

A Deficit Accumulation-Based Lower Extremity Function Index and Subsequent Falls in Chinese Community-Dwelling Older Adults: A Prospective CHARLS Cohort Study

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Abstract

Background. Falls are a leading cause of injury and lost independence in older people. Weak lower-limb function is a consistent risk factor but is usually assessed one item at a time. We applied the deficit-accumulation framework to the lower-extremity domain and examined whether the resulting index was associated with subsequent falls.

Methods. In the China Health and Retirement Longitudinal Study (CHARLS), community-dwelling adults aged 50 years or older at the 2015 wave were followed to 2018. A Lower Extremity Function Index (LEFI) was constructed as the proportion of deficits across 15 lower-extremity-related items spanning mobility, transfers and lower-limb-dependent activities of daily living (range 0–1). The outcome was self-reported falls at follow-up. Multivariable logistic regression, restricted cubic splines, receiver operating characteristic analysis and seven sensitivity analyses were used.

Results. Among 11,430 participants (mean age 64.0 years; 55% women), 2,568 (22.5%) reported a fall. In the fully adjusted model including baseline fall history, each 0.1-unit higher LEFI was associated with higher fall odds (odds ratio 1.13, 95% confidence interval 1.10–1.16). The association was non-linear and robust across sensitivity analyses, including a core 7-item index (odds ratio per 0.1 unit 1.09). Discrimination was modest (area under the curve 0.61) and improved only slightly over age, sex and fall history (0.65 to 0.67).

Conclusions. A deficit-accumulation LEFI was independently associated with subsequent falls but had limited absolute discrimination; it may serve as a low-cost first-stage screen, identifying lower-risk individuals for triage, rather than as a standalone predictor.

Background

Falls are among the leading causes of injury, disability and death in older people, and the burden is rising rapidly in ageing societies such as China. In the China Health and Retirement Longitudinal Study (CHARLS), fall prevalence among community-dwelling adults aged 50 years and older has been estimated at roughly 18–25% [1, 2]. Falls are associated with fractures, functional decline, loss of independence, increased health-care use and substantial economic burden. What remains difficult is identifying, prospectively, who is most likely to fall.

Weak lower-limb function is one of the few fall risk factors that recurs across studies. Performance measures such as the Short Physical Performance Battery and measured gait speed predict falls well [3, 4] but require standardised settings, trained assessors and time that large surveys and busy clinics rarely have. Self-reported function offers a workable alternative, yet such items are almost always analysed singly; examined one at a time each is a blunt predictor and none captures the graded, accumulating nature of functional decline.

The deficit-accumulation model of Mitnitski and Rockwood folds many items into a single proportion - the frailty index - which behaves well statistically and tracks risk smoothly [5, 6, 7, 8]. A general frailty index predicts falls, with frail individuals at about 1.8–2.4 times the odds [9, 10], and a three-cohort analysis recently confirmed the frailty-index-falls link across CHARLS, ELSA and HRS [11]. What has not been done, to our knowledge, is to apply this lens specifically to the lower limbs using a CHARLS-derived lower-extremity functional deficit index. Three considerations motivate this: prior work relies mainly on a general frailty index or on single indicators; single items are weak predictors; and a general index is not focused on lower-limb function. We therefore constructed a domain-specific Lower Extremity Function Index (LEFI) and, in the CHARLS 2015 and 2018 waves, examined whether it was prospectively associated with falls, characterised the shape of that relationship, and benchmarked its discrimination against the individual items from which it was built.

Methods

Study design and participants

We used data from CHARLS, a nationally representative cohort of Chinese adults aged 45 years and older recruited by multistage probability sampling across 28 provinces [1]. Participants aged 50 years or older at the 2015 wave with a valid LEFI score were followed to the 2018 wave (about 3 years). CHARLS was approved by the Peking University Biomedical Ethics Review Committee (IRB00001052-11015); all participants gave written informed consent. This secondary analysis of de-identified public data required no further approval.

Lower Extremity Function Index

The LEFI was built from 15 lower-extremity-related functional items, each coded as a binary deficit (1 present, 0 absent), spanning mobility (difficulty walking 1 km; slow gait speed < 0.8 m/s from a 2.5-metre timed walk, a distance-independent cut-point following EWGSOP/AWGS [12]), transfers and balance (chair rise, climbing stairs, stooping/kneeling/crouching), basic activities of daily living (dressing, bathing, eating, getting in/out of bed, toileting, continence) and related items (household chores, reaching overhead, lifting > 5 kg, picking up a coin). The LEFI is the mean of non-missing items (≥ 8 valid required), ranging 0–1 [8]. Although several items are not purely biomechanical, lower-extremity impairment in surveys is frequently expressed through mobility-dependent activities of daily living; the LEFI is therefore an index of lower-extremity-related functional burden rather than a performance battery, and its robustness was tested in a core-index analysis. Participants were classed as robust (< 0.10), prefrail (0.10 to < 0.21) or frail (≥ 0.21), approximating frailty-index categories.

Outcome and covariates

The outcome was self-reported falls since the previous interview, ascertained at 2018 (CHARLS item da023_w4). Covariates at 2015 were age, sex, body mass index (BMI), physician-diagnosed hypertension, diabetes and arthritis, and baseline fall history, defined from the corresponding 2015 fall question (da023) asking whether the participant had fallen since the previous interview. Missing chronic-disease indicators were coded as absent, a common convention for the harmonised CHARLS indicators.

Statistical analysis

Group differences used rank-sum and chi-squared tests. The LEFI-fall association was estimated by nested logistic regression: M1 unadjusted; M2 + age, sex; M3 + BMI and comorbidities; M4 + baseline fall history. Odds ratios are reported per 1-unit and per 0.1-unit increase. Non-linearity was examined with restricted cubic splines (knots at the 5th, 35th, 65th, 95th centiles) [14]. Discrimination was compared between the LEFI alone and each item alone using the area under the curve (AUC) and DeLong tests; we also compared a base model (age, sex, baseline fall history) with the same model plus the LEFI. Sensitivity, specificity and predictive values were computed at relevant thresholds. Subgroup and interaction analyses (by sex and age) were exploratory and not corrected for multiplicity. Seven sensitivity analyses were performed: multiple imputation ($m = 5$; checked at $m = 20$); exclusion of LEFI = 1.0; complete cases; a fall-naïve incident-fall analysis; survey-weighted analysis (individual weights, community clusters; an approximate design-based estimate as complete strata were unavailable); a 14-item index excluding gait speed; and a core 7-item index. Analyses used R 4.x; two-sided $P < 0.05$.

Results

Participants and main association

Among 11,430 participants (mean age 64.0 years; 55% women), 2,568 (22.5%) reported a fall during follow-up. In M4, each 0.1-unit higher LEFI was independently associated with falls (odds ratio [OR] 1.128, 95% confidence interval [CI] 1.100-1.157; per 1-unit OR 3.33, 95% CI 2.60–4.28; Table 2). The analytic sample fell to 9,805 owing to missing covariates (1,620 missing BMI; 6 missing baseline fall history; 1 overlap; 1,625 excluded). Baseline fall history was the strongest covariate (OR 2.87, 95% CI 2.57–3.21), followed by the LEFI; women and people with arthritis had higher odds (Table S5).

Table 1
Baseline characteristics by fall status at follow-up.

Characteristic	Overall (N = 11,430)	No fall (N = 8,862)	Fall (N = 2,568)	P
Age, years, mean (SD)	63.95 (8.64)	63.60 (8.48)	65.13 (9.07)	< 0.001
Female, n (%)	6,301 (55)	4,693 (53)	1,608 (63)	< 0.001
LEFI, mean (SD)	0.18 (0.20)	0.16 (0.19)	0.24 (0.23)	< 0.001
Robust, n (%)	5,475 (48)	4,572 (52)	903 (35)	< 0.001
Prefrail, n (%)	2,174 (19)	1,682 (19)	492 (19)	
Frail, n (%)	3,781 (33)	2,608 (29)	1,173 (46)	
Baseline fall history, n (%)	2,257 (20)	1,318 (15)	939 (37)	< 0.001
Hypertension, n (%)	2,962 (26)	2,239 (25)	723 (28)	0.003
Diabetes, n (%)	1,239 (11)	938 (11)	301 (12)	0.10
Arthritis, n (%)	4,628 (40)	3,408 (38)	1,220 (48)	< 0.001
BMI, kg/m ² , mean (SD)	23.76 (3.85)	23.78 (3.77)	23.70 (4.12)	0.15
<i>SD, standard deviation. Continuous variables compared with rank-sum tests, categorical with chi-squared tests. Missing: BMI n = 1,620; baseline fall history n = 6.</i>				

Table 2
Multivariable logistic regression: continuous LEFI and falls.

Model	N	OR per 0.1 (95% CI)	OR per 1 unit (95% CI)	P
M1: unadjusted	11,430	1.195 (1.171–1.219)	5.93 (4.84–7.27)	< 0.001
M2: + age, sex	11,430	1.170 (1.146–1.195)	4.83 (3.91–5.95)	< 0.001
M3: + BMI, comorbidities	9,810	1.169 (1.141–1.197)	4.77 (3.74–6.06)	< 0.001
M4: + baseline fall	9,805	1.128 (1.100–1.157)	3.33 (2.60–4.28)	< 0.001
<i>OR, odds ratio; CI, confidence interval. The per-0.1-unit OR represents about 1.5 additional deficits.</i>				

Categorical and dose-response

Compared with robust participants, frail participants had higher odds of falling (OR 1.68, 95% CI 1.50–1.89) and prefrail participants intermediate odds (OR 1.23, 95% CI 1.07–1.40; Table 3). The spline showed a significant non-linear relationship (non-linearity chi-squared 22.34, $P < 0.001$; Fig. 1), rising more steeply at lower LEFI values; the apparent plateau at higher values should be read cautiously as relatively few participants had high scores (LEFI > 0.5 in 7.8%).

Table 3
Categorical LEFI and falls (reference: robust).

Model	N	Prefrail OR (95% CI)	P	Frail OR (95% CI)	P
Unadjusted	11,430	1.48 (1.31–1.68)	< 0.001	2.28 (2.06–2.52)	< 0.001
+ age, sex	11,430	1.40 (1.23–1.58)	< 0.001	2.07 (1.87–2.29)	< 0.001
Fully adjusted	9,805	1.23 (1.07–1.40)	0.004	1.68 (1.50–1.89)	< 0.001
<i>Robust < 0.10; prefrail 0.10 to < 0.21; frail ≥ 0.21.</i>					

Discrimination and screening

The LEFI alone gave an AUC of 0.610 (95% CI 0.598–0.623), higher than each individual item (0.553–0.563; all DeLong $P < 0.001$; Table S3). Adding the LEFI to age, sex and baseline fall history increased the AUC from 0.648 to 0.668 (change 0.020; DeLong $P < 0.001$). As a binary screen at $\text{LEFI} \geq 0.10$, sensitivity was 65% and specificity 52% (positive predictive value 28%, negative predictive value 84%; Table S4); the high negative predictive value indicates the index is better at ruling out lower-risk individuals than at confirming risk.

Subgroups and sensitivity analyses

The association was consistent across sex (interaction $P = 0.44$). The LEFI x age interaction was nominally significant ($P = 0.025$), with suggestive evidence of a stronger association at 50–64 years; given the borderline P value and the exploratory, multiplicity-uncorrected analyses, this requires confirmation (Table S1). Findings were robust across all seven sensitivity analyses (Table S2 and Table 4): multiple imputation (per 1-unit OR 3.16; identical at $m = 20$), fall-naïve incident falls (OR 3.70), and survey-weighted analysis (OR 3.61). A core 7-item index restricted to the more lower-limb-specific items remained associated with falls with modest attenuation (per 0.1-unit OR 1.089; AUC 0.605; $r = 0.92$ with the full LEFI; Table 4), indicating the association is not an artefact of less lower-limb-specific items.

Table 4
Alternative LEFI specifications.

Index	Items	N	r with full LEFI	OR per 0.1 (95% CI)	OR per 1 (95% CI)	AUC
Primary LEFI	15	9,805	Reference	1.128 (1.100–1.157)	3.33 (2.60–4.28)	0.610
Excluding gait speed	14	8,169	0.997	1.109 (1.080–1.138)	2.81 (2.16–3.64)	-
Core mobility-transfer	7	9,804	0.92	1.089 (1.069–1.110)	2.35 (1.95–2.84)	0.605
<i>Fully adjusted (M4). The core index retains seven items most specific to lower-limb function. All associations $P < 0.001$.</i>						

Discussion

In this cohort of 11,430 community-dwelling Chinese adults, a deficit-accumulation Lower Extremity Function Index was prospectively associated with falls reported about three years later, independent of age, sex, BMI, chronic disease and prior fall history, a key predictor of subsequent falls. The composite discriminated slightly better than its individual items, though absolute discrimination remained modest.

These findings are consistent with, and extend, earlier work on frailty indices and falls [9, 10]. A general CHARLS frailty index reached an AUC of about 0.61 [2]; our domain-specific LEFI matched this (0.610), suggesting that both general and domain-specific indices provide only modest discrimination for falls when used alone. Our per-0.1 OR (1.13) is a little lower than some general estimates, likely because we adjusted for baseline fall history, which most prior CHARLS analyses did not. The main contribution is the application of the deficit-accumulation framework to a lower-extremity-related functional domain rather than to general health, retaining graded sensitivity that is lost when items are read singly.

The non-linear curve rose more steeply at lower LEFI values, suggesting that early accumulation of lower-extremity-related deficits may carry meaningful risk information; the high-LEFI attenuation should be interpreted cautiously given sparse data there. The strong independent effect of baseline fall history underlines a central question in fall epidemiology - whether function predicts falls beyond previous falls - which we addressed by adjusting for, and separately excluding, baseline fallers; the LEFI remained associated with falls in both.

Clinically, the LEFI can be derived from routine survey items without equipment or trained assessors. However, the modest AUC (0.610) and low positive predictive value mean it is insufficient for individual-level prediction. Its value may lie in ruling out lower-risk individuals (negative predictive value ~ 84%) and flagging others for fuller multifactorial assessment, with targeted interventions such as balance and strength exercise [17] considered according to clinical findings.

Strengths include the prospective design, a nationally representative sample, construction by established deficit-accumulation principles, and seven convergent sensitivity analyses including a core-index check. Limitations include self-reported falls over a 3-year window; the direction of any resulting bias is uncertain, as differential reporting by functional status cannot be excluded. Equal item weighting may dilute the fall-specific signal, although weighting rarely outperforms equal weighting for prediction [6, 8]. Missing chronic-disease status coded as absent could bias estimates, most plausibly towards the null. Residual confounding cannot be excluded.

Conclusions

A survey-derived lower-extremity deficit-accumulation index was independently associated with subsequent falls in Chinese older adults, but its absolute discrimination was modest. The LEFI is best positioned as a low-cost, first-stage screening marker for fall-risk stratification rather than a standalone prediction tool. Further work should validate it in other populations, test it in people without baseline fall history, refine cut-points, and assess whether LEFI-guided assessment or intervention reduces falls.

Abbreviations

ADL, activities of daily living; AUC, area under the curve; AWGS, Asian Working Group for Sarcopenia; BMI, body mass index; CHARLS, China Health and Retirement Longitudinal Study; CI, confidence interval; EWGSOP, European Working Group on Sarcopenia in Older People; LEFI, Lower Extremity Function Index; OR, odds ratio.

Declarations

Ethics approval and consent to participate

The China Health and Retirement Longitudinal Study (CHARLS) was approved by the Biomedical Ethics Review Committee of Peking University (IRB00001052-11015), and all participants provided written informed consent. The present work is a secondary analysis of de-identified, publicly available CHARLS data and required no further ethical approval. All methods were carried out in accordance with relevant guidelines and regulations, including the Declaration of Helsinki.

Clinical trial number

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets analysed during the current study are publicly available from the China Health and Retirement Longitudinal Study (CHARLS) at <http://charls.pku.edu.cn>. The analysis code is available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

GX and HL contributed equally to this work and are co-first authors. GX and HL conceptualised and designed the study, performed the statistical analysis and interpretation, and drafted the manuscript. JJ and PL contributed to data curation, interpretation and validation. HX (corresponding author) supervised the study, contributed to its conception, and critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Figures

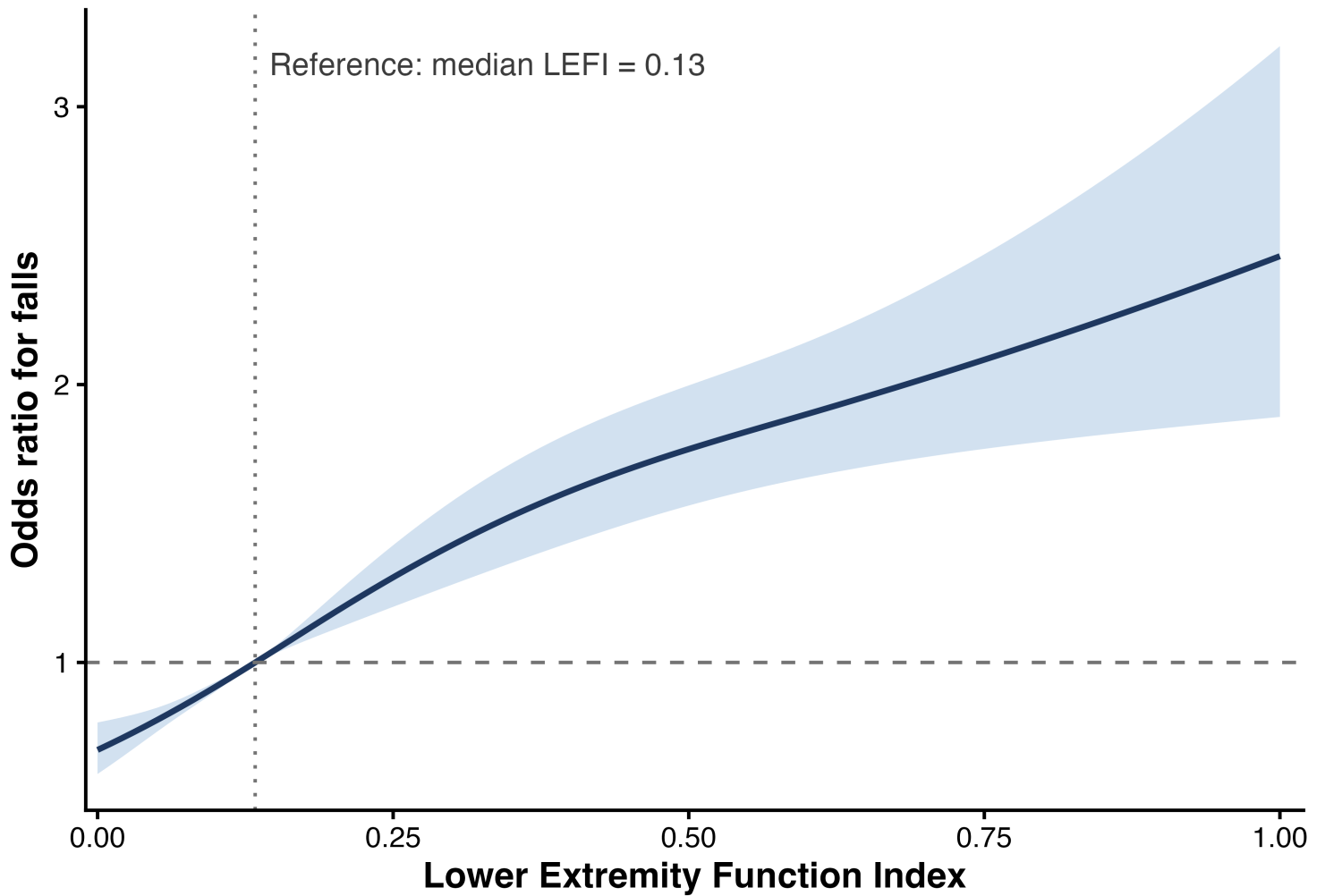


Figure 1

Restricted cubic spline of the dose-response relationship between the LEFI and the odds ratio for falls, adjusted for age and sex (n=11,430). Reference: median LEFI 0.13. Overall association chi-squared 232.79 (P<0.001); non-linearity chi-squared 22.34 (P<0.001). The plateau at higher LEFI reflects sparse data (LEFI >0.5 in 7.8%).

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