The Journal of Frailty & Aging 15 (2026) 100142

Contents lists available at ScienceDirect

The Journal of Frailty & Aging

journal homepage: www.elsevier.com/locate/tjfa

Original Research

Impact of physical activity and frailty on mortality and utilization among middle-aged and older adults in South Korea

Ho-Jun Kim [a], Kyu-Ri Hong [b], Xiao-Lin Wen [a], Da-San Kim [c], Jung-Min Lee [d,e,*]

[a] Department of Physical Education, Graduate School of Physical Education, Kyung Hee University, Yongin-si, 17104, Republic of Korea
[b] Department of Kinesiology, Iowa State University, Ames, IA, USA
[c] Department of Physical Education, Graduate School of Education, Kyung Hee University, Yongin-si, Republic of Korea
[d] Sports Science Research Center, Global Campus, Kyung Hee University, Yongin-si, 17104, Republic of Korea
[e] Department of Physical Education, Kyung Hee University, Yongin-si, 17104, Republic of Korea

ARTICLE INFO

Key words:
Frailty
Physical activity
Utilization
Longitudinal study
Mortality

ABSTRACT

This study examined the influence of frailty status and physical activity (PA) compliance on all-cause mortality and healthcare utilization among Korean adults aged 45 years and older. Data from 2104 participants in the Korean Longitudinal Study of Aging (KLoSA; 2006 - 2022) were analyzed. Frailty was assessed using a 38-item frailty index (FI), and PA was defined according to adherence to the World Health Organization guideline of at least 150 min per week. Participants were classified as robust, pre-frail, or frail. Cox proportional hazards models and generalized linear mixed models were used to evaluate associations with mortality and healthcare utilization. Compared with robust individuals, frail participants exhibited a markedly higher risk of all-cause mortality (hazard ratio [HR] = 3.37, 95% confidence interval [CI]: 2.42–4.69), while pre-frail individuals also showed an elevated mortality risk (HR = 1.72, 95% CI: 1.43–2.07). Frailty was consistently associated with greater healthcare utilization across outpatient visits, hospital admissions, length of hospital stay, and healthcare costs. Adherence to PA guidelines was not independently associated with reduced mortality among pre-frail and frail individuals after multivariable adjustment; however, a significant interaction indicated higher healthcare costs among frail individuals who met PA guidelines. In addition, higher BMI was associated with lower mortality risk, consistent with patterns described as the obesity paradox. These findings highlight frailty as a key, independent predictor of mortality and healthcare utilization beginning in midlife. Standardized PA recommendations alone may be insufficient for physiologically vulnerable populations, underscoring the importance of early frailty screening and individualized, function-sensitive intervention strategies to promote healthy aging.

1. Introduction

Frailty is characterized by heightened vulnerability to external stressors due to declining physiological reserves [1,2]. Historically observed primarily in individuals aged 65 and older [3], recent evidence indicates that frailty is increasingly prevalent among middle-aged populations [4]. Early manifestations, such as weakened grip strength and slower gait speed appear in the mid-40 s [5,6]. Midlife is a critical period shaping later-life health and mortality [7], and early frailty signs may contribute to accelerated chronic disease development and increased healthcare utilization [8,9].

Frailty is commonly assessed using the frailty index (FI) [10], based on a cumulative deficit model that quantifies health deficits across disease, functional, and cognitive domains. Frailty reduces resilience to physiological stress and is associated with increased risks of cardiovascular disease, diabetes, musculoskeletal disorders, and neurodegenerative conditions [11]. Meta-analyses and cohort studies show that frail individuals have substantially higher risks of all-cause mortality and adverse healthcare outcomes than non-frail adults. Specifically, severe frailty has been associated with a 2.79-fold higher risk of prolonged hospitalization [12]. In addition, frail individuals accrue 54 % higher healthcare costs compared with pre-frail and 101 % more than those without frailty [13].

Physical activity (PA) is widely recognized as a major protective factor against chronic disease and premature mortality [14], and regular participation in PA is associated with reduced risks of cardiovascular

* Corresponding author.
E-mail addresses: wnsghrla1@khu.ac.kr (H.-J. Kim), khong13@iastate.edu (K.-R. Hong), ssdlh0422@khu.ac.kr (X.-L. Wen), jungminlee@khu.ac.kr (J.-M. Lee).

https://doi.org/10.1016/j.tjfa.2026.100142
Received 22 September 2025; Received in revised form 9 February 2026; Accepted 16 February 2026
Available online 19 March 2026

disease, obesity, hypertension, and diabetes [15–17]. PA also slows the progression of frailty by improving muscle strength, cardiopulmonary fitness, metabolic function, and inflammatory regulation [18–21]. Among adults aged 50 and older, those with a sedentary lifestyle show approximately double the mortality risk relative to their more active peers [22], while physically active individuals have lower chronic disease prevalence and mortality [23]. Individuals meeting the World Health Organization's (WHO) PA recommendations incur lower hospital costs than those who do not [24]. Nevertheless, a large proportion of middle-aged and older adults do not meet recommended PA levels [25, 26].

Frailty and PA interact to shape health trajectories [27]. Low PA contributes to frailty development through declines in muscle strength, mobility, and energy reserves [28,29], while higher PA may delay or mitigate frailty progression [30]. Individuals engaging in at least 150 min of moderate-to-vigorous physical activity (MVPA) per week are more likely to avert physical frailty and experience lower all-cause mortality than more sedentary counterparts [31,32]. PA also attenuates the elevated cardiovascular mortality risk associated with frailty [33]. Nonetheless, according to health directives issued by the Ministry of Health and Welfare (2023) PA among middle-aged and older adults is projected to further decline with age [34], highlighting the need for longitudinal investigation.

Although substantial research highlights the bidirectional association between PA and frailty, most studies have focused on individuals aged 65 and older. Therefore, this study aimed to examine the longitudinal relationship between PA and frailty and their interaction effects on mortality and healthcare utilization using Korean Longitudinal Study of Aging (KLoSA) data among Korean adults aged 45 years and older.

2. Methods

2.1. Study participants

Data for this study were drawn from KLoSA, a nationally representative cohort study conducted biennially since 2006 by the Korea Labor Institute. This dataset provided in-depth information on individuals aged 45 and older, encompassing demographic, economic, and health factors, and was based on a multistage, stratified sampling design to preserve national representativeness. The study used panel data spanning from the first wave in 2006 to the ninth wave in 2022, allowing for the assessment of long-term changes in participants. The biennial design of KLoSA facilitated regular tracking of aging-related dynamics over time, providing comprehensive insights into trends and transitions within the target population. Participants with incomplete data on key variables, such as demographic and health-related factors, were excluded from the analysis. Additionally, individuals lost to follow-up before the ninth wave or prior to death were excluded from the analysis. Survival status was coded as 0 for alive and 1 for deceased.

2.2. Independent variables

2.2.1. Frailty

Frailty was assessed using the FI, which captures vulnerability through the accumulation of health deficits [10]. This method considered a range of health domains, including self-reported health, physical condition, cognitive performance, limitations in activities of daily living (ADL), instrumental activities of daily living (IADL), and chronic health conditions. For this study, 38 health-related variables were selected from the KLoSA dataset to construct the FI. The use of 38 deficits meets established methodological recommendations of including at least 30 deficits for predictive validity and aligns with previous investigations in aging populations, which have included between 30 and 40 deficits [35–37]. These variables were selected based on the following criteria: (1) they were consistently measured across multiple survey waves and (2) they reflected common aging-related health conditions. Each variable was scored of 0 (no deficit) or 1 (deficit present), with some ordinal variables rescaled into a 0 - 1 range. Participants with missing or incomplete responses for FI components were excluded from the analysis, and no deficits were coded as the absence of deficits. The 38 variables were grouped into six clinical domains: self-rated health, physical condition, mental status, ADL, IADL, and chronic conditions. The self-rated health domain consisted of 1 item: self-assessment of overall health. The physical condition domain included 9 items: social engagement, limitation in usual activities due to health problems, history of falls, impaired vision, impaired hearing, limitation in usual activities due to physical pain, weight loss of more than 5 kg, regular PA engagement, and taking medications as prescribed. The mental status domain was composed of 1 item: symptoms of depression. The ADL domain included 7 items: requiring assistance with dressing, personal hygiene, bathing, eating, getting in and out of bed, using the toilet, and maintaining continence. The IADL domain encompassed 10 items: needing help with grooming, housework, meal preparation, laundry, walking around the house, using transportation, shopping for essentials, managing finances, using the telephone, and preparing meals. Lastly, the chronic health conditions domain consisted of 10 items: hypertension, diabetes mellitus, chronic lung disease (e.g., asthma or COPD), heart disease (e.g., myocardial infarction or angina), stroke or cerebrovascular disease, arthritis or joint problems, liver disease, mental illness, prostate disease, and cancer. The FI for each participant was calculated using the following formula:

$$FI = \frac{\text{Sum of scores for deficits present}}{\textit{Total number of deficits measured}}$$

Frailty was classified according to established thresholds: robust (FI ≤ 0.10), pre-frail ($0.10 < \text{FI} < 0.25$), and frail (FI ≥ 0.25).

2.2.2. Physical activity

PA was assessed using a self-reported questionnaire based on WHO guidelines. PA compliance was classified into two categories: met and not met, based on whether the participant met the recommended PA threshold of 150 min of PA per week. Participants were asked the question, "Do you regularly exercise at least once a week?" Those responding 'no' were categorized as physically inactive and classified as having insufficient PA. Participants who reported engaging in regular exercise were asked to provide responses to two questions:

(1) How many times per week do you participate in exercise?
(2) What is your average exercise time per participation?

Participants meeting or exceeding this threshold classified as having sufficient PA, while those below it was deemed insufficient.

2.3. Dependent variables

2.3.1. All-cause mortality

Mortality data were collected from the first wave in 2006 through the ninth wave in 2022. All-cause mortality, encompassing deaths from cancer, cardiovascular diseases, respiratory diseases, liver diseases, natural causes, accidents, and other causes, was ascertained using information reported by family members or close relatives. Death records were confirmed through exit interviews in the tracker file and were validated via certificates provided by spouses or partners of deceased participants. The time to death was calculated using the formula:

$$\textit{Survival Time} = \textit{Date of Death} - \textit{First Survey Date}$$

2.3.2. Utilization

Healthcare utilization was assessed using data collected from the first wave in 2006 to the ninth wave in 2022. It was primarily measured through three self-reported indicators of healthcare service use over the past 12 months: (1) the number of outpatient visits, (2) the number of hospitalizations in the past 12 months, and (3) length of hospital stays for each admission. Outpatient visits were defined as the total number of visits to a doctor or medical facility, and hospital admissions were defined as the total number of inpatient admissions, both reported biennially by participants. Length of hospital stay was defined as the number of days spent hospitalized per admission. For the first wave, only information on the most recent hospitalization was collected, whereas subsequent waves were based on information since the previous survey. Healthcare costs were evaluated as the total medical expenditure (in Korean Won, KRW) incurred by participants for outpatient and inpatient services over the past 12 months, based on self-reported data. Participants with missing data on these utilization measures were excluded from the analysis to ensure data completeness.

2.4. Covariates

This analysis considered the following sociodemographic covariates: sex (male, female), marital status (married, unmarried), educational level (under elementary school graduate, middle school graduate, high school graduate, over university graduate), region (urban, rural), income level (quartiles), national health insurance coverage (yes, no), private insurance coverage (yes, no), smoking status (none, ex-smoker, smoker), and drinking status (none, ex-drinker, drinker).

2.5. Statistical analysis

Descriptive statistics were reported as means and standard deviations (SD) for continuous variables and as frequencies and percentages for categorical variables. Group differences were assessed using analysis of variance (ANOVA) for continuous variables and chi-square tests for categorical variables. Generalized linear mixed models (GLMMs) were applied to examine longitudinal changes in utilization and frailty over time, accounting for the correlation of repeated measurements within individuals. Model 1 was adjusted for marital status, sex, educational level, and income quartile. Model 2 extended Model 1 by further adjusting for smoking, drinking, BMI, national health insurance, private insurance, and the interaction between frailty and PA guideline adherence. Kaplan-Meier survival curves were used to estimate survival probabilities based on PA guideline compliance and frailty, with log-rank tests used to compare survival curves. A Cox proportional hazards model was used to evaluate the impact of PA compliance and frailty on all-cause mortality, with hazard ratios (HRs) and 95 % confidence intervals (CIs) calculated. Covariate adjustments in the Cox model mirrored those of Model 2. All data processing and statistical analyses were performed using R (Version 4.3.3) and a *p*-value of less than 0.05 was considered statistically significant.

3. Results

Table 1 presents the baseline characteristics of participants (n = 2104) by frailty, categorized as robust (n = 1427), pre-frail (n = 618),

Table 1
Baseline characteristics by frailty (n = 2104).

Variables		Frailty			*p*-value	χ[2]
		Robust (n = 1427)	Pre-frail (n = 618)	Frail (n = 59)		
Gender	Male	941 (65.9)	313 (50.6)	28 (47.5)	< 0.001	47.01
	Female	486 (34.1)	305 (49.4)	31 (52.5)		
Age (years)	45 - 54	535 (37.5)	62 (10.0)	2 (3.4)	< 0.001	358.03
	55 - 61	373 (26.1)	107 (17.3)	3 (5.1)		
	62 - 68	297 (20.8)	182 (29.4)	9 (15.3)		
	69 ≥	222 (15.6)	267 (43.2)	45 (76.3)		
Marital Status	Married	1274 (89.3)	453 (73.3)	33 (55.9)	< 0.001	114.59
	Unmarried	153 (10.7)	165 (26.7)	26 (44.1)		
Smoking	Never smoked	818 (57.3)	405 (65.5)	37 (62.7)	< 0.001	21.78
	Ex-smoker	200 (14)	96 (15.5)	7 (11.9)		
	Current smoker	409 (28.7)	117 (18.9)	15 (25.4)		
Drinking	Never drank	738 (51.7)	237 (38.3)	9 (15.3)	< 0.001	69.91
	Ex-drinker	96 (6.7)	68 (11.0)	15 (25.4)		
	Current drinker	593 (41.6)	313 (50.6)	35 (59.3)		
BMI (kg/m^2)	Underweight	36 (2.5)	41 (6.6)	2 (3.4)	< 0.001	31.52
	Normal	624 (43.7)	254 (41.1)	31 (52.5)		
	Overweight	473 (33.1)	170 (27.5)	12 (20.3)		
	Obese	294 (20.6)	153 (24.8)	14 (23.7)		
Region	Urban	560 (39.2)	209 (33.8)	27 (45.8)	0.03	7.02
	Rural	867 (60.8)	409 (66.2)	32 (54.2)		
	No	41 (2.9)	63 (10.2)	7 (11.9)	< 0.001	51.52
National Health Insurance						
	Yes	1386 (97.1)	555 (89.8)	52 (88.1)		
Private Insurance	No	797 (55.9)	511 (82.7)	57 (96.6)	< 0.001	163.10
	Yes	630 (44.1)	107 (17.3)	2 (3.4)		
PA Guideline Compliance	Not met	972 (68.1)	503 (81.4)	55 (93.2)	< 0.001	51.18
	Met	455 (31.9)	115 (18.6)	4 (6.8)		
Educational Level	Under Elementary school graduate	501 (35.1)	390 (63.1)	47 (79.7)	< 0.001	190.34
	Middle school graduate	270 (18.9)	108 (17.5)	6 (10.2)		
	High school graduate	482 (33.8)	89 (14.4)	2 (3.4)		
	Over University graduate	174 (12.2)	31 (5.0)	4 (6.8)		
Income Quartile	0 - 25 %	262 (18.4)	223 (36.1)	39 (66.1)	< 0.001	206.69
	25 - 50 %	315 (22.1)	192 (31.1)	15 (25.4)		
	50 - 75 %	404 (28.3)	124 (20.1)	4 (6.8)		
	75 - 100 %	446 (31.3)	79 (12.8)	1 (1.7)		
Mortality	Alive	1071 (75.1)	282 (45.6)	5 (8.5)	< 0.001	246.51
	Deceased	356 (24.9)	336 (54.4)	54 (91.5)		

Note. BMI; Body Mass Index.

and frail ($n = 59$). Significant differences were found across all variables ($p < .001$), including for region ($p = .03$). The gender distribution showed a higher percentage of males in the robust group (65.9 %) and a higher percentage of females in the frail group (52.5 %, $p < .001$). Age distribution showed that 76.3 % of the frail group were aged 69 years and older, compared to 15.6 % in the robust group ($p < .001$). Marital status varied significantly, with married individuals most prevalent in the robust group (89.3 %) and least in the frail group (55.9 %, $p < .001$). Regarding smoking, the proportion of none was the highest across three groups (robust: 57.3 %, pre-frail: 65.5 %, frail: 62.7 %, $p < .001$). For drinking status, non-drinker showed the highest percentage in robust group (51.7 %), whereas current drinkers were most prevalent in frail group (59.3 %, $p < .001$). BMI levels revealed that underweight individuals were more prevalent in the pre-frail group (6.6 %) than in the robust group (2.5 %) and frail group (3.4 %), whereas normal BMI was most common in the frail group (52.5 %, $p < .001$). Regarding region, the proportion of rural was higher than urban across all groups (robust: 60.8 %, pre-frail: 66.2 %, frail: 54.2 %, $p < .001$). Across all groups, the enrollment rate of national health insurance was high (robust: 97.1 %, pre-frail: 89.8 %, frail: 88.1 %, $p < .001$), whereas the rate of enrollment in private insurance was lower (robust: 44.1 %, pre-frail: 17.3 %, frail: 3.4 %, $p < .001$). Compliance with physical activity guidelines was lower in the frail group (6.8 %) than in the robust group (31.9 %, $p < .001$). Educational level differed significantly, under elementary school graduate showed the highest proportion in three groups (robust: 35.1 %, pre-frail: 63.1 %, frail: 79.7 %, $p < .001$). For income quartile, the proportion of the highest income quartile (75 - 100 %) was the highest in robust group (31.3 %), however 0 - 25 % was the highest in pre-frail group (36.1 %) and frail group (66.1 %). For mortality, the proportion of deceased increased across groups, being the lowest in the robust group (24.9 %), higher in the pre-frail group (54.4 %), and the highest in the frail group (91.5 %, $p < .001$).

Table 2 presents baseline healthcare utilization by frailty status. For healthcare costs (in 10,000 KRW), the median (interquartile range [IQR]) values were 4 (0 - 26) for the robust group, 32 (8 - 90) for the pre-frail group, and 35 (3 - 101) for the frail group, with significant differences across frailty groups ($p < .001$). For the number of hospitalizations, the median (IQR) was 0 (0 - 0) for both the robust and pre-frail groups and 0 (0 - 1) for the frail group ($p < .001$). Similarly, the median (IQR) length of hospital stay was 0 (0 - 0) for the robust and pre-frail groups and 0 (0 - 4) for the frail group ($p < .001$). Outpatient visits showed higher utilization with increasing frailty status; the median (IQR) number of outpatient visits was 4 (0 - 10) for the robust group, 11 (4 - 20) for the pre-frail group, and 12 (5 - 23) for the frail group ($p < .001$). Overall, most healthcare utilization measures exhibited highly skewed distributions, with median values of zero or near zero across frailty groups.

Table 3 shows the results of GLMM conducted to examine the effects of PA compliance, frailty, and their interaction on utilization, including healthcare costs, number and length of hospital stay, and outpatient visits. All models were adjusted for education level, sex, marital status, smoking, drinking, national health insurance, private health insurance, residential area, and BMI group. Compared to participants who did not meet PA guidelines, those who met the guidelines had significantly higher healthcare costs ($B = 0.03$, 95 % CI [0.01, 0.06], $p < .05$), but no significant differences were found for the number of hospitalizations or length of hospital stay or outpatient visits. Frailty was significantly associated with increased utilization. Pre-frail individuals had higher healthcare costs ($B = 0.13$, 95 % CI [0.11, 0.16], $p < .001$), more hospital admissions ($B = 2.78$, 95 % CI [2.22, 3.34], $p < .001$), longer hospital stays ($B = 8.16$, 95 % CI [7.15, 9.18], $p < .001$), and more outpatient visits ($B = 51.19$, 95 % CI [43.21, 59.17], $p < .001$) than the robust group. Frail groups showed even stronger associations across all outcomes: healthcare costs ($B = 0.31$, 95 % CI [0.23, 0.37], $p < .001$), number of admissions ($B = 8.62$, 95 % CI [7.23, 10.01], $p < .001$), length of hospital stay ($B = 10.7$, 95 % CI [8.28, 13.12], $p < .001$), and outpatient visits ($B = 53.26$, 95 % CI [33.91, 72.62], $p < .001$). The interaction effects between PA compliance and frailty were mostly not significant, except for a significant positive association with outpatient visits among frail individuals who also met PA guidelines ($B = 87.61$, 95 % CI [25.30, 149.91], $p < .01$).

Fig. 1 shows the survival analysis to evaluate the survival probability based on PA compliance and frailty using the Kaplan-Meier analysis. Fig. 1-(a) presents the Kaplan-Meier curve by frailty for the overall sample regardless of PA guideline adherence, with follow-up over 195 months. The initial number at risk was 1427 for the robust group, 618 for the pre-frail group, and 59 for the frail group. At the 195-month mark, the number at risk was 1144 (73 deaths) for the robust group, 347 (63 deaths) for the pre-frail group, and 11 (6 deaths) for the frail group. The log-rank test indicated a statistically significant difference in survival probability across frailty levels ($p < .001$). Fig. 1-(b) shows the Kaplan-Meier curve by frailty for the PA met group, with an initial number at risk of 455 for the robust group, 115 for the pre-frail group, and 4 for the frail group. At the 195-month mark, the number at risk was 372 (18 deaths) for the robust group, 62 (7 deaths) for the pre-frail group, and 1 (0 deaths) for the frail group. The log-rank test within the met group revealed a statistically significant difference across frailty ($p < .001$). Pairwise comparisons showed significant differences between the robust and pre-frail groups (χ[2] (1) = 54.17, $p < .001$), and between the robust and frail groups (χ[2] (1) = 9.42, $p < .001$); however, the difference between the pre-frail and frail groups was not statistically significant (χ[2] (1) = 0.37, $p = .54$). Fig. 1-(c) displays the Kaplan-Meier curve by frailty for the PA not met group, with an initial number at risk of 972 for the robust group, 503 for the pre-frail group, and 55 for the frail group. At the 195-month mark, the number at risk was 822 (105 deaths) for the robust group, 231 (58 deaths) for the pre-frail group, and 10 (6 deaths) for the frail group ($p < .001$).

Fig. 2 presents the associations between frailty status and all-cause mortality based on Cox proportional hazards models. Among pre-frail participants, Model 1 showed an increased risk of all-cause mortality compared with robust participants (HR, 2.01; 95 % CI, 1.71 - 2.35). After further adjustment in Model 2, the HR was 1.72 (95 % CI, 1.43 - 2.07). Among frail participants, the hazard ratio for all-cause mortality was 4.01 (95 % CI, 2.94 - 5.46) in Model 1. After additional adjustment in Model 2, the HR was 3.37 (95 % CI, 2.42 - 4.69). All associations were statistically significant ($p < .001$).

Table 2
Baseline characteristics of utilization by frailty ($n = 2104$).

Variables	Group			p-value
	Robust ($n = 1427$)	Pre-frail ($n = 618$)	Frail ($n = 59$)	
Healthcare costs (10,000 KRW)	4 (0 - 26)	32 (8 - 90)	35 (3 - 101)	< 0.001
Number of hospitalizations (count)	0 (0 - 0)	0 (0 - 0)	0 (0 - 1)	< 0.001
Length of hospital stay (days)	0 (0 - 0)	0 (0 - 0)	0 (0 - 4)	< 0.001
Outpatient visits (count)	4 (0 - 10)	11 (4 - 20)	12 (5 - 23)	< 0.001

Note. IQR; Interquartile Range, KRW; Korean Won, SD; Standard Deviation.
Frailty Index criteria: Robust ≤ 0.1, 0.1 < Pre-frail < 0.25, Frail ≥ 0.25.
All values are reported as median (IQR), defined as the 25th to 75th percentiles.

4. Discussion

This study advances our understanding of frailty as a key, independent predictor of all-cause mortality and healthcare utilization among Korean adults aged 45 and older. Consistent with previous longitudinal findings [38,39], both pre-frailty and frailty were significantly associated with increased risk of death and greater use of outpatient and inpatient medical services. Notably, frail individuals exhibited over a

Table 3
Generalized linear mixed model analysis of the associations between frailty, PA compliance, and utilization ($n = 2104$).

Variables	Healthcare costs		Number of hospitalizations		Length of hospital stay		Outpatient visits	
	B	95 % CI	B	95 % CI	B	95 % CI	B	95 % CI
Physical activity compliance (ref: Not met)								
Met	0.03	(0.01, 0.06)**	0.33	(−0.25, 0.90)	2.77	(1.78, 3.76)***	22.60	(14.60, 30.61)***
Frailty (ref: Robust)								
Pre-frail	0.13	(0.11, 0.16)***	2.78	(2.22, 3.34)***	8.16	(7.15, 9.175)***	51.19	(43.21, 59.17)***
Frail	0.31	(0.23, 0.37)***	8.62	(7.23, 10.01)***	10.7	(8.277, 13.12)***	53.26	(33.91, 72.62)***
Physical activity compliance × Frailty (ref: Not met × Robust)								
Met × Pre-frail	0.01	(−0.03, 0.04)	−0.357	(−1.31, 0.60)	−0.45	(−2.06, 1.16)	−5.33	(−18.51, 7.85)
Met × Frail	0.07	(−0.10, 0.25)	1.18	(−3.41, 5.77)	−1.19	(−8.73, 6.35)	87.61	(25.30, 149.91)**

Note. CI; confidence interval.
All models adjusted for covariates: education level, sex, marital status, smoking, drinking, national health insurance, private health insurance, residential area, and BMI group.
Estimates are unstandardized regression coefficients with 95 % CI.
Significance levels: * $p < .05$, ** $p < .01$, *** $p < .001$.

threefold increase in mortality risk compared to robust individuals, even after adjusting for sociodemographic and behavioral covariates. These findings support the cumulative deficit model proposed by Rockwood and Mitnitski [40], which posits that the accumulation of physiological vulnerabilities predisposes individuals to adverse outcomes [10].

Unlike most frailty studies that focus exclusively on populations aged 65 and older [41,42], this study incorporated middle-aged adults starting at age 45. This inclusion captures the earlier onset of functional decline and allows for a more nuanced understanding of frailty transitions over the life course [4,43]. Research has shown that midlife frailty is often modifiable and more responsive to intervention [44], reinforcing the importance of early detection and preventive strategies [8,9].

Quantitative results demonstrated that both pre-frail and frail individuals faced significantly elevated mortality risks compared to robust adults, with hazard ratios of approximately 1.7 and 3.3, respectively. Frailty status also predicted higher healthcare costs, more frequent outpatient visits, and increased hospital admissions, indicating not only clinical vulnerability but also substantial economic burden [45]. These findings suggest that frailty is not only a biological condition but also a driver of broader systemic strain on healthcare infrastructure.

PA is a well-established determinant of health and survival in aging populations [14,46]. Regular PA has been shown to improve cardiorespiratory function, preserve muscle mass, and reduce the risk of chronic disease [15,20]. Given this extensive evidence base and the limitations of the PA measure used in the present study, PA was treated as a covariate rather than as a primary exposure. Consistent with this approach, while previous studies have highlighted the role of PA in delaying frailty progression [30,47], our results suggest that standardized PA thresholds may be insufficient to meaningfully modify mortality risk once frailty related vulnerability is established. Consistent with this interpretation, compliance with the WHO's recommended minimum PA guideline (≥150 min/week) was not independently associated with reduced mortality risk among pre-frail and frail individuals after multivariable adjustment. Although unadjusted analyses suggested better survival among physically active individuals, this association was attenuated after accounting for frailty and other covariates, indicating that frailty may play a more central role in determining mortality risk.

An additional insight from this study is the identification of a pattern consistent with the "obesity paradox". Individuals categorized as obese exhibited lower all-cause mortality than those in the normal BMI range [48,49], even after controlling for frailty and other covariates. This paradox has been consistently reported in aging populations [50,51], underscoring the need to better elucidate the mechanisms underlying this phenomenon. While excess adiposity has traditionally been proposed as a protective metabolic reserve during illness or physiological stress, accumulating evidence suggests that preserved muscle mass, muscle strength, and cardiorespiratory fitness may more accurately account for this apparent survival advantage [48,52]. Recent studies indicate that higher fitness and muscular strength markedly attenuate mortality risk across BMI categories, highlighting the limitations of BMI as a standalone metric for risk stratification in older adults. Together, these findings suggest that the apparent survival advantages observed among individuals with higher BMI may reflect differences in underlying physical function rather than adiposity. Consistent with this interpretation, accumulating evidence indicates that muscle mass and muscle strength are critical determinants of survival in older adults [53], independent of BMI. Preservation of muscular function has been shown to substantially reduce mortality risk, underscoring the importance of resistance-based exercise interventions [54]. Notably, large scale prospective studies have demonstrated that resistance exercise is a significant predictor of survival [55], further supporting its role as a key component of frailty prevention and management strategies. Collectively, these observations reinforce the importance of moving beyond BMI alone toward more comprehensive assessments of body composition and physical function in aging populations.

This study possesses several methodological strengths. Utilizing 16 years of nationally representative longitudinal data from the KLoSA, we were able to examine frailty transitions from midlife into older age with strong temporal resolution. The inclusion of both mortality and healthcare utilization outcomes enhances the clinical and policy relevance of the findings. Furthermore, rigorous statistical approaches, including generalized linear mixed models and multivariable-adjusted Cox regressions, reinforce the robustness of the results. The exploration of the interaction between PA and frailty also provides new insights that challenge prevailing assumptions in the aging and public health literature.

Nevertheless, limitations must be acknowledged. First, PA was measured via self-report, which may be subject to recall and reporting bias, and detailed information on exercise modality, intensity, and objective physiological markers was unavailable. Second, the exclusion of individuals with incomplete data may limit generalizability due to potential selection bias. Third, lack of information on exercise modality, frequency, and objective physiological markers restricts interpretation of PA effects. Lastly, while the findings reflect a Korean context, cultural differences in aging, activity norms, and healthcare systems may limit applicability in other populations. Therefore, future studies should consider using objective PA measurement tools such as accelerometers, include broader samples with imputed missing data, examine the effects

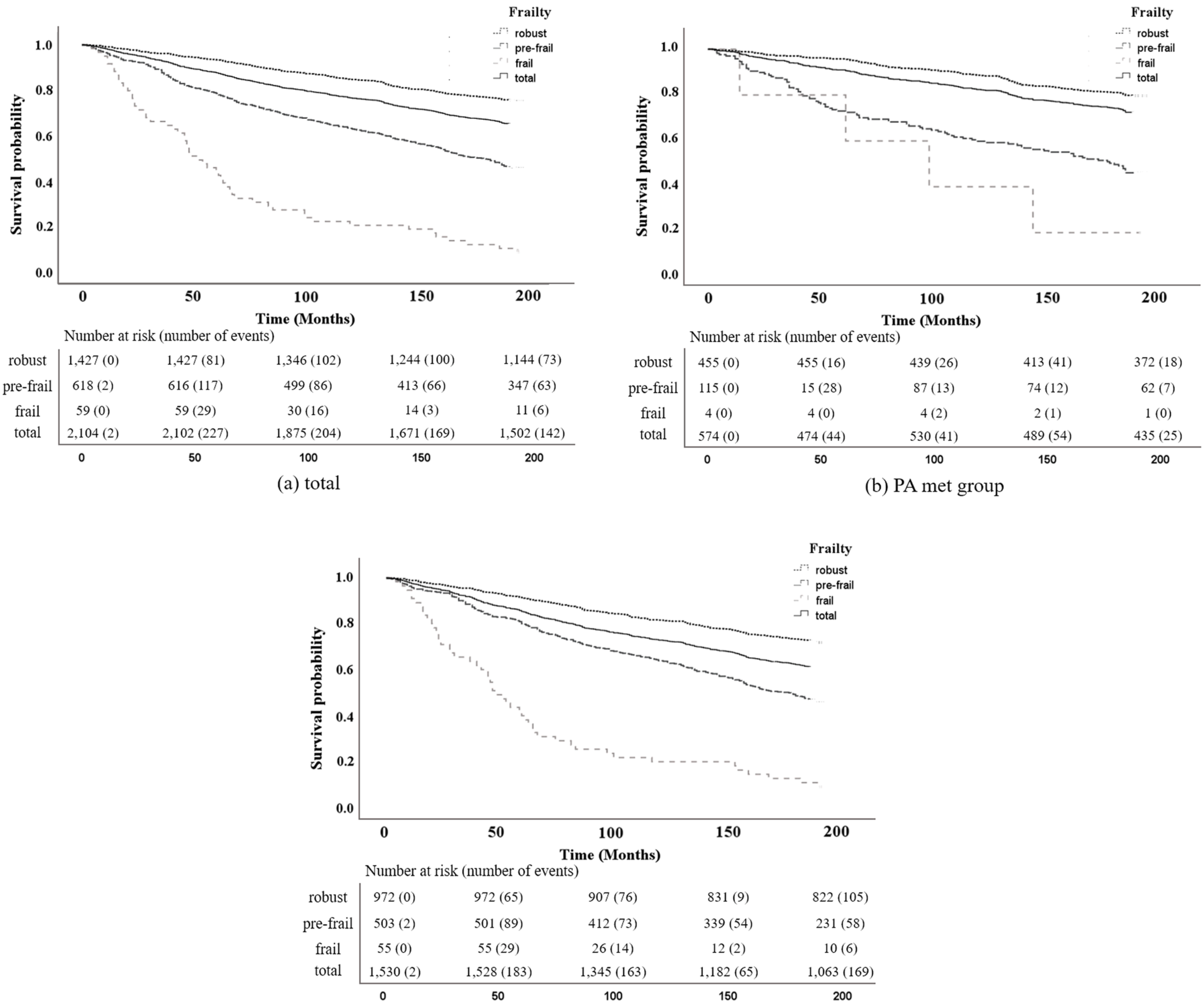

Fig. 1. Kaplan-Meier estimate for survival rate according to and PA compliance and frailty. The x-axis represents the period of survival (in months) and the y-axis represents the survival rate. (a) total PA compliance group. A total of 1427 participants were categorized as robust, 618 participants were categorized as pre-frail and 59 participants were categorized as frail. (b) PA met group. A total of 455 participants were categorized as robust, 115 participants were categorized as pre-frail and 4 participants were categorized as frail. (c) PA not met group. A total of 972 participants were categorized as robust, 503 participants were categorized as pre-frail and 55 participants were categorized as frail.

of different exercise modalities and intensities, and conduct cross national comparisons to enhance external validity.

5. Conclusion

This study demonstrates that frailty is associated with increased all-cause mortality and healthcare utilization among Korean adults aged 45 years and older, highlighting the importance of frailty assessment beginning in midlife. Frailty trajectories appear to emerge well before older age, suggesting a critical period for earlier identification and intervention. While PA remains an important component of healthy aging, meeting the standard recommendation of 150 min per week alone was not associated with lower mortality among pre-frail and frail individuals, indicating limitations of uniform PA guidelines in physiologically vulnerable populations. In addition, the observed association between higher BMI and lower mortality should be interpreted cautiously, as it may reflect differences in underlying fitness or muscle related factors rather than a protective effect of adiposity itself. Overall, these findings support early frailty screening and more individualized, function sensitive intervention strategies in clinical and public health practice.

Declaration of the use of generative AI

The authors used generative AI tools to assist with language editing and readability improvement during manuscript preparation. All scientific content, interpretations, and conclusions were developed and verified by the authors.

Ethical statement

This study involved human participants through secondary analysis of de-identified data from the Korean Longitudinal Study of Aging (KLoSA). The KLoSA study was approved by the National Statistical Office and the Institutional Review Board of the Korea Centers for Disease Control and Prevention (National Statistical Office Approval

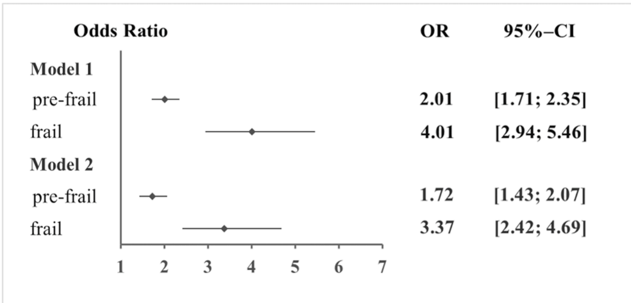

Fig. 2. Hazard ratios for all-cause mortality according to frailty status in cox proportional hazards models. Hazard ratios (HRs) and 95 % confidence intervals (CIs) for all-cause mortality are shown for pre-frail and frail participants, with the robust group serving as the reference category. Results are presented separately for Model 1, adjusted for demographic variables (marital status, sex, educational level, and income quartile), and Model 2, additionally adjusted for smoking status, alcohol consumption, body mass index, insurance status, and the physical activity × frailty interaction.

Number: 336,002). Informed consent was obtained from all participants at the time of the original data collection. No animal subjects were involved in this study.

Data statement

The data supporting the findings of this study are derived from the Korean Longitudinal Study of Aging (KLoSA), administered by the Korea Employment Information Service, and are available to researchers through the official online data access system: https://survey.keis.or.kr/eng/klosa/databoard/List.jsp

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Ho-Jun Kim: Writing – original draft, Methodology, Conceptualization. **Kyu-Ri Hong:** Writing – original draft, Data curation. **Xiao-Lin Wen:** Visualization, Data curation. **Da-San Kim:** Software, Formal analysis. **Jung-Min Lee:** Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The author would like to thank all individuals who provided support during this research, including assistance with data analysis, manuscript preparation, and language editing.

References

[1] Xue Q-L. The frailty syndrome: definition and natural history. Clin Geriatr Med 2011;27(1):1.
[2] Cifu DX, Lew HL. Braddom's rehabilitation care: a clinical handbook E-Book. Elsevier Health Sciences; 2017.
[3] Tang D, Sheehan KJ, Goubar A, Whitney J, O'Connell MD. The temporal trend in frailty prevalence from 2011 to 2020 and disparities by equity factors among middle-aged and older people in China: a population-based study. Arch Gerontol Geriatr 2025:105822.
[4] Segaux L, Broussier A, Oubaya N, et al. Several frailty parameters highly prevalent in middle age (50-65) are independent predictors of adverse events. Sci Rep 2021;11(1):8774.
[5] Park HJ, Han B, Chang S-y, Kang SH, Lee DW, Kang S. Hand grip strength, osteoporosis, and quality of life in middle-aged and older adults. Med (B Aires) 2023;59(12):2148.
[6] Xie YJ, Liu EY, Anson ER, Agrawal Y. Age-related imbalance is associated with slower walking speed: an analysis from the National Health and Nutrition Examination Survey. J geriatr phys ther 2017;40(4):183–9.
[7] Lachman ME, Teshale S, Agrigoroaei S. Midlife as a pivotal period in the life course: balancing growth and decline at the crossroads of youth and old age. Int J Behav Dev 2015;39(1):20–31.
[8] Trantham L, Sikirica MV, Candrilli SD, et al. Healthcare costs and utilization associated with muscle weakness diagnosis codes in patients with chronic obstructive pulmonary disease: a United States claims analysis. J Med Econ 2019;22(4):319–27.
[9] McGrath R, Vincent BM, Peterson MD, et al. Weakness may have a causal association with early mortality in older Americans: a matched cohort analysis. J Am Med Dir Assoc 2020;21(5):621–6. e2.
[10] Rockwood K, Mitnitski A. Frailty in relation to the accumulation of deficits. J Gerontol A: Biol Sci Med Sci 2007;62(7):722–7.
[11] Bergman H, Ferrucci L, Guralnik J, et al. Frailty: an emerging research and clinical paradigm-issues and controversies. J Gerontol A: Biol Sci Med Sci 2007;62(7):731–7.
[12] Park CM, Kim W, Rhim HC, et al. Frailty and hospitalization-associated disability after pneumonia: a prospective cohort study. BMC Geriatr 2021;21:1–8.
[13] Hajek A, Bock J-O, Saum K-U, et al. Frailty and healthcare costs-longitudinal results of a prospective cohort study. Age Ageing 2018;47(2):233–41.
[14] Bull FC, SS Al-Ansari, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med 2020;54(24):1451–62.
[15] Cleven L, Krell-Roesch J, Nigg CR, Woll A. The association between physical activity with incident obesity, coronary heart disease, diabetes and hypertension in adults: a systematic review of longitudinal studies published after 2012. BMC public health 2020;20:1–15.
[16] Sobngwi E, Mbanya J, Unwin N, et al. Physical activity and its relationship with obesity, hypertension and diabetes in urban and rural Cameroon. Int J Obes 2002;26(7):1009–16.
[17] Elagizi A, Kachur S, Carbone S, Lavie CJ, Blair SN. A review of obesity, physical activity, and cardiovascular disease. Curr Obes Rep 2020;9:571–81.
[18] Venkatasamy VV, Pericherla S, Manthuruthil S, Mishra S, Hanno R. Effect of physical activity on insulin resistance, inflammation and oxidative stress in diabetes mellitus. J clin diagn res: JCDR 2013;7(8):1764.
[19] Thyfault JP, Bergouignan A. Exercise and metabolic health: beyond skeletal muscle. Diabetologia 2020;63(8):1464–74.
[20] Bennie JA, Shakespear-Druery J, De Cocker K. Muscle-strengthening exercise epidemiology: a new frontier in chronic disease prevention. Sports med-open 2020;6:1–8.
[21] Cheng J-C, Chiu C-Y, Su T-J. Training and evaluation of human cardiorespiratory endurance based on a fuzzy algorithm. Int J Env Res Public Health 2019;16(13):2390.
[22] McPhee JS, French DP, Jackson D, Nazroo J, Pendleton N, Degens H. Physical activity in older age: perspectives for healthy ageing and frailty. Biogerontology 2016;17:567–80.
[23] Kraus WE, Powell KE, Haskell WL, et al. Physical activity, all-cause and cardiovascular mortality, and cardiovascular disease. Med Sci Sports Exerc 2019;51(6):1270.
[24] Marashi A, Ghassem Pour S, Li V, Rissel C, Girosi F. The association between physical activity and hospital payments for acute admissions in the Australian population aged 45 and over. PLoS One 2019;14(6):e0218394.
[25] Bowden Davies KA, Pickles S, Sprung VS, et al. Reduced physical activity in young and older adults: metabolic and musculoskeletal implications. Ther Adv Endocrinol Metab 2019;10:2042018819888824.
[26] Haider S, Grabovac I, Dorner TE. Effects of physical activity interventions in frail and prefrail community-dwelling people on frailty status, muscle strength, physical performance and muscle mass-a narrative review. Wien Klin Wochenschr 2019;131:244–54.
[27] Lin Y-K, Chen C-Y, Cheung DST, Montayre J, Lee C-Y, Ho M-H. The relationship between physical activity trajectories and frailty: a 20-year prospective cohort among community-dwelling older people. BMC Geriatr 2022;22(1):867.
[28] Papp ME, Grahn-Kronhed AC, Rauch Lundin H, Salminen H. Changes in physical activity levels and relationship to balance performance, gait speed, and self-rated health in older Swedish women: a longitudinal study. Aging Clin Exp Res 2022;34(4):775–83.
[29] Roubenoff R, Walsmith J, Lundgren N, Snydman L, Dolnikowski GJ, Roberts S. Low physical activity reduces total energy expenditure in women with rheumatoid arthritis: implications for dietary intake recommendations. Am J Clin Nutr 2002;76(4):774–9.
[30] Kehler DS, Theou O. The impact of physical activity and sedentary behaviors on frailty levels. Mech Ageing Dev 2019;180:29–41.
[31] Yokote T, Yatsugi H, Chu T, Liu X, Kishimoto H. Associations between various types of activity and physical frailty in older Japanese: a cross-sectional study. BMC Geriatr 2023;23(1):785.
[32] Zhao M, Veeranki SP, Magnussen CG, Xi B. Recommended physical activity and all cause and cause specific mortality in US adults: prospective cohort study. bmj 2020:370.

[33] Higueras-Fresnillo S, Cabanas-Sánchez V, Lopez-Garcia E, et al. Physical activity and association between frailty and all-cause and cardiovascular mortality in older adults: population-based prospective cohort study. J Am Geriatr Soc 2018;66(11): 2097–103.
[34] Welfare MoHa. Physical activity guidelines for koreans. Ministry of Health and Welfare; 2023 (March 13, 2025. Accessed March 13, 2025, https://www.mohw.go.kr/board.es?mid=a10411010100&bid=0019&act=view&list_no=1479208&tag=&nPage=1.
[35] Hanlon P, Politis M, Wightman H, et al. Frailty and socioeconomic position: a systematic review of observational studies. Ageing Res Rev 2024;100:102420.
[36] Jerjes W, Harding D, Jhass A. Reimagining the frailty review: meaning, metrics, and the missed opportunity in global ageing care. Front Med 2025;12:1620193.
[37] Bouillon K, Kivimaki M, Hamer M, et al. Measures of frailty in population-based studies: an overview. BMC Geriatr 2013;13(1):64.
[38] Kojima G, Iliffe S, Walters K. Frailty index as a predictor of mortality: a systematic review and meta-analysis. Age Ageing 2018;47(2):193–200.
[39] Son MK, Lee K. Frailty transition and burden on mortality risk in middle-aged and older population: a prospective cohort study. Sci Rep 2024;14(1):26498.
[40] Mitnitski A, Bao L, Skoog I, Rockwood K. A cross-national study of transitions in deficit counts in two birth cohorts: implications for modeling ageing. Exp Gerontol 2007;42(3):241–6.
[41] Peng Y, Zhong G-C, Zhou X, Guan L, Zhou L. Frailty and risks of all-cause and cause-specific death in community-dwelling adults: a systematic review and meta-analysis. BMC Geriatr 2022;22(1):725.
[42] Cesari M, Araujo de Carvalho I, Amuthavalli Thiyagarajan J, et al. Evidence for the domains supporting the construct of intrinsic capacity. J Gerontol: A 2018;73(12): 1653–60.
[43] Tang D, Sheehan KJ, Goubar A, Whitney J, O'Connell MD. The temporal trend in frailty prevalence from 2011 to 2020 and disparities by equity factors among middle-aged and older people in China: a population-based study. Arch Gerontol Geriatr 2025;133:105822.
[44] Brunner EJ, Shipley MJ, Ahmadi-Abhari S, et al. Midlife contributors to socioeconomic differences in frailty during later life: a prospective cohort study, 3. The Lancet Public Health; 2018. p. e313–22.
[45] Costa D, Aladio M, Girado CA, de la Hoz RP, Berensztein CS. Frailty is independently associated with 1-year mortality after hospitalization for acute heart failure. IJC heart vasc 2018;21:103–6.
[46] Kraus WE, Janz KF, Powell KE, et al. Daily step counts for measuring physical activity exposure and its relation to health. Med Sci Sports Exerc 2019;51(6):1206.
[47] Haider N, Yavlinsky A, Simons D, et al. Passengers' destinations from China: low risk of novel coronavirus (2019-nCoV) transmission into Africa and South America. Epidemiol Infect 2020;148:e41.
[48] Abramowitz MK, Hall CB, Amodu A, Sharma D, Androga L, Hawkins M. Muscle mass, BMI, and mortality among adults in the United States: a population-based cohort study. PloS one 2018;13(4):e0194697.
[49] Alebna PL, Mehta A, Yehya A, Lavie CJ, Carbone S. Update on obesity, the obesity paradox, and obesity management in heart failure. Prog Cardiovasc Dis 2024;82: 34–42.
[50] Kalyani RR, Corriere M, Ferrucci L. Age-related and disease-related muscle loss: the effect of diabetes, obesity, and other diseases. lancet Diabetes endocrinol 2014;2 (10):819–29.
[51] Wannamethee SG, Shaper AG, Whincup PH, Lennon L, Papacosta O, Sattar N. The obesity paradox in men with coronary heart disease and heart failure: the role of muscle mass and leptin. Int J Cardiol 2014;171(1):49–55.
[52] García-Hermoso A, Cavero-Redondo I, Ramírez-Vélez R, et al. Muscular strength as a predictor of all-cause mortality in an apparently healthy population: a systematic review and meta-analysis of data from approximately 2 million men and women. Arch Phys Med Rehabil 2018;99(10):2100–13. e5.
[53] Carbone S, Kirkman DL, Garten RS, et al. Muscular strength and cardiovascular disease: an updated state-of-the-art narrative review. J Cardiopulm Rehabil Prev 2020;40(5):302–9.
[54] Kaminsky LA, Lavie CJ, Flint K, Arena R, Bond S. Working toward optimal exercise prescription: strength training should not be overlooked. J Cardiopulm Rehabil Prev 2022;42(2):E32–3.
[55] Liu Y, Lee D-C, Li Y, et al. Associations of resistance exercise with cardiovascular disease morbidity and mortality. Med Sci Sports Exerc 2019;51(3):499.