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Modified diet balance index-16 scores and frailty index-defined health deficit accumulation in a prospective Chinese adult health-check cohort

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Introduction: Prospective evidence linking diet quality to multi-domain health deficit accumulation is limited in non-Western adults, and few studies distinguish dietary insufficiency from excessive intake.
Methods: We included 23,673 Chinese adults aged ≥25 years from the Beijing MJ Health Screening Center. Baseline diet was assessed using a modified diet balance index-16 framework, which yielded Total Score (TS), Low Bound Score (LBS), High Bound Score (HBS), and Diet Quality Distance (DQD). A 29-item frailty index identified health deficit accumulation at FI ≥0.25. Cox models estimated hazard ratios (HRs) for reaching this threshold.
Results: During a median follow-up of 3.21 years, 307 participants reached FI ≥0.25. Compared with low TS, medium and high TS were associated with lower risk (HR 0.74, 95% CI 0.56–0.97, and HR 0.64, 95% CI 0.43–0.95). High LBS was associated with higher risk (HR 1.48, 95% CI 1.04–2.10). DQD showed no clear association, and the HBS association was not statistically significant.
Discussion: A more favorable modified DBI-16 profile and less dietary insufficiency were associated with lower risk of FI-defined health deficit accumulation.

KEYWORDS
diet balance index-16, diet quality, dietary insufficiency, frailty index, health deficit accumulation, prospective cohort

1 Introduction

Frailty is a multidimensional syndrome characterized by reduced physiological reserve and resilience to stressors (1–3). Biological and social factors contributing to frailty accumulate over time, and a life-course perspective points to potentially modifiable exposures before older age (4–7).

The frailty index (FI) quantifies the proportion of health deficits present across multiple domains (8). These domains can include chronic disease, physical and cognitive function, nutritional status, and laboratory abnormalities (5). Unlike phenotype-based instruments or administrative scores (9, 10), the FI captures a broad range of health domains and can be applied to repeated health-check data.

Healthier dietary patterns have been associated with lower frailty risk and better functional outcomes (11–16). However, most evidence comes from older Western populations and uses indices that do not distinguish insufficient from excessive intake. This distinction matters in China, where nutrition transition involves under-consumption of recommended foods alongside selective over-consumption of energy-dense foods (17, 18).

The Chinese diet balance index-16 (DBI-16), based on the 2016 Chinese Dietary Guidelines, assesses dietary balance across food groups and distinguishes insufficient from excessive intake (19–22). We therefore used a modified DBI-16 based on the food frequency questionnaire components available in the Beijing MJ Health Screening Center data.

Using longitudinal data from a Chinese adult health-check cohort, we examined associations of four modified DBI-16 summary scores with subsequent FI-defined health deficit accumulation. We also evaluated dose–response patterns, food-group components, sensitivity analyses, and effect modification.

2 Materials and methods

2.1 Data source and study population

This longitudinal cohort study used health check-up data collected at the Beijing MJ Health Screening Center (MJHSC, Beijing, China) between 2008 and 2018. At each visit, standardized questionnaires captured sociodemographic characteristics, lifestyle, diet, medical history, and recent health conditions. Participants also underwent physical examinations and laboratory testing (23–25). Personal identifiers were removed before analysis. The Institutional Review Board of Peking University Health Science Center approved the study (IRB00001052-19077, approved 18 July 2019).

Among 162,307 participants (361,850 visits), we first excluded those aged <25 years or missing age or sex (n = 4,492) and those with one visit (n = 104,325). We then excluded participants with missing dietary data or implausible energy intake (<800 or >4,200 kcal/day for men and <500 or >3,500 kcal/day for women, n = 11,439). Further exclusions were missing any baseline FI component (n = 10,365), baseline FI $\geq$ 0.25 (n = 248), missing key baseline covariates (n = 4,446), or <1 year of follow-up (n = 3,319). We excluded baseline FI $\geq$ 0.25 to remove prevalent high-deficit burden. The remaining 23,673 participants comprised the analytic cohort (Supplementary Figure S1). Baseline was the first eligible health check-up during 2008–2018.

2.2 Dietary assessment

Baseline diet was assessed using a standardized semi-quantitative food frequency questionnaire (FFQ) covering the previous month (23). Participants selected intake categories defined by food-specific serving examples. Daily intakes were estimated using the portion-conversion method previously described in this health-check population (25). Reported intake categories were expressed as average portions per day and multiplied by food-specific amounts per portion. Appendix 1A describes intake conversion and modified DBI-16 scoring.

Diet quality was evaluated using a modified DBI-16 framework based on the 2016 Chinese Dietary Guidelines and Chinese Food Guide Pagoda (19–21). Six available components yielded four summary scores: TS, DQD, HBS, and LBS. In this cohort, higher TS generally reflected less predominance of under-consumption and a more favorable profile. Higher DQD indicates greater overall imbalance, whereas HBS and LBS represent excess-related and insufficiency-related imbalance, respectively. We categorized each summary score as low (Q1), medium (Q2-Q4), or high (Q5).

2.3 Assessment of frailty index-defined health deficit accumulation

Multidomain health deficit accumulation was assessed using a 29-item FI comprising self-reported conditions and symptoms, examination findings, and laboratory measures (24, 26). Supplementary Table S1 lists all deficits. Each deficit was scored from 0 to 1, with partial scoring for graded variables, and the FI was calculated as the sum divided by 29. FI $\geq$ 0.25 indicated a high burden of accumulated health deficits. In this relatively young health-check cohort, this outcome represents FI-defined multidomain health deficit accumulation rather than established geriatric clinical frailty. Follow-up accrued from baseline to the first visit with FI $\geq$ 0.25 or the last available visit for participants who did not reach this threshold. Appendix 1B provides further details.

2.4 Definition and measurement of covariates

Baseline covariates included age, sex, education, marital status, annual personal income, smoking, leisure-time physical activity, sleep quality, and total energy intake. Questionnaires captured sociodemographic and lifestyle variables, and the baseline FFQ provided total energy intake. Appendix 1C describes all definitions and coding.

2.5 Statistical analysis

Baseline characteristics were summarized across TS categories. Mean-based continuous variables were compared using ANOVA, baseline FI was presented as median (IQR) and compared using the Kruskal-Wallis test, and categorical variables were compared using chi-square tests. Follow-up time was measured from baseline. The event date was the first follow-up visit with FI $\geq$ 0.25. Participants who did not reach this threshold were censored at their last visit. Cox models with time since baseline as the time scale estimated hazard ratios (HRs) and 95% confidence intervals (CIs). Schoenfeld residual tests showed no evidence of non-proportionality for the dietary exposures or global models. Because marital status showed borderline time dependence in some models, analyses stratifying baseline hazards by marital status were performed and produced materially unchanged estimates. Model 1 adjusted for age and sex. Model 2 additionally adjusted for education, marital status, annual personal income, smoking, physical activity, sleep quality, and total energy intake.

Dose–response relationships were assessed using restricted cubic splines with knots at the 5th, 50th, and 95th percentiles under Model 2. Likelihood ratio tests evaluated nonlinearity. Separate Model 2 Cox models examined each food-group component by comparing values above the empirical 20th-percentile cutoff with values at or below the cutoff. Sensitivity analyses excluded outcomes during the first 2 years,

used an alternative outcome threshold of FI ≥ 0.20 among participants below 0.20 at baseline, and recalculated FI when at least 80% (i.e., at least 24 of 29) items were available. For the latter analysis, FI was the sum of observed deficit scores divided by the number of observed items. Subgroup analyses added interaction terms between each modified DBI-16 score and age, sex, education, annual personal income, marital status, smoking, physical activity, or sleep quality. Age was categorized as ≤50 and >50 years to retain adequate representation in both strata. We reported stratum-specific estimates and interaction *p*-values.

All analyses were performed using R version 4.3.1, with a two-sided $p < 0.05$ indicating statistical significance.

3 Results

3.1 Baseline characteristics

Among 23,673 participants, the mean baseline age was 40.22 years (Table 1). Mean (SD) TS, DQD, HBS, and LBS values were 4.61 (6.86), 22.66 (5.08), 13.63 (4.58), and 9.03 (3.93), respectively. Median baseline FI was 0.069 (IQR 0.034–0.103). Participants with lower TS were more often female, unmarried, and in lower education, income, physical activity, and sleep-quality categories (all $p < 0.001$).

TABLE 1 Baseline characteristics of participants by modified DBI-16 Total Score (TS) category.

Characteristic	Overall	Low score	Medium score	High score	*p*-value
N	23,673	4,996	15,093	3,584	
TS, mean (SD)	4.61 (6.86)	−5.49 (4.38)	5.71 (3.28)	14.03 (1.78)	<0.001
DQD, mean (SD)	22.66 (5.08)	22.05 (6.73)	22.37 (4.66)	24.71 (3.27)	<0.001
HBS, mean (SD)	13.63 (4.58)	8.28 (4.04)	14.04 (3.03)	19.37 (1.98)	<0.001
LBS, mean (SD)	9.03 (3.93)	13.77 (3.99)	8.33 (2.67)	5.34 (1.74)	<0.001
Baseline FI, median (IQR)	0.069 (0.034–0.103)	0.069 (0.046–0.114)	0.069 (0.034–0.103)	0.069 (0.034–0.103)	<0.001
Female, counts (%)	10,915 (46.1)	2,521 (50.5)	6,688 (44.3)	1706 (47.6)	<0.001
Age, years, mean (SD)	40.22 (10.37)	39.44 (9.84)	40.42 (10.50)	40.46 (10.45)	<0.001
Annual personal income, CNY, counts (%)					<0.001
<100 k	11,860 (50.1)	2,956 (59.2)	7,441 (49.3)	1,463 (40.8)	
100 to <200 k	7,165 (30.3)	1,261 (25.2)	4,619 (30.6)	1,285 (35.9)	
≥200 k	4,648 (19.6)	779 (15.6)	3,033 (20.1)	836 (23.3)	
Education level, counts (%)					<0.001
Sub-bachelor or lower	5,083 (21.5)	1,368 (27.4)	3,129 (20.7)	586 (16.4)	
Bachelor	10,907 (46.1)	2,389 (47.8)	6,901 (45.7)	1,617 (45.1)	
Master or higher	7,683 (32.5)	1,239 (24.8)	5,063 (33.5)	1,381 (38.5)	
Marital status, counts (%)					<0.001
Single	3,107 (13.1)	759 (15.2)	1925 (12.8)	423 (11.8)	
Married	19,977 (84.4)	4,097 (82.0)	12,792 (84.8)	3,088 (86.2)	
Divorced or widowed	589 (2.5)	140 (2.8)	376 (2.5)	73 (2.0)	
Smoking status, counts (%)					<0.001
Never	16,544 (69.9)	3,248 (65.0)	10,666 (70.7)	2,630 (73.4)	
Ex smoker or passive smoker	2,552 (10.8)	648 (13.0)	1,541 (10.2)	363 (10.1)	
Current smoker	4,577 (19.3)	1,100 (22.0)	2,886 (19.1)	591 (16.5)	
Physical activity score, *n* (%)					<0.001
Q1	5,268 (22.3)	1,355 (27.1)	3,312 (21.9)	601 (16.8)	
Q2–4	15,152 (64.0)	3,029 (60.6)	9,694 (64.2)	2,429 (67.8)	
Q5	3,253 (13.7)	612 (12.2)	2087 (13.8)	554 (15.5)	
Sleep quality score, mean (SD)	1.81 (0.87)	1.74 (0.88)	1.82 (0.87)	1.88 (0.86)	<0.001

TS categories were defined as low (Q1), medium (Q2–Q4), and high (Q5). Sleep scores were calculated as follows. Sleep duration was scored as 3 for 7–9 h/night, 2 for 6 to <7 h/night or >9 h/night, and 1 for <6 h/night. One point was subtracted for symptoms such as trouble falling asleep, frequent awakenings, frequent dreams, or use of sleeping pills or tranquilizers. Values are mean (SD), median (IQR), or *n* (%), as indicated. *p*-values are from ANOVA for mean-based continuous variables, the Kruskal-Wallis test for baseline FI, or chi-square tests for categorical variables.

3.2 Associations of modified DBI-16 scores with the FI-defined outcome

During a median follow-up of 3.21 years (IQR 2.00–5.18), 307 participants reached FI ≥ 0.25. Cumulative incidence was 1.5%, 1.3%, and 1.1% in the low, medium, and high TS groups, respectively. In Model 2, medium and high TS were associated with lower risk than low TS (HR 0.74, 95% CI 0.56–0.97, and HR 0.64, 95% CI 0.43–0.95). Each 1-SD increase in TS was associated with lower risk (HR 0.84, 95% CI 0.75–0.94, $p = 0.003$). High LBS was associated with higher risk (HR 1.48, 95% CI 1.04–2.10), and the per-SD HR was 1.18 (95% CI 1.06–1.32, $p = 0.003$). DQD showed no clear association. The per-SD estimate for HBS was inverse but not statistically significant (HR 0.89, 95% CI 0.80–1.00, $p = 0.059$; Table 2). Restricted cubic splines suggested approximately linear associations for TS and LBS (all p-for nonlinearity >0.05; Figure 1).

Lagged analyses supported the main associations. With FI ≥ 0.20 among participants below 0.20 at baseline, 902 events occurred in 23,182 participants. The per-SD HRs were 0.92 (95% CI 0.86–0.99) for TS and 1.09 (95% CI 1.02–1.17) for LBS. When FI was calculated at visits with at least 24 of 29 items available, 539 events occurred in 37,247 participants. The per-SD HRs were 0.89 (95% CI 0.82–0.97) for TS and 1.14 (95% CI 1.05–1.24) for LBS. DQD and HBS were not statistically significant in either analysis (Supplementary Table S2).

3.3 Component analysis

Higher cereals component scores were associated with lower risk (per-SD HR 0.88, 95% CI 0.79–0.98, $p = 0.019$). Participants above the component-specific 20th-percentile cutoff for animal-sourced foods also had lower risk than those at or below the cutoff (HR 0.74, 95% CI 0.58–0.95, $p = 0.017$). Dairy and soy products showed an inverse per-SD association (HR 0.88, 95% CI 0.78–0.98, $p = 0.025$), whereas the categorical estimate was less precise (HR 0.81, 95% CI 0.62–1.04, $p = 0.102$). Other components were not materially associated with the outcome (Supplementary Table S3).

3.4 Subgroup analyses

No interaction was observed for TS, DQD, or LBS in the age groups shown in Figure 2 and Supplementary Figures S3–S5 (p-for interaction = 0.17, 0.09, and 0.83, respectively). For HBS, the inverse estimate was evident at age ≤50 years (HR 0.80, 95% CI 0.68–0.94) but not at >50 years (HR 1.01, 95% CI 0.86–1.19; p-for interaction = 0.04; Supplementary Figure S4). TS and LBS also differed by marital status. The TS association was stronger among divorced or widowed participants (HR 0.53, 95% CI 0.35–0.80; p-for interaction = 0.04). The LBS association was stronger among divorced or widowed participants (HR 1.94, 95% CI 1.32–2.84; p-for interaction = 0.01) and among those with the poorest sleep quality (HR 1.64, 95% CI 1.30–2.06; p-for interaction < 0.001).

4 Discussion

In this prospective Chinese adult health-check cohort, a more favorable modified DBI-16 total score was associated with lower risk of FI-defined health deficit accumulation, whereas greater dietary insufficiency was associated with higher risk. Insufficiency-related

TABLE 2 Associations of modified DBI-16 scores with the FI-defined outcome.

Exposure	Measurement/ Model	Low	Medium	High	Per SD increment	p-per SD
TS	Case/Total	74/4,996	194/15,093	39/3,584		
	Incidence rate	3.86	3.35	2.87		
	Model 1	Ref.	0.70 (0.54, 0.92)	0.58 (0.39, 0.86)	0.81 (0.73, 0.91)	<0.001
	Model 2	Ref.	0.74 (0.56, 0.97)	0.64 (0.43, 0.95)	0.84 (0.75, 0.94)	0.003
DQD	Case/Total	67/5,138	198/15,043	42/3,492		
	Incidence rate	3.39	3.42	3.23		
	Model 1	Ref.	1.00 (0.76, 1.32)	1.16 (0.78, 1.71)	1.07 (0.95, 1.20)	0.298
	Model 2	Ref.	0.98 (0.74, 1.30)	1.05 (0.70, 1.55)	1.04 (0.92, 1.17)	0.573
HBS	Case/Total	65/4,811	199/15,181	43/3,681		
	Incidence rate	3.53	3.41	3.12		
	Model 1	Ref.	0.80 (0.60, 1.06)	0.83 (0.57, 1.23)	0.88 (0.79, 0.99)	0.034
	Model 2	Ref.	0.81 (0.61, 1.08)	0.88 (0.59, 1.29)	0.89 (0.80, 1.00)	0.059
LBS	Case/Total	79/6,584	169/12,975	59/4,114		
	Incidence rate	3.12	3.40	3.77		
	Model 1	Ref.	1.27 (0.97, 1.66)	1.65 (1.17, 2.32)	1.23 (1.10, 1.37)	<0.001
	Model 2	Ref.	1.19 (0.91, 1.57)	1.48 (1.04, 2.10)	1.18 (1.06, 1.32)	0.003

The FI-defined outcome was the first follow-up visit at which FI met or exceeded 0.25. Case/Total indicates the number of participants reaching FI ≥ 0.25 and the number of participants in each exposure category. Incidence rates are per 1,000 person-years. Low, medium, and high categories were defined as Q1, Q2–Q4, and Q5, respectively. Model 1 adjusted for age and sex. Model 2 additionally adjusted for education, marital status, annual personal income, smoking status, physical activity level, sleep quality, and total energy intake. Per SD increment estimates modeled each modified DBI-16 score continuously per 1-SD increase. In this modified DBI-16 implementation, higher TS generally reflected less predominance of under-consumption rather than greater dietary imbalance.

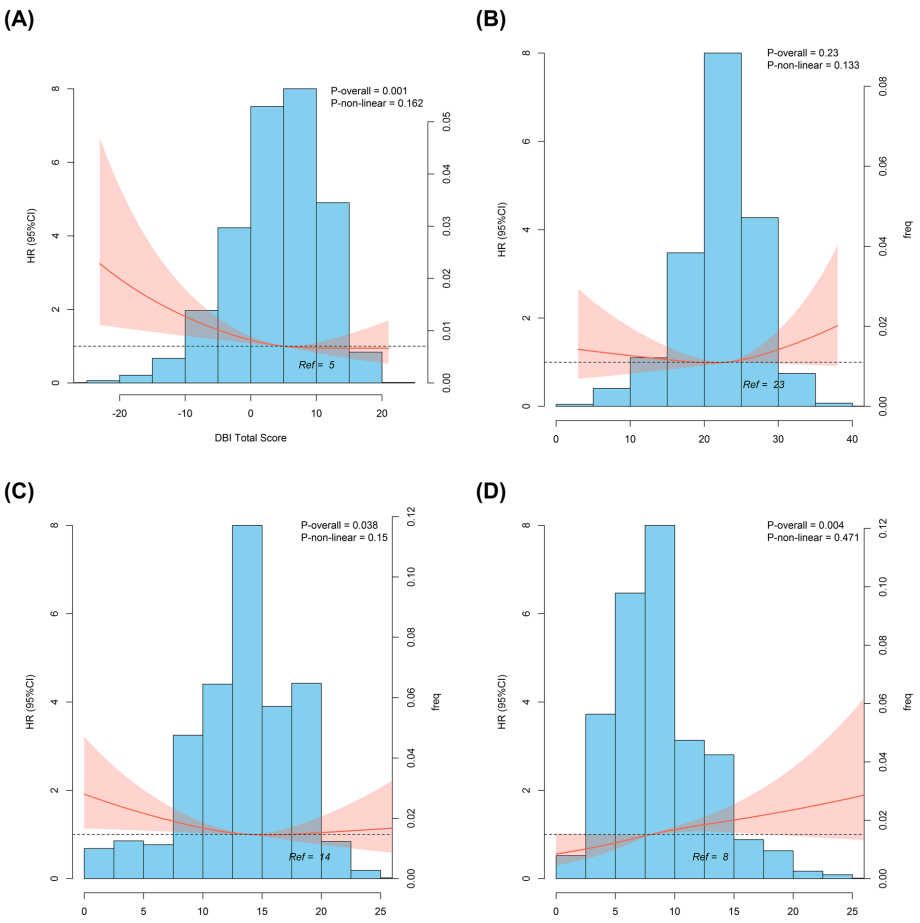


FIGURE 1
Dose–response associations between modified DBI-16 scores and the FI-defined outcome using restricted cubic splines. **(A)** shows Total Score (TS), **(B)** Diet Quality Distance (DQD), **(C)** High Bound Score (HBS), and **(D)** Low Bound Score (LBS). Solid lines indicate hazard ratios (HRs), shaded areas indicate 95% confidence intervals (CIs), bars show score distributions, and dashed horizontal lines indicate HR = 1. Models were adjusted for age, sex, education, marital status, annual personal income, smoking status, physical activity level, sleep quality, and total energy intake.

imbalance showed a more consistent association with the outcome than excess-related imbalance.

Our study extends prospective evidence on diet quality and frailty-related outcomes, which has largely come from older Western populations using indices such as the Healthy Eating Index or DASH score (11–16). In China, overweight and inadequate micronutrient intake can coexist. The DBI-16 evaluates insufficient and excessive intake separately against recommendations in the Chinese Dietary Guidelines (17–22). In our cohort, the more consistent association for LBS suggests that insufficient intake of recommended food groups deserves attention in relatively young adults attending health checks. The component findings for animal-sourced foods and dairy and soy products provide additional context for this pattern.

These associations may partly reflect protein and overall nutrient adequacy, which are relevant to maintaining muscle mass and function (27, 28). Protein intake is important for maintaining muscle function (29). The inverse estimates for animal-sourced foods and dairy and soy products were compatible with this explanation, although the component results were not uniform. By contrast, the HBS association was not statistically significant in the primary analysis or the analyses using alternative FI definitions, and DQD showed no clear association. Excess-related imbalance may operate through adiposity or insulin resistance over longer periods (30, 31). The FFQ-derived estimates of cooking oil and alcohol intake may also be imprecise. The modified scores did not include separate salt- or sugar-related components, limiting assessment of excessive intake.

Dietary routines and social support can differ by marital status, while poor sleep may co-occur with metabolic and behavioral risk factors. Variation in LBS estimates across these strata is consistent with evidence linking marital status and sleep quality to frailty-related outcomes (32, 33). Some stratum-specific estimates were imprecise. Larger studies with repeated diet and lifestyle measurements are needed to assess whether these factors modify associations between dietary imbalance and FI-defined deficit accumulation.

Strengths of this study include its prospective design, large sample, standardized health check-ups, and multi-domain FI. The modified DBI-16 also provided a culturally relevant assessment that separated insufficient from excessive intake. Several limitations merit consideration. First, unavailable DBI-16 components reduced comparability with the full instrument. Second, requiring repeated visits, complete baseline data, and at least 1 year of follow-up restricted the primary sample to returning health-check participants. Selection bias is possible if return attendance or data completeness was associated with diet and deficit accumulation. Recalculating FI with at least 80% item completeness increased the sample, while preserving the directions of the TS and LBS associations. Third, the short follow-up and modest

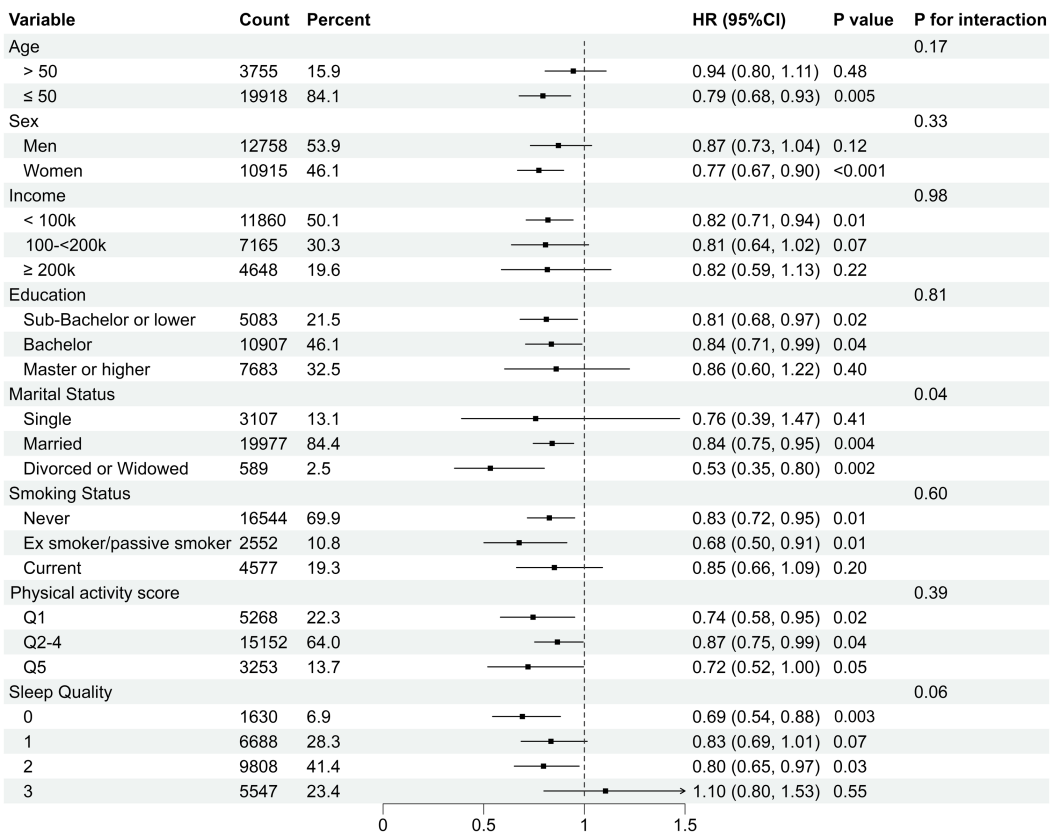


FIGURE 2
Subgroup associations between modified DBI-16 Total Score and the FI-defined outcome. Points and horizontal lines represent HRs and 95% CIs per 1-SD increase in TS from Model 2. *p*-for interaction was obtained by adding a multiplicative interaction term between TS and each subgroup factor. Model 2 adjusted for age, sex, education, marital status, annual personal income, smoking status, physical activity level, sleep quality, and total energy intake. Physical activity score categories were defined using the 20th and 80th percentile cutoffs (Q1, Q2–Q4, and Q5, from lowest to highest). Sleep quality scores ranged from 0 to 3, with higher scores indicating better sleep quality. Detailed covariate definitions are provided in Appendix 1C.

event count limited precision, particularly for excess-related scores. Fourth, diet was self-reported only at baseline, preventing assessment of dietary change. Fifth, FI was measured only at health-check visits, so threshold crossing was interval-observed. Assigning the first qualifying visit as the event date may have introduced timing error. Sixth, information on acute events and treatment was unavailable, and some threshold crossings may reflect transient changes. Results were similar after excluding events during the first 2 years, but residual outcome misclassification remains possible. Finally, in this relatively young cohort, the outcome represents FI-defined multi-domain health deficit accumulation rather than established geriatric clinical frailty.

In conclusion, a more favorable modified DBI-16 profile and less dietary insufficiency were associated with lower risk of FI-defined health deficit accumulation in this Chinese adult health-check cohort. Dietary insufficiency showed a more consistent association than excess-related imbalance. Studies in older populations with repeated diet assessments and acute-event data should determine whether these associations extend to clinically defined frailty.

Data availability statement

The datasets presented in this article are not readily available because the data analyzed in this study are not publicly available due to privacy and ethical restrictions. The data were obtained from the Beijing MJ Health Screening Center and were used under authorization for the current study. Requests to access the datasets should be directed to the corresponding authors and will be considered subject to institutional approval and data-use agreements. Requests to access the datasets should be directed to yucanqing@pku.edu.cn.

Ethics statement

The studies involving humans were approved by the Institutional Review Board of Peking University Health Science Center (IRB00001052-19077 approval date: 18 July 2019). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

ZW: Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft. CYa: Formal analysis, Methodology, Writing – review & editing. JL: Funding acquisition,

Writing – review & editing. SM: Writing – review & editing. YZ: Writing – review & editing. XW: Writing – review & editing. LL: Funding acquisition, Writing – review & editing. BW: Data curation, Resources, Writing – review & editing. CYu: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2026.1909713/full#supplementary-material

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