent variable with the same covariates.[14] Finally, receiver operating characteristic (ROC) curve analysis was performed separately for men and women to calculate the area under the curve (AUC) and optimal cut-off values to evaluate the predictive ability of LL-PA for walking independence.[15]

RESULTS

Participant Characteristics

This study included 256 participants with a mean age of 74.09 ± 12.86 years. The primary diagnoses were cerebrovascular disease (n=114, 44.5%), orthopedic conditions (n=76, 29.7.0%), and disuse syndrome (n=66, 25.8%). Disease distribution differed by sex, with men (n=146) showing a predominance of cerebrovascular disease (n= 83, 56.8%), followed by disuse syndrome (n=41, 28.1%) and orthopedic conditions (n=22, 15.1%). In contrast, women (n=110) showed a higher prevalence of orthopedic conditions (n= 54, 49.1%), followed by cerebrovascular disease (n=31, 28.2%) and disuse syndrome (n=25, 22.7%). Among patients with disuse syndrome, the underlying conditions in men included COVID-19 (n=14), pneumonia (n=12), septic shock (n=4), post-cardiovascular surgery (n=4), and others (n=7). In women, these conditions included pneumonia (n=9), COVID-19 (n=6), septic shock (n=4), post-cardiovascular surgery (n=2), and others (n=4).

Admission LL-PA values were significantly higher in men than in women (male, 3.8 ± 0.9°; female, 3.2 ± 0.8°; P

Table 1. Baseline characteristics of study participants

Characteristic	Total (n=256)	Male (n=146)	Female (n=110)	P value
Demographic data				
Age, years	74.09±12.86	70.42±13.48	78.85±10.84	<0.001
MMSE	26.22±4.24	26.47±4.44	25.90±3.96	0.752
Primary diagnosis				
Orthopedic conditions	76 (29.7)	22 (15.1)	54 (49.1)	<0.001
Cerebrovascular disease	114 (44.5)	83 (56.8)	31 (28.2)	<0.001
Disuse syndrome	66 (25.8)	41 (28.1)	25 (22.7)	0.042
FIM scores at admission				
Transfer	3.84±1.11	3.89±1.25	3.77±0.89	0.382
Walking	1.67±1.42	1.75±1.53	1.56±1.27	0.298
Stairs	1.02±0.12	1.03±0.16	1.00±0.00	0.064
FIM scores at discharge				
Transfer	6.37±0.98	6.53±0.94	5.89±1.40	<0.001
Walking	6.01±1.21	6.12±1.37	5.82±1.40	0.258
Stairs	5.49±1.37	5.65±1.37	5.29±1.36	<0.001
Physical performance				
Walking speed, m/s	0.719±0.278	0.767±0.284	0.659±0.263	0.003
TUG, s	20.73±10.91	19.46±12.49	22.39±8.41	0.038
Discharge walking speed, m/s	0.987±0.29	1.031±0.30	0.932±0.28	0.009
Discharge TUG, s	13.63±8.67	13.28±10.39	14.08±5.44	0.047
Clinical parameters				
CONUT score	2.53±1.71	2.59±1.81	2.45±1.57	0.298
Length of stay, days	81.15±29.02	83.23±30.01	78.49±27.43	0.215

Values are presented as mean ± standard deviation or number (percentage).
SMI, Skeletal Muscle Mass Index.
P values were calculated using independent *t*-tests for continuous variables and chi-square tests for categorical variables.

Table 2. Distribution of CONUT scores by sex and disease category

Sex	Disease category	Normal (0–1)	Mild (2–4)	Moderate (5–8)	Severe (≥9)
Male					
	Cerebrovascular disease (n=83)	8	14	2	1
	Orthopedic conditions (n=22)	3	4	3	0
	Disuse syndrome (n=41)	6	8	4	0
Female					
	Cerebrovascular disease (n=31)	4	11	1	0
	Orthopedic conditions (n=54)	6	12	2	0
	Disuse syndrome (n=25)	3	6	2	0

Values are presented as number of patients.
CONUT scores were categorized as normal (0–1), mild (2–4), moderate (5–8), and severe (≥9).

<0.001). The detailed baseline characteristics of the patients are presented in **Table 1**.

The nutritional status assessed by CONUT score showed varying distributions across disease categories and for sex (**Table 2**). In male patients with cerebrovascular disease, orthopedic conditions, and disuse syndrome, the majority showed normal to mild nutritional impairment (CONUT score 0–4). Similarly, female patients predominantly exhibited normal to mild nutritional impairment across all disease categories. Only one male cerebrovascular disease patient

Table 3. Correlation coefficients between LL-PA and functional outcomes by sex

Variable	Male (n=146)		Female (n=110)	
	r	P value	r	P value
Functional measures				
Motor FIM	0.429	<0.001	0.659	<0.001
FIM transfer	0.381	<0.001	0.454	<0.001
FIM walking	0.414	<0.001	0.478	<0.001
FIM stairs	0.496	<0.001	0.474	<0.001
Physical performance				
10-m walking speed	0.573	<0.001	0.712	<0.001
TUG test	−0.347	<0.001	−0.558	<0.001
Clinical parameters				
CONUT score	−0.411	<0.001	−0.284	<0.03
SMI	0.551	<0.001	−0.133	0.164

Values are presented as Pearson correlation coefficients (r).
SMI, Skeletal Muscle Mass Index.

showed severe nutritional impairment (CONUT score ≥9).

Relationship between LL-PA and Functional Indicators

Correlation analysis between admission LL-PA and functional measures revealed significant associations (**Table 3**). In men, LL-PA showed moderate positive correlations with motor FIM (r=0.429, P <0.001), transfer (r=0.381, P <0.001), walking (r=0.414, P <0.001), and stairs (r=0.496, P <0.001). In women, stronger correlations were observed, particularly with motor FIM (r=0.659, P <0.001), and there were moderate correlations with transfer (r=0.454, P <0.001), walking (r=0.478, P <0.001), and stairs (r=0.474, P <0.001). Regarding physical function assessments, significant positive correlations were found between LL-PA and 10-m walking speed in both sexes, with females showing a stronger correlation (male, r=0.573; female, r=0.712; P <0.001). In contrast, significant negative correlations were observed for the TUG test (male, r=−0.347; female, r=−0.558; P <0.001). The stronger correlations observed in women suggest that LL-PA might be a more sensitive predictor of functional performance in female patients.

Multiple Regression Analysis

Multiple regression analysis was performed with the discharge motor FIM score as the dependent variable. The results showed that LL-PA remained a significant independent predictor (β=0.323, P <0.001) after adjusting for confounding factors. Other significant predictors included MMSE (β=0.427, P <0.001), cerebrovascular disease (β=−0.221, P <0.001), and disuse syndrome (β=−0.117, P=0.034). The motor FIM score also showed a significant association (β=0.134, P=0.01). Age, sex, and length of stay did not show significant associations with the discharge motor FIM score (**Table 4**).

Prediction of Walking Independence

Logistic regression analysis revealed that LL-PA was an independent predictor of walking independence at discharge [odds ratio (OR)=3.302, 95% confidence interval (CI): 1.714–6.360; P <0.001). Other significant predictors included MMSE (OR=1.197, 95% CI: 1.096–1.307; P <0.001) and motor FIM (OR=1.067, 95% CI: 1.011–1.126; P=0.017). ROC curve analysis showed good predictive ability for walking independence in both sexes (male, AUC=0.820, 95% CI: 0.731–0.909; female, AUC=0.835, 95% CI: 0.749–0.920). The optimal cut-off value was 3.050° for men (sensitivity, 0.804; specificity, 0.853) and 2.650° for women (sensitivity, 0.769; specificity, 0.812) (**Table 5** and **Fig. 2**).

DISCUSSION

In this study, we demonstrated that LL-PA level measured at admission is a useful prognostic indicator of functional outcomes in patients admitted to convalescent rehabilitation hospitals. The non-invasive and nature of BIA measurement and the ability to implement BIA at the bedside offers practical advantages in the rehabilitation setting. Notably, LL-PA remained an independent predictor after adjusting for conventional prognostic factors, including age and admission motor FIM scores.

Table 4. Multiple regression analysis for predicting discharge motor FIM score

Variable	B	SE	β	t	P value	VIF
(Constant)	45.07	7.118	-	6.332	<0.001	-
Clinical measures						
Motor FIM	0.131	0.05	0.134	2.607	0.01	1.367
MMSE	1.055	0.121	0.427	8.731	<0.001	1.231
Disease categories						
Cerebrovascular disease	−4.642	1.355	−0.221	−3.427	<0.001	2.133
Disuse syndrome	−2.797	1.311	−0.117	−2.134	0.034	1.548
Other variables						
Length of stay	−0.003	0.019	−0.009	−0.179	0.858	1.386
Age	−0.062	0.051	−0.077	−1.224	0.222	2.046
Sex	0.707	1.065	0.034	0.664	0.507	1.309
LL-PA	3.418	0.753	0.323	4.539	<0.001	2.599

VIF, Variance Inflation Factor.
Sex was coded as male=1 and female=0. Disease categories were coded as presence=1 and absence=0, with orthopedic conditions as references.
Model statistics: R^2=0.519, adjusted R^2=0.504, F=33.334 (P <0.001), and Durbin-Watson=1.244.

Table 5. Logistic regression analysis for predicting walking independence at discharge

Variable	OR	95% CI	P value
Clinical measures			
MMSE	1.197	1.096–1.307	<0.001
Motor FIM	1.067	1.011–1.126	0.017
Disease categories			
Cerebrovascular disease	0.394	0.136–1.142	0.086
Disuse syndrome	0.644	0.259–1.598	0.343
Other variables			
Length of stay	1.008	0.992–1.023	0.321
Sex	1.380	0.637–2.988	0.414
Age	0.985	0.945–1.028	0.495
LL-PA	3.302	1.714–6.360	<0.001

The model was adjusted for age, sex, MMSE score, cerebrovascular disease, disuse syndrome, length of hospital stay, motor FIM score, and LL-PA. Sex was coded as male=1 and female=0. Disease categories were coded as presence=1 and absence=0, with orthopedic conditions as references. Walking independence was defined as FIM walking score ≥6.

The relationship between LL-PA and functional independence at discharge revealed several significant findings. Multiple regression analysis showed that LL-PA was a significant independent predictor of discharge motor FIM scores (β=0.323, P <0.001), along with MMSE and disease categories. The timing of LL-PA measurement within 4 weeks of admission was chosen to ensure stable medical conditions while providing early prognostic information. Correlation analysis demonstrated moderate-to-strong positive correlations between the LL-PA and FIM subscores, particularly in transfer, walking, and stair climbing. These findings support those of previous studies by Norman et al.[3] and Yamada et al.[4] regarding the relationship between PA and muscle function.

Regarding walking ability, significant correlations were observed with the 10-m walking speed and TUG test results. The correlation with the 10-m walking speed was notable, showing moderate-to-strong positive correlations in both sexes (male, r=0.573; female, r=0.712; P <0.001), consistent with the findings of Beaudart et al.[5]

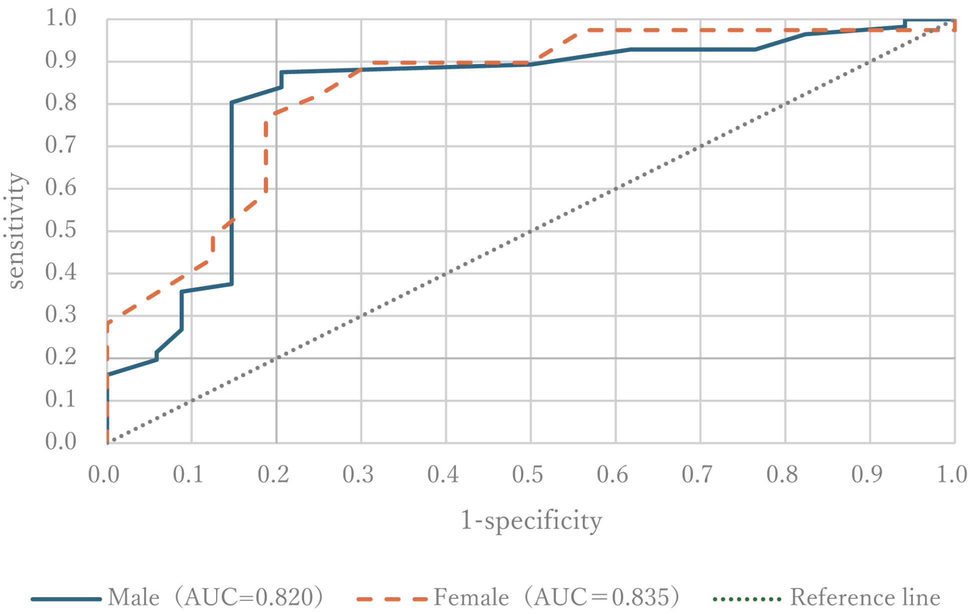

Fig. 2. ROC curves showing the predictive ability of LL-PA for walking independence at discharge stratified by sex. Walking independence was defined as a FIM walking score of 6 or higher. The blue solid line represents male (AUC=0.820, 95% CI: 0.731–0.909; optimal cut-off value=3.050°; sensitivity, 0.804; specificity, 0.853), and the red dashed line represents female (AUC=0.835, 95% CI: 0.749–0.920; optimal cut-off value=2.650°; sensitivity, 0.769; specificity, 0.812). Dotted line shows the reference line. Both curves demonstrated good discriminative ability for predicting walking independence regardless of sex.

Interestingly, the relationship between LL-PA and skeletal muscle mass index was sex-dependent. A moderate positive correlation was observed in male participants (r=0.551, P <0.001), whereas no significant correlation was observed in female participants. This sex-specific difference in the relationship between LL-PA and muscle mass suggests that LL-PA may provide information about muscle quality that is distinct from quantitative measures of muscle mass. According to Lukaski et al.,[16] LL-PA reflects not only muscle mass but also cellular integrity and muscle quality. This finding emphasizes that LL-PA could serve as a unique indicator of muscle function, particularly in rehabilitation settings where both quantitative and qualitative aspects of muscle tissue may be relevant to functional recovery. The non-invasive nature of BIA measurements further supports its practical utility in clinical settings.

The relationship between LL-PA and nutritional status, as assessed by CONUT score, revealed important sex-specific patterns. Male participants showed a moderate negative correlation with CONUT scores (r=−0.411, P <0.001), whereas female participants showed a weak negative correlation (r=−0.284, P <0.03). The varying distributions of CONUT scores across disease categories and sex, with most patients showing normal to mild nutritional impairment, suggests that LL-PA might provide complementary information to traditional nutritional assessment tools. According to Cruz-Jentoft et al.,[17] these sex differences may reflect variations in body composition and the relationship between muscle function and nutritional status. This comprehensive evaluation approach could enhance the accuracy of functional outcome predictions in rehabilitation settings.

The clinical significance of our findings is particularly evident in predicting walking independence. Logistic regression analysis revealed that LL-PA was an independent predictor of walking independence at discharge (OR=3.302, 95% CI: 1.714–6.360; P <0.001), along with MMSE and motor FIM scores. This indicates that for each degree rise in admission LL-PA, the likelihood of achieving walking independence at discharge increases by approximately 3.3-fold. Furthermore, the sex-specific cut-off values derived from ROC curve analysis (male, 3.3050°; female, 2.650°) demonstrated high sensitivity (male, 0.804; female, 0.769) and high specificity (male, 0.853; female, 0.812), indicating practical clinical applicability for early prognostic assessment.

Several limitations should be considered when interpreting the results of our study. First, our study was limited to patients who could maintain a standing position for BIA measurements, which might have excluded more severely impaired patients. This requirement for standing measurement could have led to selection bias, potentially limiting the generalizability of our findings to patients with severe mobility impairments. Second, although early functional assessment is crucial for rehabilitation planning, the timing of LL-PA measurements within 4 weeks of admission was chosen to ensure medical stability and reliable measurements, considering that patients' physical conditions typically stabilize during this period. Third, we did not examine the longitudinal changes in LL-PA during rehabilitation or their relationship with functional recovery. Therefore, the effect of rehabilitation interventions on LL-PA and subsequent functional outcomes remains uncertain. Fourth, nutritional status was assessed using the CONUT score; however, other nutritional indicators, as well as the effects of medications and comorbidities, could not be fully evaluated. Finally, we focused on discharge outcomes without long-term follow-up data, which limited our understanding of the long-term prognostic value of LL-PA.

CONCLUSION

We demonstrated that LL-PA level measured at admission is a useful prognostic indicator of functional outcomes in patients admitted to convalescent rehabilitation hospitals. The non-invasive and straightforward nature of LL-PA measurement and its predictive ability, particularly when considering sex-specific differences, highlight its potential application in clinical practice. Although our findings are promising, they should be interpreted within the context of our study limitations, particularly regarding the requirement for standing measurements. LL-PA, when combined with conventional assessment tools such as MMSE and motor FIM, may enhance accurate prognosis prediction and individualized rehabilitation planning. Future studies should investigate the longitudinal changes in LL-PA during rehabilitation interventions and their relationship with long-term outcomes in diverse rehabilitation settings.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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