

Development and Validation of a Frailty Index for Ischemic Stroke Patients

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ABSTRACT

This study aimed to develop and validate a frailty index (FI) tailored to ischemic stroke patients based on the cumulative deficit model. Using data from 537 patients, 34 health-related variables were initially selected through literature review. A series of statistical methods, including correlation analysis, critical ratio method, homogeneity testing, and factor analysis, were applied to screen variables. 31 variables covering physical, psychological, and cognitive domains were retained. The final FI showed good internal consistency (Cronbach's $\alpha = 0.879$), construct validity, and moderate criterion validity with the Fried's frailty phenotype (FP) ($r = 0.504$, $P < 0.001$). These findings support the FI as a reliable and valid tool for assessing frailty in ischemic stroke patients, offering a multidimensional and sensitive measure suitable for clinical practice and long-term monitoring.

KEYWORDS

Frailty; Frailty Index; Ischemic stroke; Reliability and validity test

1. INTRODUCTION

Frailty is a geriatric syndrome characterized by reduced physiological reserves across multiple systems and heightened vulnerability to stressors [1]. Frailty can lead to an elevated risk of functional decline and adverse health outcomes in response to internal or external stressors. A growing body of evidence indicates that frailty is strongly associated with adverse outcomes, including falls, fractures, hospitalizations, disability, mortality, and poor quality of life [2-4].

Stroke is the second leading cause of death and the third leading cause of disability worldwide [5]. The majority of stroke patients face the challenge of frailty, with approximately two-thirds of acute cases exhibiting frailty or pre-frailty [6]. However, standardized instruments for evaluating frailty remain scarce for stroke patients in routine clinical practice [7].

The Fried's frailty phenotype (FP) and the frailty index (FI) are the most frequently used frailty assessment tools [8]. The FP is based on functional status and relies on objective physical performance measures, but its applicability in hospitalized stroke patients remains limited [9]. The FI, proposed by Rockwood and colleagues [10], quantifies the accumulation of health deficits and serves as a comprehensive and flexible tool applicable to a wide range of diverse types of clinical and functional data [2]. However, its reliability and validity in specific populations, such as in stroke patients, require further validation.

This study aimed to construct an FI for ischemic stroke patients based on the cumulative deficit model and to evaluate its reliability and validity in a clinical setting. The findings would provide a practical

tool for frailty screening and comprehensive management in ischemic stroke populations, contributing to early identification and timely intervention for frailty in this vulnerable group.

2. MATERIALS AND METHODS

2.1. Study Population

In this study, ischemic stroke patients admitted to the Neurology and Rehabilitation Departments of a tertiary hospital in southwestern China between July 2022 and January 2025 were recruited. Inclusion criteria were as follows: (1) age ≥ 18 years; and (2) diagnosis of ischemic stroke confirmed by MRI or CT. Exclusion criteria included: (1) severe impairments in speech, vision, hearing, or neuropsychiatric function that precluded assessment; and (2) progressive disease deterioration or the presence of other acute or critical illnesses. The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the hospital's Ethics Review Board (LL-202225). All participants provided written informed consent.

Based on the principle that each variable requires a sample size of 5 to 20 participants [11], 34 health deficit indicators were initially identified. Considering a 20% anticipated attrition rate, the minimum sample size was determined to be 408 participants.

2.2. Selection of Health Deficits

Table 1. FI variables coding table

Variables	Coding
S1. Hypertension	No = 0, Yes = 1
S2. Diabetes	No = 0, Yes = 1
S3. Dyslipidemia	No = 0, Yes = 1
S4. Heart disease	No = 0, Yes = 1
S5. Need personal help for feeding	Unable=1, Partially dependent = 0.5, Fully independent = 0
S6. Need personal help for bathing	Partially or fully dependent = 1, Fully independent = 0
S7. Need personal help for grooming	Partially or fully dependent = 0, Fully independent = 1
S8. Need personal help for dressing	Unable=0, Partially dependent = 0.5, Fully independent = 1
S9. Need personal help for using toilet	Fully dependent = 0, Partially dependent = 0.5, Independent = 1
S10. Need personal help for bed-chair transfer	Fully dependent = 0, Needs major help = 0.33, Needs minor help = 0.67, Fully independent = 1
S11. Need personal help for walk 45 meters on level ground	Unable = 0, Independent with wheelchair $\geq 45m$ = 0.33, With some help $\geq 45m$ = 0.67, Fully independent $\geq 45m$ = 1
S12. Need personal help for stairs	Unable = 0, Needs help = 0.5, Independent = 1
S13. Orientation	One error = 0.1 point
S14. Memory	1 error = 0.33, 2 errors = 0.67, 3 errors = 1
S15. Recall	1 error = 0.33, 2 errors = 0.67, 3 errors = 1
S16. Calculation	One error = 0.2 point
S17. Language	One error = 0.125 point
S18. Visuospatial ability	Correct = 0, Incorrect = 1

Health deficits were screened according to the criteria proposed by Rockwood et al. [12, 13], including: (1) related to health status; (2) typically age-related; (3) variables were excluded if the prevalence of a deficit was greater than 80% or less than 1% among valid, non-missing responses;

and (4) a minimum of 30 deficits is recommended for a reliable FI. Taking into account the existing FI indexes for stroke patients and the available health deficits, 34 health deficit variables were initially included, encompassing five dimensions of chronic diseases, functional limitation, anxiety, depression, and cognitive function. Functional limitations were assessed using the Barthel Index. Anxiety was measured with the Generalized Anxiety Disorder-7 (GAD-7) scale, while depression was evaluated using the Patient Health Questionnaire-9 (PHQ-9). Cognitive function was assessed with the Mini-Mental State Examination (MMSE). All variables were coded on a scale from 0 to 1 to reflect the severity of health deficits. Dichotomous variables were coded as 0 (absence of deficit) or 1 (presence of deficit), while polytomous variables were assigned intermediate values to indicate varying degrees of deficit severity. The coding for each variable is presented in Table 1. The FI was calculated as the ratio of the number of deficits present to the total number of variables included.

Table 2. (continued). FI variables coding table

Variables	Coding
S19. Felling nervous or anxious	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S20. Unable to stop or control worrying	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S21. Worried too much about different things	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S22. Difficult to relax	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S23. Restlessness	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S24. Easily annoyed or irritable	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S25. Fear of something awful happening	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S26. Little interest or pleasure in doing things	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S27. Feeling down, depressed, or hopeless	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S28. Trouble sleeping or sleeping too much	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S29. Feeling tired	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S30. Poor appetite or overeating	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S31. Feeling bad about yourself	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S32. Trouble concentrating	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S33. Moving or speaking slowly	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1
S34. Thoughts of self-harm	Not at all = 0, Several days = 0.33, More than a week = 0.67, Nearly every day = 1

The initial pool of variables was refined through a series of screening procedures. A variable was considered for deletion if it performed poorly on three or more of the following criteria: (1) correlation analysis: the correlation between each deficit variable and the total FI score was calculated. Variables with correlation coefficients ($|r| < 0.30$ or $P > 0.05$) were to be deleted [14]; (2) critical ratio method:

participants were ranked by their total FI scores, and the top 27% and bottom 27% were defined as the high and low groups, respectively. If no significant difference ($P > 0.05$) was observed between the groups or the critical ratio < 3.00 , the variable was considered for deletion [15]; (3) homogeneity testing: Cronbach's α coefficient and the corrected item-total correlation were assessed. A variable was considered for deletion if its removal resulted in a significant increase in Cronbach's α or if the corrected item-total correlation < 0.30 [11]; (4) exploratory factor analysis: the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity were conducted to assess the sampling adequacy and the suitability of the data for factor analysis. Principal component analysis with varimax rotation was employed to explore the underlying factor structure of the included health deficit variables. Variables were excluded if they exhibited cross-loadings, factor loadings < 0.40 , or communalities < 0.20 [11, 16].

2.3. Reliability and Validity

Construct validity was assessed through exploratory factor analysis [16]. Criterion validity was evaluated by examining the correlation between the constructed FI and the Fried's FP, which served as a reference standard. A correlation coefficient (r) > 0.50 is indicative of good criterion-related validity [17]. The internal consistency reliability of the FI was assessed using Cronbach's α coefficient, and a coefficient ≥ 0.7 was considered acceptable [18].

2.4. Data Analysis

Statistical analyses were performed using Stata 16.0 (StataCorp, College Station, USA). For continuous variables with a normal distribution, means and standard deviations were reported; for non-normally distributed data, medians and interquartile ranges were used. Categorical variables were presented as frequencies and percentages. A P value < 0.05 was considered statistically significant.

3. RESULTS

The characteristics of the sample are provided in Table 3. A total of 537 ischemic stroke patients were included in the study, with 324 males (60.3%) and 213 females (39.7%). Approximately 58% of participants were aged < 70 years. The majority were married or cohabiting (85.3%), and 56.2% had attained an education level of lower secondary school or above.

Table 3. Characteristics of study participants

	Total (N=537)	Sex	
		Men (N=324)	Women (N=213)
Age (N, %)			
<70	310 (57.73)	201 (62.04)	109 (51.17)
≥70	227 (42.27)	123 (37.96)	104 (48.83)
Missing	0 (0.00)	0 (0.00)	0 (0.00)
Education (N, %)			
≤Primary school	232 (43.20)	129 (39.81)	103 (48.36)
Lower secondary school	161 (29.98)	93 (28.70)	68 (31.92)
≥Upper secondary school	141 (26.26)	101 (31.17)	40 (18.78)
Missing	3 (0.56)	1 (0.31)	2 (0.94)
Marital status (N, %)			
Married/cohabiting	458 (85.29)	290 (89.51)	168 (78.87)
Unmarried/divorced/widowed	72 (13.41)	31 (9.57)	41 (19.25)
Missing	7 (1.30)	3 (0.93)	4 (1.88)
Smoking (N, %)			
Never smokers	293 (54.56)	89 (27.47)	204 (95.77)
Former smokers	94 (17.50)	94 (29.01)	0 (0)
Current smokers	127 (23.65)	124 (38.27)	3 (1.41)
Missing	23 (4.28)	17 (5.25)	6 (2.82)
Alcohol drinking (N, %)			
Never drinker	310 (57.73)	113 (34.88)	197 (92.49)
Former drinker	92 (17.13)	89 (27.47)	3 (1.41)
Current drinker	111 (20.67)	105 (32.41)	6 (2.82)
Missing	24 (4.47)	17 (5.25)	7 (3.29)

Multiple approaches, including correlation analysis, critical ratio method, homogeneity testing, and factor analysis, were used to screen the 34 health deficit variables. The results indicated that variables 3, 4, and 28 failed to meet more than three of the screening criteria and were considered for deletion. Variable 27 was also recommended for deletion as it did not align with the predefined dimensions. However, considering that heart disease is widely recognized as a major component of frailty and has been retained in several previously published FI studies, the research team decided to retain it after discussion. Therefore, variables 3, 27, and 28 were deleted, and 31 variables were retained for the final FI calculation (Table 4).

Table 4. Summary results of FI scale items screening

Variables	Correlation with Total Score (r)	Critical ratio	Corrected Item-Total Correlation (r)	Cronbach's α if Item Deleted	Factor Loading	Communality
S1.	0.312	7.674	0.164	0.876	0.630	0.440
S2.	0.307	7.286	0.184	0.876	0.597	0.418
S3.	0.077	1.274	0.027	0.879	0.520	0.385
S4.	0.188	4.113	0.102	0.876	0.499	0.363
S5.	0.368	6.529	0.439	0.869	0.634	0.440
S6.	0.636	21.177	0.634	0.862	0.806	0.697
S7.	0.523	11.834	0.555	0.864	0.871	0.765
S8.	0.576	12.776	0.643	0.864	0.866	0.776
S9.	0.571	13.288	0.612	0.864	0.883	0.801
S10.	0.577	13.100	0.607	0.864	0.890	0.805
S11.	0.592	14.270	0.621	0.863	0.917	0.850
S12.	0.625	18.973	0.620	0.862	0.843	0.741
S13.	0.455	10.160	0.430	0.868	0.752	0.627
S14.	0.279	6.076	0.236	0.871	0.585	0.430
S15.	0.351	8.359	0.282	0.871	0.648	0.454
S16.	0.402	9.957	0.343	0.870	0.722	0.552
S17.	0.488	12.533	0.351	0.871	0.576	0.424
S18.	0.496	11.163	0.443	0.868	0.799	0.691
S19.	0.462	10.311	0.456	0.867	0.774	0.639
S20.	0.471	10.969	0.478	0.867	0.827	0.707
S21.	0.434	10.215	0.458	0.867	0.809	0.670
S22.	0.477	10.175	0.512	0.867	0.789	0.675
S23.	0.405	8.345	0.426	0.868	0.699	0.511
S24.	0.373	8.332	0.391	0.869	0.705	0.540
S25.	0.355	6.752	0.389	0.869	0.538	0.368
S26.	0.405	8.639	0.448	0.868	0.493	0.486
S27.	0.518	12.329	0.533	0.866	0.683	0.635
S28.	0.285	6.803	0.184	0.874	0.602	0.423
S29.	0.379	8.396	0.367	0.869	0.420	0.404
S30.	0.343	7.423	0.355	0.869	0.666	0.534
S31.	0.444	9.658	0.437	0.868	0.579	0.555
S32.	0.330	7.108	0.334	0.870	0.613	0.478
S33.	0.466	11.528	0.429	0.868	0.427	0.348
S34.	0.325	5.483	0.366	0.870	0.630	0.508

Structural validity analyses were performed on the 31 variables that were screened. The results indicated that the KMO value was 0.906, and the Bartlett's test of sphericity ($\chi^2 = 8016.650$, $P < 0.001$) demonstrated that the data were suitable for factor analysis. Principal component analysis was employed to extract the common factors, and the results showed a total of six factors with eigenvalues >1 , which cumulatively explained 58.740% of the total variance. The scree plot exhibited a clear inflection point at factor 4, indicating a notable change in the slope of eigenvalues. Considering the number of extracted factors, theoretical interpretability, and the principle of structural parsimony, a five-factor solution was ultimately adopted, accounting for 55.35% of the total variance. After varimax rotation, factor loadings ranged from 0.413 to 0.916, with all items loading >0.40 on their respective components (Table 5). Based on the clustering pattern and alignment with the original

conceptual framework, the five factors were interpreted as functional limitation, anxiety, cognitive function, depression, and chronic illness. This factor structure was consistent with the hypothesized dimensions, supporting the construct validity of the FI. The Pearson correlation coefficient between the FI total score and the FP score was $r=0.504$ ($P<0.001$), suggesting that the constructed FI demonstrated good external criterion validity. The Cronbach's α coefficient for the total scale was 0.875, indicating that the scale had good internal consistency reliability.

Table 5. The results of the loading matrix of the second factor analysis

Variables	Factor Loadings After Varimax Rotation				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
S1.					0.654
S2.					0.585
S4.					0.600
S5.	0.636				
S6.	0.804				
S7.	0.874				
S8.	0.867				
S9.	0.885				
S10.	0.889				
S11.	0.916				
S12.	0.840				
S13.			0.752		
S14.			0.579		
S15.			0.653		
S16.			0.726		
S17.			0.580		
S18.			0.803		
S19.		0.773			
S20.		0.818			
S21.		0.807			
S22.		0.789			
S23.		0.709			
S24.		0.688			
S25.		0.561			
S26.				0.554	
S29.				0.520	
S30.				0.593	
S31.				0.596	
S32.				0.415	
S33.				0.469	
S34.				0.413	

4. DISCUSSION

In this study, we followed the standard procedure proposed by Rockwood et al. [12] to systematically construct an FI applicable to patients with ischemic stroke, based on the cumulative deficit model. Health deficit variables were identified through comprehensive literature review and statistical screening, encompassing multiple domains including chronic conditions, functional impairments, psychological states (e.g., anxiety and depression), and cognitive function. It reflects the health status

of stroke patients in a multidimensional way, providing a more comprehensive perspective on the assessment of frailty.

During the variable selection process, a combination of analytical approaches—including correlation analysis, critical ratio assessment, internal consistency testing, and factor analysis—was utilized to ensure the robustness and validity of the frailty index. Variables that exhibited weak associations with the overall FI, limited discriminatory capacity, or poor internal consistency were excluded. This multi-step screening process enhanced the coherence and measurement performance of the FI [14]. Additionally, factor analysis supported the structural validity of the retained items, while items with ambiguous factor loadings were excluded to preserve the conceptual clarity of the scale.

Based on the above analyses, the final FI comprised 31 health deficit variables encompassing physiological, psychological, and cognitive domains. The retained indicators demonstrated good representativeness and measurement properties, providing a robust foundation for subsequent scale validation and clinical application.

In terms of reliability and validity tests, the constructed FI demonstrated satisfactory reliability and validity. For structural validity, factor analysis confirmed that the FI effectively captured the multidimensional nature of frailty, consistent with the theoretical framework. Regarding external validity, the FI showed a moderate and statistically significant correlation with the FP ($r = 0.504$, $P < 0.001$), supporting its criterion-related validity in ischemic stroke patients. In examining the internal consistency of the FI, the Cronbach's alpha coefficient was 0.879, indicating strong internal coherence and a reliable reflection of the construct of frailty.

The FI developed in this study demonstrated good applicability and feasibility among patients with ischemic stroke. It effectively identified health deficits and quantified the degree of frailty, serving as a robust tool for precise clinical assessment and personalized intervention. Compared with traditional frailty assessment tools, the FI provides a more comprehensive and flexible approach, making it well-suited for dynamic monitoring and long-term follow-up across varying levels of frailty.

Nonetheless, several limitations should be acknowledged. First, the study was conducted at a single center with a relatively limited sample size, which may restrict the generalizability of the FI to broader patient populations. Future studies should expand the sample and perform multicenter validation to enhance the external validity and representativeness of the findings. Second, although the FI was constructed through a systematic process, the included variables were constrained by available clinical data. Some potentially important indicators may have been omitted. Future research should integrate clinical practice and emerging evidence to further enrich the variable dimensions and enhance the comprehensiveness and sensitivity of the index.

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