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Association between dietary diversity changes and frailty among Chinese older adults: findings from a nationwide cohort study

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Abstract

Background Dietary diversity has been suggested as a potential preventive measure against frailty in older adults, but the effect of changes in dietary diversity on frailty is unclear. This study was conducted to examine the association between the dietary diversity score (DDS) and frailty among older Chinese adults.

Methods A total of 12,457 adults aged 65 years or older were enrolled from three consecutive and nonoverlapping cohorts from the Chinese Longitudinal Healthy Longevity Survey (the 2002 cohort, the 2005 cohort, and the 2008 cohort). DDS was calculated based on nine predefined food groups, and DDS changes were assessed by comparing scores at baseline and the first follow-up survey. We used 39 self-reported health items to assess frailty. Cox proportional hazard models were performed to examine the association between DDS change patterns and frailty.

Results Participants with low-to-low DDS had the highest frailty incidence (111.1/1000 person-years), while high-to-high DDS had the lowest (41.1/1000 person-years). Compared to the high-to-high group of overall DDS pattern, participants in other DDS change patterns had a higher risk of frailty (HRs ranged from 1.25 to 2.15). Similar associations were observed for plant-based and animal-based DDS. Compared to stable DDS changes, participants with an extreme decline in DDS had an increased risk of frailty, with HRs of 1.38 (1.24, 1.53), 1.31 (1.19, 1.44), and 1.29 (1.16, 1.43) for overall, plant-based, and animal-based DDS, respectively.

Conclusions Maintaining a lower DDS or having a large reduction in DDS was associated with a higher risk of frailty among Chinese older adults. These findings highlight the importance of improving a diverse diet across old age for preventing frailty in later life.

Keywords Frailty, Dietary diversity changes, Older adults, Cohort study

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Introduction

With the noted increase in the average age of global populations, frailty in older people is gaining international attention [1]. Frailty is associated with an increased risk of adverse outcomes, such as falls, hospitalization, and mortality [2, 3], and effective treatments are currently lacking. Therefore, identifying possible modifiable protective and risk factors has become increasingly crucial for preventing and delaying the progression of frailty.

Diet has been identified as a key factor in preventing the development of frailty [4, 5]. Previous studies have highlighted the association between frailty and individual food groups, such as proteins, fruits and vegetables, and dairy products, as well as energy intake [6–8]. Recently, dietary patterns, such as the Healthy Eating Index (HEI), Diet Quality Index (DQI), Mediterranean Diet Score (MDS), and Dietary Approach to Stop Hypertension (DASH) diet score, have aroused particular interest worldwide. Increasing evidence showing that a high-quality diet may be associated with a lower risk of frailty [9–12].

Dietary diversity, which ensures an adequate intake of essential nutrients [13, 14], has been acknowledged as a critical component of high-quality diets and is advocated by dietary guidelines in numerous countries [15–17]. It is quantified by counting the consumption of different foods or food groups within a specified period [13]. Several cross-sectional [18–21] and prospective studies [22, 23] have shown the relationship between dietary variety and frailty. Moreover, our previous large-scale prospective cohort study of Chinese older adults demonstrated that higher dietary diversity scores (DDS) were associated with lower frailty risk [24]. However, considering potential fluctuations in the diet of participants during the follow-up, baseline dietary diversity as the relevant exposure may introduce some measurement errors [24]. Moreover, it is unclear how the DDS changes during follow-up affected the development of frailty.

Therefore, the aim of this study was to examine the association between DDS changes and frailty among Chinese older adults by using the Chinese Longitudinal Healthy Longevity Survey (CLHLS). We hope that these real data can reflect dynamic changes in the diet of Chinese older adults and provide reliable evidence for the formulation of dietary plans.

Materials and methods

Study setting and participants

The data were derived from the Chinese Longitudinal Healthy Longevity Survey (CLHLS), a large prospective cohort study of the Chinese population aged 65 years or over. For a more detailed description of the study design and data quality assessment can be referred to the published literature [25]. In brief, this survey began in 1998, follow-up surveys and recruitment of new participants in 2000, 2002, 2005, 2008/2009, 2011/2012, 2014, and 2017/2018. Using a multi-stage cluster sampling method, the CLHLS randomly recruit participants from 22 of 34 provinces in China, and the study covered 85% of the total population of China. The questionnaire information was collected by trained interviewers through face-to-face surveys, including family structure, living arrangement, self-rated health, self-rated life satisfaction, chronic diseases, diet, smoking status and alcohol consumption, physical activity, psychological characteristics, education, preretirement occupation, economic status, activities of daily living (ADL), instrumental activities of daily living (IADL), and cognitive function [24]. The CLHLS study was approved by the Biomedical Ethics Committee of Peking University (IRB00001052-13074) and written informed consent was provided by all participants or their proxy respondents.

Given that all items used to construct the frailty index (FI) were only included from the 2002 survey onwards, data from the 1998 and 2000 waves were excluded [24]. We assessed data from three consecutive and nonoverlapping cohorts from CLHLS cohorts: the 2002 cohort (waves from 2002, 2005, 2008 and 2011), the 2005 cohort (waves from 2005, 2008, 2011 and 2014) and the 2008 cohort (waves from 2008, 2011, 2014 and 2017). In each time period, the first wave was considered the baseline survey, the three subsequent waves were considered follow-up surveys. Out of a total of 33,009 participants, we excluded those who were below 65 years of age ($n=460$), with frailty at baseline ($n=11,542$), without follow-up measurements of frailty ($n=8474$), and had missing dietary data at baseline survey ($n=12$) or the first follow-up survey ($n=64$). Ultimately, 12,457 participants were included in the study. The flowchart of the participant enrollment process is shown in Figure S1.

Definitions of dietary diversity score change patterns

Dietary intake information was collected through a face-to-face interview, using a food frequency questionnaire that included several food items traditionally consumed in the Chinese diet, such as fresh fruits, fresh vegetables, beans, salted vegetables, garlic, tea, meat, fish, and eggs. Notably, garlic and salted vegetables, as traditional and prevalently consumed foods [26, 27], along with tea [28], a cornerstone of Chinese cultural expression, are considered independent food groups in the formulation of the DDS. The reproducibility and validity of the questionnaire have been confirmed in the Chinese population [29, 30]. Participants were asked about their current consumption frequency of the nine food groups, which were categorized into three categories: "almost every day" (coded as 2 point), "sometimes or occasionally" (coded as 1 point), or "rarely or never" (coded as 0 point) without consideration for minimum intake levels [31–33]. DDS is calculated by summing the scores of the above nine food groups, and previous studies have shown that this DDS is associated with various health outcomes in the Chinese elderly population [22, 24, 31, 34–37].

The DDS was calculated at baseline and the first follow-up survey. The overall DDS, plant-based DDS (including fresh fruits, fresh vegetables, beans, salted vegetables, garlic, and tea), and animal-based DDS (including meat, fish, and eggs) were scored from 0 to 18, 0 to 12, and 0 to 6, respectively [34]. We divided the overall DDS into three groups: high (13–18 points), middle (7–12 points), and low (0–6 points). Similarly, the plant-based DDS was divided into high (9–12 points), medium (5–8 points), and low (0–4 points) groups; and the animal-based DDS was divided into high (5–6 points), medium (3–4 points), and low (0–2 points) groups.

Nine patterns of relative changes in DDS were identified, including high-to-high, high-to-medium, high-to-low, medium-to-high, medium-to-medium, medium-to-low, low-to-high, low-to-medium, and low-to-low. Additionally, five patterns of absolute changes in DDS were defined using the DDS score changes from baseline to the first follow-up: stable (score of 0), extreme decline (score from "minimum" to "median between minimum and −1"), moderate decline (score from "median between minimum and −1" to -1), moderate improvement (score from 1 to "median between 1 and maximum"), and extreme improvement (score from "median between 1 and maximum" to "maximum") [31]. The specific score ranges of absolute change patterns for overall DDS, plant-based DDS, and animal-based DDS were provided in Table S1.

Ascertainment of frailty

The FI was constructed to evaluate the frailty status. Following the previous CLHLS study, we incorporated 39 health deficits, including self-reported health status, cognitive function, ADL, IADL, functional limitations, hearing and vision, mental health, chronic diseases, and interviewer-rated health status [24, 38, 39] (Table S2). Each item was dichotomous or ordinal variable, mapped to the interval 0 to 1 to indicate the severity of the health deficit. Participants were assigned a score of 2 if they had reported two or more serious illnesses in the previous 2 years. The FI was calculated as the number of health deficiencies present divided by the total number of measured included deficits, with the range from 0 to 1. For participants with missing data, we calculated the FI after removing these variables in the denominator and numerator. A higher FI indicated the worse the health status of the participants. We defined individuals with an FI ≥ 0.25 as frail [1, 38, 40]. The duration of the survival analysis was defined as the time from the baseline survey date to the first time that a participant developed frailty or the last assessment.

Assessment of covariates

A range of potential confounders and effect modifying variables were assessed and defined according to prior literature [31, 34, 41], including: age (year), sex (male or female), residence (rural or urban), occupation (farmer or others), education background (literate or illiterate), marital status (married or others), living pattern (with family members or alone/at nursing home), source of income (pension or others), sufficient income (yes or no), smoking status (current smoker, former smoker, or never smoker), drinking status (current drinker, former drinker, or non-drinker), regular exercise (yes or no), and body mass index (BMI; < 18.5, 18.5–23.9, or ≥24.0 kg/m^2). More detailed information on the covariates was shown in Method S1. Information on all covariates was collected using standardized and structured questionnaires during the baseline survey [42].

Statistical analysis

The characteristics of the study populations were presented as means (standard deviations [SD]) for continuous variables and numbers (percentages [%]) for categorical variables. The proportion of missing values for any individual covariates were less than 0.3% (Table S3). Multiple imputation were performed to reduce potential inference bias and increase statistical power [43].

Cox proportional hazards model was used to estimate hazard ratios (HRs) and 95% confidence intervals (95%CI) of DDS change patterns and frailty. We tested the proportional-hazards assumption by establishing a cross-product of the duration of follow-up and the pattern of change in DDS. Dose–response relationships of DDS change scores and frailty were analyzed using non-parametric restricted cubic spline regression with knots at the 25th, 50th, and 75th percentiles [44]. Two sets of models were used. Model 1 adjusted for baseline age and sex; model 2 further adjusted for residence, occupation, education background, marital status, living pattern, source of income, sufficient income, smoking status, drinking status, regular exercise, and BMI. Cox proportional hazard models were also performed to examine the relationship of frailty with nine major food groups, adjusted with referred covariates.

Subgroup analyses were conducted in participants with different baseline characteristics, including age (65–79, ≥80years), sex (male or female), residence (rural or urban), smoking status (current/former smoker or never smoker), drinking status (current/former drinker or non-drinker), and regular exercise (yes or no). Sensitivity analyses were also conducted to assess the robustness of the

Table 1 Baseline characteristics

	Overall (*n* = 12,457)	High-High(*n* = 568)	High-Medium (*n* = 1481)	High-Low (*n* = 173)	Medium-High (*n* = 1031)	Medium-Medium(*n* = 6209)	Medium-Low (*n* = 1421)	Low-High (*n* = 75)	Low-Medium (*n* = 1030)	Low-Low (*n* = 469)
Age, mean (SD), y	80.54 (10.75)	76.91 (9.97)	78.58 (10.56)	82.09 (10.81)	78.28 (10.18)	80.61 (10.74)	83.16 (10.90)	79.72 (10.08)	81.97 (10.59)	83.59 (10.24)
Sex										
Male	6071 (48.7)	386 (68.0)	833 (56.2)	85 (49.1)	590 (57.2)	3045 (49.0)	529 (37.2)	27 (36.0)	416 (40.4)	160 (34.1)
Female	6386 (51.3)	182 (32.0)	648 (43.8)	88 (50.9)	441 (42.8)	3164 (51.0)	892 (62.8)	48 (64.0)	614 (59.6)	309 (65.9)
Residence										
Rural	7391 (59.3)	193 (34.0)	700 (47.3)	107 (61.8)	482 (46.8)	3807 (61.3)	984 (69.2)	41 (54.7)	731 (71.0)	346 (73.8)
Urban	5066 (40.7)	375 (66.0)	781 (52.7)	66 (38.2)	549 (53.2)	2402 (38.7)	437 (30.8)	34 (45.3)	299 (29.0)	123 (26.2)
Occupation										
Farmer	7929 (63.7)	159 (28.0)	732 (49.4)	109 (63.0)	519 (50.3)	4169 (67.1)	1042 (73.3)	51 (68.0)	775 (75.2)	373 (79.5)
Others	4528 (36.3)	409 (72.0)	749 (50.6)	64 (37.0)	512 (49.7)	2040 (32.9)	379 (26.7)	24 (32.0)	255 (24.8)	96 (20.5)
Education background										
Literate	5602 (45.0)	411 (72.4)	857 (57.9)	77 (44.5)	582 (56.5)	2748 (44.3)	468 (32.9)	24 (32.0)	319 (31.0)	116 (24.7)
Illiterate	6855 (55.0)	157 (27.6)	624 (42.1)	96 (55.5)	449 (43.5)	3461 (55.7)	953 (67.1)	51 (68.0)	711 (69.0)	353 (75.3)
Marital status										
Married	5776 (46.4)	374 (65.8)	827 (55.8)	74 (42.8)	535 (51.9)	2847 (45.9)	509 (35.8)	28 (37.3)	413 (40.1)	169 (36.0)
Others	6681 (53.6)	194 (34.2)	654 (44.2)	99 (57.2)	496 (48.1)	3362 (54.1)	912 (64.2)	47 (62.7)	617 (59.9)	300 (64.0)
Living pattern										
With family members	10,247 (82.3)	523 (92.1)	1295 (87.4)	142 (82.1)	889 (86.2)	5130 (82.6)	1119 (78.7)	57 (76.0)	770 (74.8)	322 (68.7)
Alone or at nursing home	2210 (17.7)	45 (7.9)	186 (12.6)	31 (17.9)	142 (13.8)	1079 (17.4)	302 (21.3)	18 (24.0)	260 (25.2)	147 (31.3)
Source of income										
Pension	2643 (21.2)	326 (57.4)	508 (34.3)	28 (16.2)	351 (34.0)	1135 (18.3)	140 (9.9)	13 (17.3)	112 (10.9)	30 (6.4)
Others	9814 (78.8)	242 (42.6)	973 (65.7)	145 (83.8)	680 (66.0)	5074 (81.7)	1281 (90.1)	62 (82.7)	918 (89.1)	439 (93.6)
Income sufficient										
Yes	10,055 (80.7)	530 (93.3)	1325 (89.5)	151 (87.3)	886 (85.9)	5087 (81.9)	1100 (77.4)	55 (73.3)	644 (62.5)	277 (59.1)
No	2402 (19.3)	38 (6.7)	156 (10.5)	22 (12.7)	145 (14.1)	1122 (18.1)	321 (22.6)	20 (26.7)	386 (37.5)	192 (40.9)
Smoking status										
Current smoker	2929 (23.5)	160 (28.2)	403 (27.2)	45 (26.0)	289 (28.0)	1450 (23.4)	272 (19.1)	18 (24.0)	222 (21.6)	70 (14.9)
Former smoker	1712 (13.7)	122 (21.5)	235 (15.9)	25 (14.5)	159 (15.4)	825 (13.3)	170 (12.0)	13 (17.3)	114 (11.1)	49 (10.4)
Never smoker	7816 (62.7)	286 (50.4)	843 (56.9)	103 (59.5)	583 (56.5)	3934 (63.4)	979 (68.9)	44 (58.7)	694 (67.4)	350 (74.6)
Drinking status										
Current drinker	3010 (24.2)	198 (34.9)	445 (30.0)	44 (25.4)	293 (28.4)	1476 (23.8)	280 (19.7)	13 (17.3)	195 (18.9)	66 (14.1)

Table 1 (continued)

	Overall (n = 12,457)	High-High(n = 568)	High-Medium (n = 1481)	High-Low (n = 173)	Medium-High (n = 1031)	Medium-Medium(n = 6209)	Medium-Low (n = 1421)	Low-High (n = 75)	Low-Medium (n = 1030)	Low-Low (n = 469)
Former drinker	1188 (9.5)	50 (8.8)	150 (10.1)	18 (10.4)	110 (10.7)	598 (9.6)	113 (8.0)	14 (18.7)	97 (9.4)	38 (8.1)
Never drinker	8259 (66.3)	320 (56.3)	886 (59.8)	111 (64.2)	628 (60.9)	4135 (66.6)	1028 (72.3)	48 (64.0)	738 (71.7)	365 (77.8)
Regular exercise										
Yes	4721 (37.9)	360 (63.4)	751 (50.7)	83 (48.0)	477 (46.3)	2214 (35.7)	427 (30.0)	19 (25.3)	270 (26.2)	120 (25.6)
No	7736 (62.1)	208 (36.6)	730 (49.3)	90 (52.0)	554 (53.7)	3995 (64.3)	994 (70.0)	56 (74.7)	760 (73.8)	349 (74.4)
BMI										
Low	4358 (35.0)	94 (16.5)	421 (28.4)	69 (39.9)	308 (29.9)	2155 (34.7)	589 (41.4)	31 (41.3)	456 (44.3)	235 (50.1)
Normal	6290 (50.5)	296 (52.1)	772 (52.1)	80 (46.2)	534 (51.8)	3214 (51.8)	687 (48.3)	36 (48.0)	480 (46.6)	191 (40.7)
High	1809 (14.5)	178 (31.3)	288 (19.4)	24 (13.9)	189 (18.3)	840 (13.5)	145 (10.2)	8 (10.7)	94 (9.1)	43 (9.2)

BMI, body mass index; SD, standard deviation

BMI(Low: <18.5 kg/m^2; Normal: 18.5 kg/m^2-23.9 kg/m^2; High: ≥24.0 kg/m^2)

results:1) excluding participants who developed frailty in the first follow-up survey; 2) excluding those with missing covariates; 3) additionally adjusting for the number of teeth and the use of artificial dentures; 4) additionally adjusting for the year of recruitment.

All statistical analyses were performed with the use of R software, version 4.0.0 (R Development Core Team, Vienna, Austria). A two-sided P value of less than 0.05 was considered statistically significant.

Results

Baseline characteristics of the participants

Among 12,457 participants, 48.7% were male, and the mean age was 80.54 years (SD, 10.75). In the nine patterns of relative changes of DDS, the medium-to-medium group had the largest number of people (6,209, 49.84%), while the low-to-high group had the least number of people (75, 0.60%). Participants with high-to-high patterns tended to be male, live in urban areas, have non-farming occupations, be literate, married, live with family members, have a pension, have sufficient income, never smoke or drink, engage in regular exercise, and have normal BMI (Table 1).

Association between DDS change and frailty

Figure 1 presents the association between the DDS change patterns and the risk of frailty. Among the 12,457 participants, the high-to-high DDS change pattern had the lowest incidence of frailty at 41.1 per 1000 person-years, whereas the low-to-low DDS change pattern had the highest incidence of frailty at 111.1 per 1000 person-years. Compared to those with a high-to-high of overall DDS pattern, participants in the high-to-medium, high-to-low, medium-to-high, medium-to-medium, medium-to-low, low-to-medium, and low-to-low groups had a higher risk of frailty, with HRs (95%CI) of 1.44 (1.19, 1.75), 2.13 (1.62, 2.80), 1.25 (1.02, 1.54), 1.40 (1.18, 1.67), 1.90 (1.57, 2.29), 1.64 (1.34, 2.00), and 2.15 (1.73, 2.66), respectively. The relationships between plant-based DDS and animal-based DDS and frailty were similar to the overall DDS (Fig. 1). Compared with the high-to-high plant-based DDS pattern, the high-to-medium, high-to-low, medium-to- medium, medium-to-low, low-to-medium, and low-to-low patterns had a higher risk of frailty, with HRs (95%CI) of 1.33 (1.07, 1.65), 2.20 (1.71, 2.84), 1.39 (1.14, 1.69), 1.67 (1.37, 2.05), 1.46 (1.19, 1.81), and 1.70 (1.37, 2.11), respectively. For animal-based DDS, compared to the high-to-high pattern, the high-to-medium, high-to-low, medium-to-low, low-to-medium, and low-to-low patterns had a higher risk of frailty, with HRs (95%CI) of 1.17 (1.02, 1.36), 1.41 (1.16, 1.71), 1.40 (1.21, 1.62), 1.24 (1.07, 1.44), and 1.55 (1.33, 1.80), respectively.

In addition, we examined the associations between special food consumption and the risk of frailty (Table 2). Compared to those who always-to-always consumed specific foods, participants who never-to-never consumed fresh fruit, fresh vegetables, garlic, tea, meat, and fish had a higher risk of frailty, with HRs (95% CI) of 1.31 (1.07, 1.59), 2.53 (1.43, 4.48), 1.38 (1.19, 1.60), 1.30 (1.18, 1.43), 1.86 (1.62, 2.14), and 1.32 (1.13, 1.54), respectively (Table 2).

Figure S2 illustrates the dose-response relationship between DDS change scores and frailty risk. In general, the degree of DDS decline was positively associated with the risk of frailty compared to stable (score change of 0)

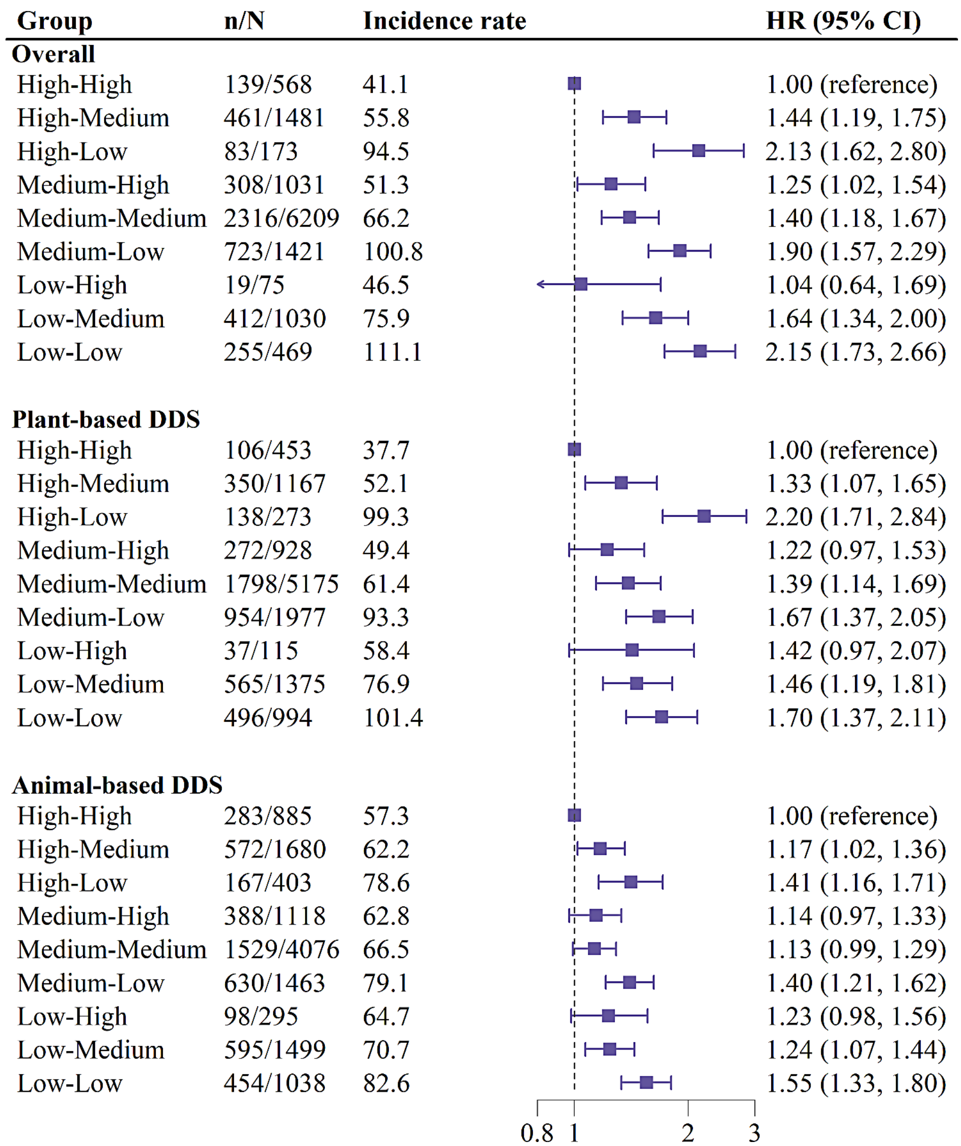

Fig. 1 The association between the dietary diversity score change patterns and frailty. HR, hazard ratio; CI, confidence interval. The model Adjusted for age, sex, residence, occupation, education background, marital status, living pattern, source of income, sufficient income, smoking status, drinking status, regular exercise, and BMI

in overall DDS, plant-based DDS, and animal-based DDS. An increase in plant-based DDS was not significantly associated with the risk of frailty, whereas an increase in overall DDS exceeding 7 points or an increase in animal-based DDS exceeding 2 points was gradually associated with an increased risk of frailty (Figure S2). Moreover, we assessed the association of absolute patterns of DDS change with frailty (Fig. 2). Compared to participants with stable DDS changes, those with an extreme decline in DDS had an increased risk of frailty, with HRs of 1.38 (1.24, 1.53), 1.31 (1.19, 1.44), and 1.29 (1.16, 1.43) for overall, plant-based, and animal-based DDS, respectively. The extreme increase in animal-based DDS was also associated with an increased risk of frailty, with an HR of 1.12 (1.03, 1.23) (Fig. 2).

Subgroup and sensitivity analyses

The associations between DDS change patterns and frailty remained consistent when stratified by age group, sex, residence, smoking status, drinking status, and regular exercise, with no significant interaction (all P for interactions > 0.00625; Table 3). Sensitivity analyses were robust, showing no significant changes after excluding participants who developed frailty in the first follow-up survey (Figure S3) or those with missing covariates (Figure S4). Additionally, adjusting for the number of teeth and the use of artificial dentures (Figure S5), as well as

Table 2 Associations between changes in dietary diversity scores and frailty (classification by food groups)

	Always-Always	Always-Sometimes	Always-Never	Sometimes-Always	Sometimes-Sometimes	Sometimes-Never	Never-Always	Never-Sometimes	Never-Never
Fresh fruit									
n/N	135/448	272/784	90/190	284/830	1874/5366	875/1920	61/165	621/1617	504/1137
HR (95%CI) [model 1]	1.00 (reference)	1.00 (0.82, 1.23)	1.36 (1.04, 1.78)	0.87 (0.71, 1.06)	0.89 (0.75, 1.06)	1.11 (0.92, 1.33)	1.05 (0.77, 1.42)	1.00 (0.83, 1.20)	1.15 (0.95, 1.39)
HR (95%CI) [model 2]	1.00 (reference)	1.07 (0.87, 1.32)	1.43 (1.10, 1.88)	0.93 (0.75, 1.14)	1.00 (0.83, 1.20)	1.26 (1.04, 1.52)	1.14 (0.84, 1.55)	1.13 (0.93, 1.37)	1.31 (1.07, 1.59)
Fresh vegetable									
n/N	1389/4332	1136/2853	111/188	873/2343	972/2330	122/185	44/91	57/119	12/16
HR (95%CI) [model 1]	1.00 (reference)	1.23 (1.14, 1.33)	1.96 (1.62, 2.38)	1.07 (0.98, 1.17)	1.26 (1.16, 1.37)	2.00 (1.66, 2.41)	1.47 (1.09, 1.98)	1.25 (0.96, 1.62)	2.37 (1.34, 4.19)
HR (95%CI) [model 2]	1.00 (reference)	1.26 (1.16, 1.36)	2.02 (1.67, 2.46)	1.09 (1.00, 1.18)	1.29 (1.19, 1.40)	2.03 (1.68, 2.44)	1.48 (1.10, 2.01)	1.28 (0.98, 1.67)	2.53 (1.43, 4.48)
Beans									
n/N	572/1735	843/2224	202/502	480/1395	1552/4019	395/946	139/325	365/917	168/394
HR (95%CI) [model 1]	1.00 (reference)	0.94 (0.84, 1.04)	1.10 (0.94, 1.30)	0.97 (0.86, 1.09)	0.82 (0.75, 0.91)	0.91 (0.80, 1.04)	1.20 (1.00, 1.45)	0.97 (0.85, 1.10)	0.97 (0.82, 1.16)
HR (95%CI) [model 2]	1.00 (reference)	0.96 (0.87, 1.07)	1.14 (0.97, 1.33)	0.98 (0.86, 1.10)	0.87 (0.79, 0.96)	0.98 (0.86, 1.12)	1.22 (1.01, 1.47)	1.03 (0.90, 1.18)	1.03 (0.87, 1.23)
Salted vegetable									
n/N	359/1119	452/1335	423/1048	288/855	633/1770	692/1722	212/573	588/1565	1069/2470
HR (95%CI) [model 1]	1.00 (reference)	1.00 (0.87, 1.15)	1.20 (1.04, 1.38)	0.98 (0.84, 1.14)	0.96 (0.84, 1.09)	0.96 (0.84, 1.09)	0.96 (0.81, 1.14)	0.96 (0.84, 1.10)	1.08 (0.96, 1.22)
HR (95%CI) [model 2]	1.00 (reference)	1.02 (0.89, 1.17)	1.20 (1.04, 1.38)	0.98 (0.84, 1.15)	0.97 (0.85, 1.11)	0.97 (0.85, 1.10)	0.95 (0.80, 1.13)	0.98 (0.86, 1.12)	1.09 (0.97, 1.23)
Garlic									
n/N	228/841	431/1268	289/600	367/1145	1049/2835	764/1744	188/560	629/1692	771/1772
HR (95%CI) [model 1]	1.00 (reference)	1.21 (1.03, 1.42)	1.52 (1.28, 1.81)	1.10 (0.93, 1.30)	1.14 (0.99, 1.32)	1.32 (1.14, 1.54)	1.22 (1.00, 1.48)	1.17 (1.00, 1.36)	1.35 (1.16, 1.57)
HR (95%CI) [model 2]	1.00 (reference)	1.25 (1.07, 1.47)	1.58 (1.33, 1.88)	1.12 (0.95, 1.32)	1.19 (1.03, 1.37)	1.36 (1.17, 1.58)	1.23 (1.01, 1.49)	1.20 (1.03, 1.40)	1.38 (1.19, 1.60)
Tea									

Table 2 (continued)

	Always-Always	Always-Sometimes	Always-Never	Sometimes-Always	Sometimes-Sometimes	Sometimes-Never	Never-Always	Never-Sometimes	Never-Never
n/N	587/2071	275/769	525/1265	230/699	182/559	446/1030	298/911	396/1015	1777/4138
HR (95%CI) [model 1]	1.00 (reference)	1.37 (1.18, 1.58)	1.39 (1.24, 1.57)	1.16 (1.00, 1.35)	1.12 (0.95, 1.32)	1.30 (1.14, 1.47)	1.17 (1.02, 1.35)	1.32 (1.16, 1.50)	1.26 (1.14, 1.38)
HR (95%CI) [model 2]	1.00 (reference)	1.37 (1.19, 1.58)	1.42 (1.26, 1.60)	1.16 (0.99, 1.35)	1.15 (0.98, 1.36)	1.35 (1.19, 1.53)	1.18 (1.03, 1.36)	1.35 (1.18, 1.53)	1.30 (1.18, 1.43)
Meat									
n/N	822/2466	684/1874	162/385	603/1632	1262/3380	406/900	120/314	385/937	272/569
HR (95%CI) [model 1]	1.00 (reference)	1.26 (1.14, 1.40)	1.64 (1.39, 1.94)	1.15 (1.04, 1.28)	1.13 (1.03, 1.23)	1.60 (1.42, 1.80)	1.45 (1.20, 1.76)	1.45 (1.28, 1.64)	1.84 (1.60, 2.11)
HR (95%CI) [model 2]	1.00 (reference)	1.27 (1.15, 1.41)	1.66 (1.40, 1.96)	1.19 (1.07, 1.32)	1.17 (1.07, 1.28)	1.64 (1.46, 1.86)	1.44 (1.19, 1.75)	1.49 (1.32, 1.68)	1.86 (1.62, 2.14)
Fish									
n/N	220/743	518/1498	143/343	288/831	1603/4417	664/1481	86/246	595/1529	599/1369
HR (95%CI) [model 1]	1.00 (reference)	1.11 (0.95, 1.30)	1.38 (1.12, 1.70)	1.04 (0.88, 1.24)	1.02 (0.88, 1.17)	1.21 (1.03, 1.40)	1.01 (0.79, 1.30)	1.06 (0.91, 1.24)	1.25 (1.07, 1.46)
HR (95%CI) [model 2]	1.00 (reference)	1.13 (0.96, 1.32)	1.43 (1.16, 1.77)	1.04 (0.88, 1.25)	1.07 (0.93, 1.24)	1.28 (1.09, 1.49)	1.04 (0.81, 1.34)	1.12 (0.96, 1.31)	1.32 (1.13, 1.54)
Egg									
n/N	972/2571	821/2187	177/438	617/1599	1147/3145	353/823	151/426	315/849	163/419
HR (95%CI) [model 1]	1.00 (reference)	0.95 (0.86, 1.04)	1.07 (0.91, 1.26)	0.97 (0.88, 1.07)	0.83 (0.76, 0.91)	0.99 (0.87, 1.12)	1.09 (0.92, 1.29)	0.97 (0.85, 1.10)	1.08 (0.91, 1.27)
HR (95%CI) [model 2]	1.00 (reference)	0.97 (0.89, 1.07)	1.08 (0.92, 1.27)	0.98 (0.88, 1.08)	0.86 (0.79, 0.94)	1.03 (0.91, 1.17)	1.08 (0.91, 1.29)	1.01 (0.89, 1.15)	1.11 (0.94, 1.31)

CI, confidence interval; HR, hazard ratio

Model 1: Adjusted for age and sex

Model 2: Adjusted for age, sex, residence, occupation, education background, marital status, living pattern, source of income, sufficient income, smoking status, drinking status, regular exercise, and BMI

adjusting for the year of recruitment (Figure S6) did not substantially alter the results.

Discussion

In this large cohort study of Chinese older adults, maintaining a low level of overall DDS was significantly associated with an increased risk of frailty. This association also existed in both plant-based and animal-based DDS. Furthermore, an extreme decline in overall DDS was associated with a 38% increased risk of frailty. We adjusted for a range of confounding factors and conducted subgroup and sensitivity analyses, which increased the reliability of our results.

Over recent years, more attention has been devoted to the relationship between dietary patterns and frailty, rather than focusing on single food groups such as protein, fruits, vegetables, dairy products. Previous studies examining the relationship between dietary patterns (including HEI, DQI, MDS, and DASH dietary scores) and frailty found that higher diet quality scores were

Group	n/N	Incidence rate	HR (95% CI)
Overall			
Extreme decline	1044/2382	83.1	1.38 (1.24, 1.53)
Moderate decline	1447/3819	68.1	1.10 (0.99, 1.22)
Stable	505/1446	62.6	1.00 (reference)
Moderate improvement	917/2513	64.3	1.07 (0.96, 1.19)
Extreme improvement	803/2297	63.4	1.11 (0.99, 1.24)
Plant-based DDS			
Extreme decline	1110/2515	83.8	1.31 (1.19, 1.44)
Moderate decline	1319/3449	68.9	1.05 (0.96, 1.15)
Stable	691/1928	64	1.00 (reference)
Moderate improvement	1046/2983	61.9	1.00 (0.91, 1.10)
Extreme improvement	550/1582	62.9	1.02 (0.92, 1.15)
Animal-based DDS			
Extreme decline	493/1182	78.2	1.29 (1.16, 1.43)
Moderate decline	1446/3746	70.2	1.10 (1.02, 1.19)
Stable	1188/3270	65	1.00 (reference)
Moderate improvement	813/2175	66.2	0.97 (0.89, 1.06)
Extreme improvement	776/2084	68.4	1.12 (1.03, 1.23)

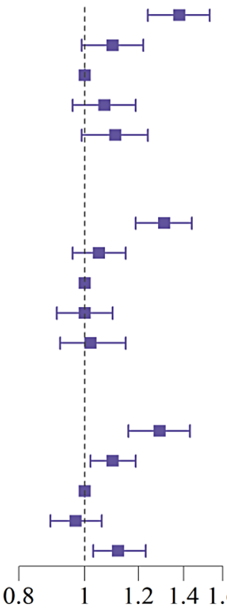

Fig. 2 The association between the absolute patterns of dietary diversity score change and frailty. HR, hazard ratio; CI, confidence interval. Absolute DDS change patterns: stable (score of 0), extreme decline (score from "minimum" to "median between minimum and – 1"), moderate decline (score from "median between minimum and – 1" to -1), moderate improvement (score from 1 to "median between 1 and maximum"), and extreme improvement (score from "median between 1 and maximum" to "maximum"). The model Adjusted for age, sex, residence, occupation, education background, marital status, living pattern, source of income, sufficient income, smoking status, drinking status, regular exercise, and BMI

associated with a lower risk of frailty [9–12]. However, measuring the above diet quality scores may be difficult, and DDS may be a more feasible option without requiring quantitative measurement. Moreover, evidence regarding the links between DDS change and frailty in older adults is rather sparse. Therefore, focused on the population of Chinese older adult, the present study expands on our earlier research, examined the association between baseline DDS and frailty [24], and found that maintaining a low level DDS was associated with an increased risk of frailty in subsequent years among older adults.

Previous studies have found that lowering or maintaining a lower DDS increases the risk of cognitive impairment and all-cause mortality [31, 34]. Our study is the first to demonstrate a relationship between changes in DDS and frailty in the older population. This finding may be explained by the fact that a higher DDS might indicate a high-quality diet, which is a proxy and rapid indicator of nutrient adequacy. Increasing the variety of foods in the diet is strongly associated with adequate nutritional intake [45, 46]. Lowering or maintaining a lower DDS can increases the odds of nutrient deficiencies, especially in older adults, and malnutrition and multiple nutrient deficiencies or a single diet may be associated with frailty [47–49]. Our study suggested that maintaining a higher dietary diversity, even after older age can still reduce the risk of frailty, which has important public health implications for older Chinese adults.

In addition, maintaining a lower intake of these foods, including fresh fruit, fresh vegetables, garlic, tea, meat, and fish, was associated with a higher risk of frailty. The possible mechanism is that fresh fruits, fresh vegetables, and teas contain high levels of antioxidants, which can prevent frailty by reducing reactive oxygen species, and garlic has been demonstrated to prevent osteoporosis and its active component allicin has various biological activities including antioxidant, anti-inflammatory, and anti-apoptotic effects [50, 51]. Moreover, meat and fish contain high-quality protein, which can help prevent or delay age-related muscle atrophy, and affect the development of frailty [52] 53. These findings emphasize the importance of maintaining a varied diet for the long-term health of older adults.

We also conducted analyses of plant-based and animal-based DDS changes and observed similar patterns to the main findings. Interestingly, we found that an extreme improvement in animal-based DDS was associated with an increased risk of frailty, a correlation not observed with plant-based DDS. A possible explanation includes that an extreme improvement in animal-based DDS primarily reports a transition from low-to-high and low-to-medium DDS within animal food groups, and it may also be associated with a lower intake of plant products rich in antioxidants, thereby contributing to the development of frailty [50, 51].

Table 3 Subgroup analysis of the association between the dietary diversity score change patterns and frailty

	High-High	High-Medium	High-Low	Medium-High	Medium-Medium	Medium-Low	Low-High	Low-Medium	Low-Low	Interaction *P* value
Age (years)										0.01
< 80	1.00 (reference)	1.10 (0.80, 1.51)	2.06 (1.23, 3.46)	1.18 (0.85, 1.64)	1.41 (1.06, 1.88)	2.15 (1.56, 2.96)	0.65 (0.20, 2.08)	1.59 (1.12, 2.26)	2.19 (1.47, 3.25)	
≥ 80	1.00 (reference)	1.60 (1.26, 2.04)	2.13 (1.53, 2.97)	1.26 (0.97, 1.63)	1.37 (1.09, 1.71)	1.84 (1.46, 2.33)	1.14 (0.66, 1.95)	1.62 (1.26, 2.07)	2.06 (1.59, 2.68)	
Sex										0.04
Male	1.00 (reference)	1.53 (1.19, 1.98)	2.63 (1.76, 3.93)	1.36 (1.03, 1.78)	1.67 (1.32, 2.10)	2.23 (1.72, 2.90)	0.93 (0.38, 2.31)	1.97 (1.48, 2.62)	3.11 (2.27, 4.27)	
Female	1.00 (reference)	1.22 (0.91, 1.63)	1.57 (1.07, 2.32)	1.06 (0.78, 1.43)	1.08 (0.82, 1.41)	1.47 (1.11, 1.95)	0.93 (0.52, 1.68)	1.27 (0.95, 1.70)	1.54 (1.13, 2.10)	
Residence										0.85
Rural	1.00 (reference)	1.35 (0.98, 1.86)	2.16 (1.44, 3.22)	1.26 (0.91, 1.76)	1.42 (1.06, 1.91)	1.90 (1.40, 2.58)	0.82 (0.40, 1.68)	1.69 (1.23, 2.31)	2.30 (1.65, 3.19)	
Urban	1.00 (reference)	1.49 (1.17, 1.89)	2.04 (1.36, 3.05)	1.24 (0.96, 1.61)	1.36 (1.09, 1.70)	1.91 (1.48, 2.45)	1.38 (0.72, 2.67)	1.57 (1.19, 2.08)	1.89 (1.37, 2.60)	
Smoking status										0.06
Current or Former smoker	1.00 (reference)	1.70 (1.25, 2.31)	3.01 (1.91, 4.74)	1.53 (1.11, 2.11)	1.83 (1.38, 2.41)	2.76 (2.04, 3.74)	0.98 (0.42, 2.30)	1.94 (1.39, 2.72)	2.98 (2.06, 4.31)	
Never smoker	1.00 (reference)	1.24 (0.97, 1.59)	1.65 (1.17, 2.34)	1.05 (0.81, 1.37)	1.14 (0.91, 1.43)	1.47 (1.16, 1.87)	1.02 (0.57, 1.83)	1.38 (1.08, 1.78)	1.72 (1.31, 2.25)	
Drinking status										0.57
Current or Former drinker	1.00 (reference)	1.56 (1.13, 2.15)	2.84 (1.80, 4.48)	1.31 (0.93, 1.84)	1.63 (1.21, 2.19)	2.10 (1.52, 2.90)	1.35 (0.66, 2.77)	1.79 (1.26, 2.55)	2.85 (1.93, 4.22)	
Never drinker	1.00 (reference)	1.36 (1.07, 1.73)	1.80 (1.28, 2.55)	1.21 (0.94, 1.56)	1.28 (1.03, 1.59)	1.76 (1.40, 2.22)	0.88 (0.46, 1.70)	1.53 (1.20, 1.96)	1.90 (1.46, 2.46)	
Regular exercises										0.84
Yes	1.00 (reference)	1.33 (1.04, 1.71)	1.80 (1.22, 2.65)	1.22 (0.93, 1.59)	1.38 (1.10, 1.73)	1.80 (1.39, 2.34)	1.23 (0.54, 2.81)	1.49 (1.11, 1.99)	2.23 (1.59, 3.11)	
No	1.00 (reference)	1.57 (1.16, 2.13)	2.55 (1.70, 3.83)	1.32 (0.96, 1.80)	1.46 (1.10, 1.94)	2.01 (1.50, 2.70)	1.02 (0.55, 1.88)	1.77 (1.31, 2.40)	2.20 (1.60, 3.02)	

The multivariate Cox regression model was adjusted for age, sex, residence, occupation, education background, marital status, living pattern, source of income, sufficient income, smoking status, drinking status, regular exercise, and BMI

The strengths of this study include a prospective design, large sample size, long-term follow-up, repeated assessment of diet, and the robustness of results, supported by subgroup and sensitivity analyses. However, there were several limitations with regard to the study design and measurements in this study. Firstly, detailed quantitative dietary intake assessments were not performed, so we were unable to adjust for energy intake in our analyses. However, some key determinants of energy intake were considered, such as age, sex, BMI, economic situation, and lifestyle. Secondly, there is no direct evidence that this Chinese culture-based DDS reflects rich nutrient intake. However, previous studies have also shown that higher scores on this DDS are associated with a lower risk of adverse outcomes in the Chinese elderly population [22, 24, 31, 34–37]. Thirdly, despite carefully adjusting for a series of confounders, residual and unmeasured confounders may still be present. Fourthly, due to the observational design, a causal relationship cannot be established. Fifthly, although we conducted sensitivity analyses by excluding participants who developed frailty at the first follow-up, reverse causation may still exist. Finally, despite the findings might have important public health implications, the results may not be generalizable to other populations or countries given the unique characteristics of the study participants and the differences between Chinese and Western diets.

Conclusions

Among Chinese older adults, maintaining a lower DDS was associated with a higher risk of frailty, and a large reduction in DDS may significantly increase the risk of frailty. These findings highlight that maintaining a higher dietary diversity can still reduce frailty risk even after old age, which has important public health implications for older Chinese.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12937-024-00997-3.

Supplementary Material 1

Author contributions

X-MW and W-FZ contributed to the statistical analyses, and had primary responsibility for writing the manuscript. CM and X-MS directed the study, revised the article critically for important intellectual content, and determined the final version to be submitted. X-MW, W-FZ, Y-TZ, J-XX, HC, Z-HL, Q-QS, DS, W-QS, QF, and JG contributed to the data cleaning. X-MW, W-FZ, Y-TZ, Z-TC, CL, J-HX, DL and Y-BL contributed to the analysis or interpretation of the data. All authors critically reviewed the manuscript for important intellectual content.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The study was conducted with the ethical approval of the Biomedical Ethics Committee of Peking University (IRB00001052-13074).

Competing interests

The authors declare no competing interests.

Consent for publication

Informed consent was obtained from all subjects involved in the study.

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