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The relation between BMR and Sarcopenia in middle-aged and older Chinese: A latent class growth model analysis and cohort study based on CHARLS

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Article

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Abstract

Background

Sarcopenia is an age-related syndrome characterized by progressive loss of muscle mass and function. Basal Metabolic Rate (BMR) may play a role in its pathogenesis, but evidence from longitudinal studies with dynamic BMR trajectories is limited.

Objective

To investigate the cross-sectional and longitudinal associations between BMR and sarcopenia in middle-aged and older Chinese adults, and to identify distinct BMR trajectories over time using latent class growth modeling.

Methods

Data from 6,348 participants aged ≥ 45 years in the China Health and Retirement Longitudinal Study (CHARLS) from 2011 to 2015 were analyzed. BMR was estimated using the Harris-Benedict equation. Sarcopenia was defined according to the AWGS2025 criteria. Latent class growth models (LCGM) were used to identify BMR trajectories. Multivariate logistic regression examined associations between BMR and sarcopenia.

Results

Three distinct BMR trajectories were identified: persistently low (Class 1, 35.9%), decreasing (Class 2, 48.1%), and persistently high (Class 3, 16.0%). Cross-sectional analysis showed BMR was significantly inversely associated with sarcopenia (OR = 0.97, 95%CI:0.97–0.98, p < 0.001). Longitudinal analysis confirmed baseline BMR predicted future sarcopenia risk (OR = 0.99, 95%CI:0.99–0.99, p < 0.001). Compared with Class 1, sarcopenia risk was reduced by 21.7% in Class 2 and 28.4% in Class 3 after full adjustment.

Conclusion

Lower BMR and declining BMR trajectory are independently associated with increased sarcopenia risk in middle-aged and older Chinese adults. Monitoring dynamic BMR changes may help identify high-risk populations for early intervention.

Background

Sarcopenia is a syndrome that occurs with aging and involves progressive deterioration of skeletal muscle mass and function. Its pathological features include reduced muscle fiber volume and muscle fat infiltration [1]. It was first proposed by Rosenberg [2]. According to research reports, the prevalence of sarcopenia among people aged 60 and above worldwide is 10% to 27% [3]. It is estimated that the number of people with sarcopenia will reach 500 million by 2050. Numerous studies have shown that sarcopenia is associated with various clinical adverse outcomes: it increases the risk of falls and dependence on daily living abilities for patients; increases the risk of disability; prolongs the length of hospital stay and the probability of readmission; and raises the 5-year all-cause mortality rate of patients [4, 5, 6], imposing a huge burden on patients, families, and society.

Basal Metabolic Rate (BMR) refers to the minimum energy expenditure required to maintain basic life functions (such as breathing, blood circulation, and cell repair) at rest [7]. Current evidence indicates that BMR is a key physiological factor related to sarcopenia in the elderly population [8]. As people age, the loss of muscle mass and function becomes increasingly common. In a cross-sectional survey involving 305 elderly men, it was found that the BMR of the sarcopenia and frailty groups decreased more significantly [9]. In multiple clinical studies, it has been discovered that BMR is associated with other clinical diseases, such as cognitive dysfunction and depression [7, 10], and sarcopenia acts as a mediator. However, the direct association between BMR and sarcopenia has not yet been clearly studied. Some research suggests that BMR may help predict sarcopenic obesity and the high risk of sarcopenia, but the sample size included was small (n = 402) [11]. A large cohort study in South Korea (n = 163,133) found that energy intake/BMR and physical activity were negatively correlated with the risk of sarcopenia [12]. In Iranian postmenopausal women, it was shown that a low BMR may be an early predictor of osteoporosis and sarcopenia in postmenopausal women [13]. Additionally, the connection between BMR and sarcopenia is influenced by factors such as physical exercise and nutrition. Studies have shown that exercise, especially the intake of sufficient energy, can increase BMR and reduce the risk of sarcopenia, especially in the elderly [8].

These findings highlight the significance of BMR as a key indicator of metabolic health. Abnormal changes in BMR can serve as early warning signals for various diseases, and they have particular clinical value in the co-morbidity mechanisms of sarcopenia, metabolic syndrome, and neuropsychiatric disorders. However, existing studies mainly focused on the direct association between BMR and sarcopenia, and few studies focused on the impact of dynamic changes in BMR on sarcopenia. This research aims to explore the dynamic association between BMR and sarcopenia and construct latent class trajectory models to effectively distinguish the effects of different development trajectories of BMR on sarcopenia, providing a practical basis for differentiating between the "accelerated loss" and "slow progression" groups of muscle mass in sarcopenia research.

Meterials and Methods

Ethical approval

The clinical information used in this study was all publicly available from public databases. It represents a secondary utilization of the original data and has received ethical exemption approval from the Ethics Committee of the First People's Hospital of Jiashan. This secondary analysis was conducted in accordance with the Declaration of Helsinki.

Study design and population

CHARLS is a nationally representative longitudinal survey targeting Chinese individuals aged 45 and above, along with their spouses. This survey collected high-quality data reflecting the current situation of the Chinese middle-aged and elderly population through a multi-stage proportional sampling method. The study covered 150 counties within 28 provinces, encompassing 450 communities, totaling 17,000 people. Data collection was conducted through face-to-face interviews [14]. The collected data were updated through biennial follow-ups combined with questionnaires and physical measurements. Access to the original data: http://charls.pku.edu.cn. The Biomedical Ethics Committee of Peking University approved this work (IRB00001052-11014/11015), and obtained the informed consent of the participants.

The above data cover the participants' socioeconomic status, social activities, and various indicators related to the BMR index and sarcopenia. We selected the data from CHARLS from 2011 to 2015 (waves 1 to 3) as the analytical data for this study. We took wave 1 (2011) as the baseline data and wave 3 (2015) as the assessment point for evaluating the dynamic changes of BMR and their impact on the outcome of sarcopenia.

Assessments

Basal Metabolic Rate

BMR was estimated using the Harris-Benedict equations [15], formulated as:

Men : BMR = 88.362 + (13.397*Weight) + (4.799*Height)-(5.677*Age)

Women: BMR= 447.593 + (9.247*Weight) + (3.098*Height) - (4.330*Age)

Assessment of Sarcopenia

The 2025 Asian Working Group on Sarcopenia (AWGS2025) criteria [15] removed functional indicators such as gait speed. The 2025 Asian Working Group on Sarcopenia (AWGS2025) criteria [15] removed functional indicators such as gait speed. Sarcopenia can be diagnosed when both "low muscle mass" and "low muscle strength" are present. Sarcopenia can be diagnosed when both "low muscle mass" and "low muscle strength" are present. At the same time, physical function indicators (including gait speed, 5-times sit-to-stand test, and the Simple Physical Performance Status Scale) are classified as outcome indicators rather than diagnostic indicators [15].

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The criterion for physical impairment is: walking speed below 1.The criterion for physical impairment is: walking speed below 1.0 m/s, requiring 12 seconds or more to complete 5 chair stands, or a SPPB total score of 9 or lower [16].

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The scapular muscle mass (ASM) is used as an estimate of the total muscle mass. The scapular girdle muscle mass (ASM) is used as an estimate of the total muscle mass. It is calculated using previously validated and applied anthropometric equation formulas [17, 18]. It is calculated using previously validated and applied anthropometric equation formulas [17, 18]. Studies have shown that in Chinese individuals, the ASM obtained using this equation formula is highly consistent with the ASM obtained by dual-energy X-ray absorptiometry (DXA) in the Chinese population [19]. Studies have shown that in Chinese individuals, the ASM obtained using this equation formula is highly consistent with the ASM obtained by dual-energy X-ray absorptiometry (DXA) in the Chinese population [19].

ASM=0.193 * weight (kg)+0.107*height (cm) −4.157 *sex (1=Men, 2=Women) −0.037 *age (years) −2.631

Control variables

The demographic variables include age (< 65 years, ≥ 65 years), gender (male/female), marital status (married/unmarried), smoking status (current/never), drinking (yes/no), depression status (yes/no), moderate physical exercise (yes/no), education (< high school, high school, ≥ university), and chronic diseases including hypertension (yes/no) and diabetes (yes/no).

Statistical methods

Descriptive statistics are used to summarize the sample characteristics: continuous variables are expressed as mean ± standard deviation (SD), and categorical variables are expressed as frequency and percentage. Spearman correlation analysis is used to evaluate the pairwise association between variables. All analyses are stratified by gender.

In inferential analysis, results are presented in the form of mean ± standard error or frequency (percentage). Univariate and multivariate linear regression models are used to evaluate the association between the basal metabolic rate (BMR) index and various demographic and physiological variables; multivariate logistic regression models are used to identify the factors associated with sarcopenia. Covariates include age, gender, marital status, smoking, drinking, depression status, moderate physical exercise, education level, and chronic disease history such as hypertension and diabetes.

The above comprehensive statistical methods provide support for a rigorous assessment of the potential associations between the BMR index and various demographic and physiological variables.

***Latent Variable Categorical Growth Model (*LCGM)**

We employ the latent variable categorical growth model (LCGM) for the analysis and statistics of longitudinal data, which can identify the different development trajectories of individuals with sarcopenia among the included participants over time [20], and track the development path of the BMR of patients with sarcopenia. The core advantage of this model lies in its ability to handle various data distributions and reveal different development patterns existing in the overall population, thus becoming an effective method for analyzing longitudinal data [21]. The LCGM can visually reveal the heterogeneity of group development and provide scientific basis for formulating precise and differentiated intervention strategies.

All 6,348 participants from CHARLS 2011 (wave 1) who completed the baseline survey were included in the analysis and followed up until CHARLS 2015 (wave 3), with at least two cycles of follow-up information not lost. The LCGM can fit the distribution of different types of data [22]. Count data can be fitted to the Poisson distribution or zero-inflated Poisson distribution model; binary data can be fitted to the binary logit distribution model; and continuous data within a certain range or approximately normally distributed can be fitted to the censored normal distribution model [23]. The model can confirm the optimal number of subgroups and trajectory shapes through multiple fittings. The fit effect of the model can be evaluated by several indicators, such as the Bayesian information criterion (BIC), the numerical value of the Bayesian factor, and the average posterior probability (AvePP) [24].

We use the full information maximum likelihood (FIML) under the LCGM framework for parameter estimation. The FIML method has been proven to generate effective parameter estimates under the assumption of random missingness (MAR). Unlike traditional longitudinal methods that usually directly eliminate cases with incomplete follow-up, FIML can fully utilize all available observations of each participant. This strategy not only helps reduce the selection bias introduced by data missingness but also effectively maintains the statistical test power [25].

These methods are implemented using the R 4.2.2 software.

Results

Baseline characteristics of the included individuals

Table 1 presents the baseline characteristics of the participants in the CHARLS cohort study. A total of 6,348 middle-aged and elderly participants were included in this study (average age = 59.65 ± 9.39 years), among whom: 3,274 were female (average age = 59.24 ± 9.51 years), and 3,074 were male (60.08 ± 9.24 years). Among them, the gender difference in the included population was significant ($p < 0.001$), and it occurred in social demographic factors (age, marital status, educational level), lifestyle behaviors (smoking, drinking, moderate physical activity), and underlying diseases (hypertension, diabetes, depression). The prevalence of sarcopenia between females (BMR: 1199.61 ± 136.50 kcal/d) and males (BMR: 1378.42 ± 200.94 kcal/d) was 27.58% (n = 903) vs. 13.13% (n = 355), both of which were statistically significant ($p < 0.001$).

Cross-sectional study results of BMR and sarcopenia

We conducted univariate and multivariate Logistic regression analyses of BMR and sarcopenia for the participants of CHARLS 2011 (wave 1). From the results of the univariate Logistic regression, it was found that BMR was significantly correlated with sarcopenia and was a protective factor for sarcopenia (HR: 0.98, 95% CI 0.98 - 0.98, p < 0.001). In addition, Education level, Drinking, Smoking, Marital Status, Diabetes, High blood pressure, Depression, Gender, and Age were all individually associated with sarcopenia. To further eliminate the interference of confounding factors, we conducted multivariate Logistic regression. The results showed that BMR and High blood pressure still had a significant correlation with sarcopenia (BMR: HR 0.97, 95% CI 0.97 - 0.98, $p < 0.001$; High blood pressure: HR 0.57, 95% CI 0.40 - 0.83, $p = 0.003$) (**Table 2**). To verify the robustness of the analysis results, we conducted a sensitivity analysis by adding Heart problem, Stroke, Lung disease, and Cancer as covariates. The multivariate Logistic indicated that BMR still had a significant correlation with sarcopenia (BMR: HR 0.97, 95% CI 0.97 - 0.98, $p < 0.001$) (**Supplementary Table 1**).

Longitudinal cohort analysis of BMR and sarcopenia

To explore the dynamic association between BMR and sarcopenia, we followed up the cohort study data from CHARLS 2011 (wave 1) to CHAFRLS 2015 (wave 3). The follow-up endpoint was selected at CHARLS 2015 (wave 3), and participants diagnosed with sarcopenia in wave 1 were excluded. We further explored the relationship between non-sarcopenia patients and sarcopenia after 2 follow-up cycles in wave 1. Univariate Logistic regression analysis showed that BMR still had a significant correlation with sarcopenia, and was a protective factor for sarcopenia (HR: 0.99, 95% CI 0.99 - 0.99, $p < 0.001$); Education level (high school), moderate physical activity, marital status, depression, gender, and age were all independently associated with sarcopenia. After excluding confounding factors through multivariate Logistic regression, it was found that only BMR still had a significant correlation with sarcopenia (HR: 0.99, 95% CI

0.99 - 0.99, $p < 0.001$) (**Table 3**). We further conducted a sensitivity analysis, adjusting the covariates to Drinking, Smoking, Marital Status, Diabetes, High blood pressure, Cancer, Depression, Gender, Age, moderate physical activity. Multivariate Logistic regression analysis showed that BMR and Age were both significantly correlated with sarcopenia (BMR: HR 0.99, 95% CI 0.99 - 0.99, $p < 0.001$; Age: HR 1.78, 95% CI 1.29 - 2.48, $p = 0.003$); Age was an independent risk factor for sarcopenia (**Supplementary Table 2**).

The latent class growth model identified three BMR trajectories

This study included a total of 13,598 participants. A latent class growth model was fitted based on the BMR measurements at two time points. The model fitting indicators showed that the three-category model was the optimal choice (BIC = 338,137.5, SABIC = 338,099.4, Entropy = 0.768). The average posterior probability of all categories was greater than 0.87, indicating good classification quality. The characteristics of the three BMR trajectories are as follows:

Class 1 (low BMR throughout the period group, n = 4,886, 35.9%): The baseline BMR was the lowest (1106.6 ± 8.7 kcal), and the trend over time was not significant (linear term β = 11.06, p = 0.247; quadratic term β = -3.61, p = 0.121), showing a stable low-level state. This group was mainly composed of elderly men (average age 63.8 years, males accounted for 75.8%), and the depression rate was the highest (40.1%). Class 2 (decrease group, n = 6,539, 48.1%): The baseline BMR was moderate (1322.0 ± 8.0 kcal), showing a significant downward trend (quadratic term β = -5.76, p = 0.005), and was the only group with statistically significant decline. This group had a medium age (56.6 years), and the gender ratio was balanced. Class 3 (high BMR throughout the period group, n = 2,173, 16.0%): The baseline BMR was the highest (1596.9 ± 14.6 kcal), showing a slight decrease but not significant (quadratic term β = -7.14, $p = 0.056$). This group was mainly composed of young women (average age 54.4 years, females accounted for 96.1%), but the proportions of alcohol consumption (67.7%), smoking (49.6%), hypertension (35.6%), and diabetes (8.4%) were the highest.

Overall, compared with Class 1, the risk of sarcopenia in Class 2 (decreased basal metabolism rate) decreased by 21.7%. Compared with Class 1, the risk of sarcopenia in Class 3 (persistent high basal metabolism rate) decreased by 28.4%. After adjusting for confounding factors, the trend of changes in basal metabolism rate could still independently predict the occurrence of sarcopenia. Female gender and hypertension were associated with a lower risk of sarcopenia.

The above analysis results can be found in **Supplementary Table 3, Figure 1.**

The association between BMR trajectory and sarcopenia

Multivariate linear regression analysis showed that after adjusting for demographic characteristics, lifestyle, and chronic diseases, the BMR trajectory category was significantly and independently associated with sarcopenia in cycle 3 (β = -0.22, 95% CI: -0.24 to -0.20, $p < 0.001$) (**Table 4**). Compared with Class 1, the risk of Class 3 sarcopenia was reduced by 21.7%, suggesting that a persistent high BMR trajectory is a protective factor for sarcopenia. Other independent influencing factors included smoking (β = 0.040, $p = 0.002$), depression (β = 0.030, $p = 0.005$), age (β = 0.012 per year, p < 0.001), and unmarried status (β = 0.052, p = 0.001), while being female (β = -0.077, p < 0.001) and having hypertension (β = -0.063, $p < 0.001$) were associated with a lower risk of sarcopenia (**Supplementary Table 4**)

To further explore the correlations and interactions between age, gender and the BMR trajectory, we conducted multinomial Logistic regression, VIF test, chi-square test and forest plot drawing. The results are as follows:

Gender was significantly correlated with the BMR trajectory category ($\chi^2 = 1480.5$, $p < 0.001$), with 96.1% of females in Class 3 (**Figure 2**). However, the interaction between gender and age was not significant (LR = 1.91, $p = 0.384$), indicating that the influence of age on the BMR trajectory is consistent in males and females. Stratified analysis showed that the age effects for males (OR = 0.87, 95% CI: 0.86 - 0.88) and females (OR = 0.86, 95% CI: 0.85 - 0.87) were highly similar, suggesting that age is an independent predictor of the BMR trajectory, and its effect is not modified by gender (**Figure 3**).

Discussion

Sarcopenia, as a progressive and systemic skeletal muscle disorder associated with aging, has become a research hotspot in the fields of geriatrics and public health in recent years [26]. Its core characteristics include reduced muscle mass, decreased strength, and/or impaired physical function, which not only significantly affect the quality of life of the elderly but are also closely related to the risks of falls, fractures, disability, and even death [27]. With the acceleration of the global aging process, in-depth exploration of the mechanisms of sarcopenia occurrence and identification of potential modifiable targets are crucial for formulating effective prevention strategies. Basal metabolic rate (BMR) refers to the minimum energy consumption required by the human body to maintain basic life activities in a state of wakefulness, quietness, and fasting, accounting for approximately 60%-75% of the total daily energy expenditure [28]. The level of BMR is mainly influenced by factors such as age, gender, body composition, and hormone levels, and its changes may directly reflect the alteration of the body's energy metabolism status. In recent years, the role of BMR in the occurrence and development of sarcopenia has gradually attracted attention. From a biological perspective, BMR may affect muscle metabolism through multiple pathways: Firstly, BMR is closely related to the rate of protein turnover in the resting state [29], and a higher BMR may indicate a more active protein synthesis and catabolism. If synthesis predominates, it is conducive to maintaining muscle mass; Secondly, BMR reflects the basic energy requirements of the body, and when BMR is too low, it may indicate a "low consumption" state of energy metabolism, which is not conducive to muscle consumption under stress conditions; Thirdly, BMR is associated with mitochondrial function, inflammatory state, hormone levels, and other factors, which themselves are also important regulatory nodes of sarcopenia[30]. Therefore, systematically exploring the association between BMR and sarcopenia not only helps deepen the understanding of the energy metabolism mechanism of sarcopenia but also provides a new entry point for clinical early identification of high-risk populations and formulation of individualized intervention plans.

This study is based on the China Health and Retirement Longitudinal Study (CHARLS), a large-scale and nationally representative cohort dataset. It systematically explores the association between BMR and sarcopenia from three dimensions: cross-sectional, longitudinal cohort, and trajectory analysis. In the cross-sectional study, we included a total of 6,348 middle-aged and elderly participants. Univariate Logistic regression analysis revealed a significant negative correlation between BMR and sarcopenia, and it was found to be a protective factor for sarcopenia (OR = 0.98, 95% CI: 0.98 - 0.98, $p < 0.001$). On this basis, the multivariate Logistic regression model, after adjusting for confounding factors such as social demographic characteristics (age, gender, marital status, education level), lifestyle behaviors (smoking, drinking, moderate physical activity), and underlying diseases (hypertension, diabetes, depression), still showed a significant independent association between BMR and sarcopenia (OR = 0.97, 95% CI: 0.97 - 0.98, $p < 0.001$), suggesting that the protective effect of BMR on sarcopenia is not mediated by these confounding factors but has a relatively independent predictive value. It is notable that in the cross-sectional analysis, a significant negative correlation was also found between hypertension and sarcopenia (OR = 0.57, $p = 0.003$). This seemingly "protective" effect may be related to the medication status, medical-seeking behavior, or lifestyle changes of patients with hypertension, or it may have an inverse causal relationship, that is, sarcopenic patients are more likely to have lower blood pressure due to physical weakness, which needs to be further explored in subsequent studies. To further validate the robustness of the results, we conducted a sensitivity analysis by including chronic diseases such as heart disease, stroke, lung diseases, and cancer as covariates for adjustment. The results showed that BMR still maintained a significant independent association with sarcopenia (OR = 0.97, 95% CI: 0.97 - 0.98, $p < 0.001$), indicating that this association was not affected by the confounding influence of other common chronic diseases, further supporting the stability of BMR as a protective factor for sarcopenia.

Based on the cross-sectional findings, we conducted a longitudinal cohort analysis to verify whether the predictive effect of BMR on sarcopenia is temporally stable. This study followed the data from CHARLS from 2011 (wave 1) to 2015 (wave 3), excluding participants who were diagnosed with sarcopenia at the baseline. Finally, non-sarcopenia individuals were included for analysis. Univariate analysis showed that the baseline BMR was significantly negatively correlated with the risk of sarcopenia two years later (OR = 0.99, $p < 0.001$). Factors such as education level, moderate physical activity, marital status, depression, gender, age, and others were also significantly associated with sarcopenia. In the multivariate Logistic regression model, after comprehensive adjustment for the aforementioned confounding factors, BMR remained the only factor significantly independently associated with the occurrence of sarcopenia (OR = 0.99, $p < 0.001$). This result not only verified the conclusion of the cross-sectional study but also strengthened the causal inference between BMR and sarcopenia in terms of temporal sequence. That is, a lower baseline BMR can independently predict the future risk of sarcopenia. It is notable that the effect size of BMR (OR = 0.99) in the longitudinal analysis was slightly weaker than that in the cross-sectional analysis (OR = 0.97), which might be related to the changes in BMR of some participants during the follow-up period. It also suggests that a single measurement of BMR at a certain time point may have certain limitations and is difficult to fully reflect the dynamic changes of BMR on the occurrence of sarcopenia. To further test the robustness of the results, we adjusted multiple covariates such as alcohol consumption, smoking, marital status, diabetes, hypertension, cancer, depression, gender, age, and moderate physical activity in the sensitivity analysis. The results showed that BMR remained significantly independently associated with sarcopenia (OR = 0.99, $p < 0.001$), and age was also identified as an independent risk factor for sarcopenia (OR = 1.78, $p = 0.003$), further confirming the independent predictive effect of BMR on sarcopenia.

In order to more precisely depict the trajectory characteristics of BMR over time and its association with sarcopenia, this study for the first time employed the latent class growth model (LCGM), based on the BMR measurement data from two time points, to identify three groups of BMR trajectories with different change characteristics: the continuously low BMR group (Class 1, accounting for 35.9%), the decreasing group (Class 2, accounting for 48.1%), and the continuously high BMR group (Class 3, accounting for 16.0%). The model fitting indicators showed that the three-category model was the optimal choice (BIC = 338,137.5, Entropy = 0.768), and the average posterior probabilities of each category were all greater than 0.87, indicating reliable classification results. The continuously low BMR group was mainly composed of elderly men, with the highest depression rate, the lowest baseline BMR, and no significant change over time, presenting a "low-level steady state" feature; the decreasing group had a medium baseline BMR, and was the only group showing a significant downward trend (quadratic term $\beta = -5.76$, $p = 0.005$), suggesting that this group may have a progressive decline in energy metabolism; the continuously high BMR group was mainly composed of young women, with the highest baseline BMR, although it showed a slight decrease but did not reach statistical significance; however, this group had the highest proportions of smoking, drinking, hypertension, and diabetes, suggesting that the high BMR group may have complex characteristics of "metabolic hyperactivity" and "behavioral risks" coexisting.

Further analysis of the association between BMR trajectories and sarcopenia revealed that, with the continuous low BMR group as the reference, the risk of sarcopenia in the decreased group and the continuous high BMR group was reduced by 21.7% and 28.4% respectively. After multivariate regression analysis adjusted for demographic characteristics, lifestyle, and chronic diseases, the BMR trajectory category was still significantly independently associated with sarcopenia ($\beta = -0.22$, $p < 0.001$). This result has significant clinical implications: Firstly, the changing trend of BMR is more predictive than a single baseline value. Although the baseline BMR of the decreased group was moderate, due to its significant downward trend, the risk of sarcopenia in this group was still significantly higher than that of the continuous high BMR group, suggesting that in clinical monitoring, attention should be paid to the dynamic changes of BMR rather than only focusing on single measurement values; Secondly, although the continuous high BMR group had the highest proportion of behavioral risk factors (smoking, alcohol consumption, etc.), the risk of sarcopenia was the lowest, which may reflect the "protective advantage" of high BMR on muscle metabolism, sufficient to partially offset the impact of unhealthy lifestyles, or may be related to the protective effect of estrogen levels in young women on muscles; Thirdly, the identification of the decreased group is of great significance. This group accounted for nearly half of the sample (48.1%) and showed a significant downward trend, possibly representing an intermediate state from "normal metabolism" to "metabolic decline", and is a key population for early intervention.

When exploring the interaction between gender and age and the trajectory of BMR, we found that gender was significantly correlated with the BMR trajectory category ($\chi^2 = 1480.5$, $p < 0.001$). In Class 3, the proportion of females was as high as 96.1%. This might be related to the different weights of body composition parameters in the BMR calculation formula for females, and it might also reflect that females maintain a relatively high energy metabolism level in middle age. However, the interaction between gender and age was not significant (LR = 1.91, $p = 0.384$), and the stratified analysis showed that the age effects for males (OR = 0.87) and females (OR = 0.86) were highly similar, suggesting that age is an independent predictor of the BMR trajectory, and its

impact on BMR is consistent between males and females, unaffected by gender modification. This finding simplifies the understanding of the pattern of BMR changes, that is, regardless of gender, aging is accompanied by a downward trend in BMR, and intervention strategies should universally focus on the maintenance of energy metabolism in the middle-aged and elderly population.

Although this study has advantages such as a large sample size, high data quality, and rigorous research design, it still has the following limitations: First, the measurement of BMR is based on formula estimation rather than the gold standard methods like indirect calorimetry. Although the formula method is feasible in large-scale epidemiological studies, it may introduce certain measurement errors. Future research can conduct sub-sample verification using portable metabolic carts and other equipment. Second, this study only measures BMR at two time points. Although this is sufficient to identify linear or quadratic change trends, it is difficult to capture more complex non-linear change patterns. A longer follow-up period and multi-time-point measurements will help to more accurately depict the life course trajectory of BMR. Third, although we adjusted for various potential confounding factors, there may still be unmeasured confounding factors, such as dietary intake (especially protein intake), hormone levels (such as testosterone, insulin-like growth factor-1), and inflammatory markers (such as C-reactive protein, interleukin-6). These factors may be associated with both BMR and sarcopenia. Future research should include more comprehensive biomarkers. Fourth, the follow-up period of this study is relatively short (2 years). Although the predictive effect of BMR on sarcopenia was observed, it is difficult to assess the long-term health effects of BMR changes. Extending the follow-up period will help to clarify the association between BMR trajectory and the progression of sarcopenia, other geriatric syndromes, and mortality. Fifth, this study is an observational design. Although longitudinal analysis strengthens causal inference, it cannot completely rule out reverse causation and residual confounding. Future studies can consider genetic epidemiological methods such as Mendelian randomization to further verify the causal association between BMR and sarcopenia.

Declarations

Clinical trial number:

Not applicable.

Human Ethics and Consent to Participate declarations

This study used data from the China Health and Retirement Longitudinal Study (CHARLS). The original data collection was approved by the Biomedical Ethics Committee of Peking University (IRB00001052-11015), and all participants provided written informed consent at enrollment. The authors accessed the data through the official CHARLS website after registering and agreeing to the data use terms. As this study involves secondary analysis of de-identified, publicly available data, additional informed consent was not required.

Data Availability

Data supporting the findings of this study were obtained from the official, publicly available repositories of the following longitudinal studies: the China Health and Retirement Longitudinal Study (CHARLS)(https://charls.pku.edu.cn/).

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Declaration of Generative AI and AI-assisted technologies in the writing process

This manuscript was not created using generative AI, and no AI-related technologies were employed during the writing process.

Author contributions

Wenwen Xu: conceptualization, data curation, supervision, visualization, writing–review & editing; Hongbing Fu: data curation, formal analysis, visualization, writing–original draft, writing–review & editing, verified the underlying data; Yuan Li and Zhiwei Hu: formal analysis, writing–review & editing; Yuchang Fei: conceptualization, funding acquisition ,writing–review & editing. All authors read and approved the final version of the manuscript, and ensure it is the case.

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Competing interests

The authors declare no competing interests.

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Tables

Table 1. Characters of participants in CHARLS 2011.

Variables	Total	Gender		P value
		Female	Male	
	n=6348	n=3274	n=3074	
Age,Mean±SD	59.65±9.39	59.24±9.51	60.08±9.24	<0.001
Marital status(%)				
Married or partnered	5588(88.03)	2783(85.00)	2805(91.25)	<0.001
Other marital status	760(11.97)	491(15.00)	269(8.75)	
Education level(%)				
below high school	5674（89.38）	3040(92.85)	2634(85.69)	<0.001
high school	446（7.03）	168(5.13)	278(9.04)	
college or above	228（3.69）	66(2.02)	162(5.27)	
Smoking status(%)				
Non-smoker	4338（68.33）	3018（92.18）	1320（42.94）	<0.001
Smoker	2010（31.66）	256（9.82）	1754（57.06）	
Drinking stuatus(%)				
Non-drinker	3846(60.59)	2826(86.32)	1020(33.18)	<0.001
Drinker	2502(39.41)	448(13.68)	2054(66.82)	
High Blood Pressure(%)				
Yes	4525(71.28)	2270(69.33)	2255(73.36)	<0.001
No	1823(28.72)	1004(30.67)	819(26.64)	
Diabetes(%)				
Yes	5934(93.48)	3033(92.64)	2901(94.37)	<0.001
No	414(6.52)	241(7.36)	173(5.63)	
Depression(%)				
Yes	4386(69.09)	2066(63.10)	2320(75.47)	<0.001
No	1962(30.91)	1208(36.90)	754(24.53)	
Moderate physical activity(%）				
Yes	4828(76.06)	2472(75.50)	2356(76.64)	<0.001
No	1520(23.94)	802(24.50)	718(23.36)	

Table 2. Association of Metabolic Ratec rate with Sarcopenia.

	Events=6348			
Variables	HR(95%CI)a	***P1***a	HR(95%CI)b	***P2***b
BMR	0.98 (0.98 ~ 0.98)	<0.001	0.97 (0.97 ~ 0.98)	<0.001
Education level				
below high school	1.00 (Reference)		1.00 (Reference)	
high school	0.19 (0.12 ~ 0.29)	<0.001	1.16 (0.51 ~ 2.63)	0.732
college or above	0.29 (0.18 ~ 0.48)	<0.001	0.61 (0.17 ~ 2.16)	0.446
Drinking				
Non-drinker	1.00 (Reference)		1.00 (Reference)	
Drinker	0.53 (0.47 ~ 0.61)	<0.001	0.94 (0.63 ~ 1.40)	0.756
Marital Status				
Married or partnered	1.00 (Reference)		1.00 (Reference)	
Other marital status	3.49 (2.97 ~ 4.09)	<0.001	0.90 (0.59 ~ 1.37)	0.632
Moderate physical activity				
No	1.00 (Reference)		1.00 (Reference)	
Yes	0.85 (0.70 ~ 1.03)	0.097	0.93 (0.68 ~ 1.28)	0.668
Smoking				
Non-smoker	1.00 (Reference)		1.00 (Reference)	
Smoker	0.72 (0.63 ~ 0.83)	<0.001	1.28 (0.81 ~ 2.02)	0.294
Diabetes				
No	1.00 (Reference)		1.00 (Reference)	
Yes	0.39 (0.28 ~ 0.55)	<0.001	0.68 (0.33 ~ 1.38)	0.285
High blood pressure				
No	1.00 (Reference)		1.00 (Reference)	
Yes	0.68 (0.59 ~ 0.79)	<0.001	0.57 (0.40 ~ 0.83)	0.003
Depression				
No	1.00 (Reference)		1.00 (Reference)	
Yes	2.01 (1.77 ~ 2.28)	<0.001	1.37 (0.99 ~ 1.88)	0.055
Gender				
Female	1.00 (Reference)		1.00 (Reference)	
Male	0.34 (0.30 ~ 0.39)	<0.001	1.12 (0.68 ~ 1.83)	0.656
Age				
<65	1.00 (Reference)		1.00 (Reference)	
≥65	6.36 (5.57 ~ 7.26)	<0.001	0.94 (0.65 ~ 1.34)	0.719
OR: Odds Ratio, CI: Confidence Interval				
a: Univariate Logist regression.				
b: adjusted for Age, Gender, Educational level, Marital status,Drinking, Smoking, High blood pressure, Diabetes,Depression, Moderate physical activity.				

Table 3. The relationship between Metabolic Ratec rate with Sarcopenia from wave1 to wave3.

	Events=3889			
Variables	**HR(95%CI)[a]**	P1[a]	**HR(95%CI)[b]**	P2[b]
BMR	0.99 (0.99 ~ 0.99)	<.001	0.99 (0.99 ~ 0.99)	<.001
Education level				
below high school	1.00 (Reference)		1.00 (Reference)	
high school	0.15 (0.05 ~ 0.47)	0.001	0.43 (0.10 ~ 1.81)	0.248
college or above	0.55 (0.22 ~ 1.37)	0.200	0.33 (0.04 ~ 2.54)	0.287
Drinking				
Non-drinker	1.00 (Reference)		1.00 (Reference)	
Drinker	0.76 (0.57 ~ 1.00)	0.051	1.43 (0.85 ~ 2.40)	0.179
Marital Status				
Married or partnered	1.00 (Reference)		1.00 (Reference)	
Other marital status	2.32 (1.60 ~ 3.36)	<.001	1.00 (0.51 ~ 1.99)	0.991
Moderate physical activity				
No	1.00 (Reference)		1.00 (Reference)	
Yes	0.62 (0.41 ~ 0.92)	0.018	0.66 (0.43 ~ 1.01)	0.055
Smoking				
Non-smoker	1.00 (Reference)		1.00 (Reference)	
Smoker	0.93 (0.70 ~ 1.24)	0.618	0.89 (0.49 ~ 1.61)	0.697
Diabetes				
No	1.00 (Reference)		1.00 (Reference)	
Yes	1.30 (0.81 ~ 2.10)	0.277	1.10 (0.48 ~ 2.55)	0.818
High blood pressure				
No	1.00 (Reference)		1.00 (Reference)	
Yes	0.82 (0.61 ~ 1.11)	0.205	1.05 (0.65 ~ 1.69)	0.855
Depression				
No	1.00 (Reference)		1.00 (Reference)	
Yes	1.36 (1.03 ~ 1.81)	0.032	1.04 (0.66 ~ 1.63)	0.877
Gender				
Female	1.00 (Reference)		1.00 (Reference)	
Male	0.54 (0.41 ~ 0.70)	<.001	1.16 (0.61 ~ 2.21)	0.654
Age				
<65	1.00 (Reference)		1.00 (Reference)	
≥65	3.48 (2.64 ~ 4.57)	<.001	1.41 (0.86 ~ 2.31)	0.179
OR: Odds Ratio, CI: Confidence Interval				
a: Univariate Logist regression.				
b: adjusted for Age, Gender, Educational level, Marital status,Drinking, Smoking, High blood pressure, Diabetes,Depression, Moderate physical activity.				

Table 4. Multivariable Linear Regression Analysis Predicting Sarcopenia at Wave 3.

Predictor	β	SE	95% CI
Intercept	-0.08	0.05	[-0.17, 0.02]
BMR Trajectory			
Class 2 (Declining) vs Class 1 (Low)	-0.22	0.01	[-0.24, -0.20]
Class 3 (High) vs Class 1 (Low)	-0.28	0.01	[-0.31, -0.26]
Covariates			
Drinking (yes)	0.02	0.01	[-0.00, 0.04]
Smoking (yes)	0.04	0.01	[0.02, 0.07]
Diabetes (yes)	-0.04	0.02	[-0.08, 0.00]
High blood pressure (yes)	-0.06	0.01	[-0.09, -0.04]
Depression (yes)	0.03	0.01	[0.01, 0.05]
Age (per year)	0.01	0	[0.01, 0.01]
Gender (female)	-0.08	0.02	[-0.11, -0.05]
Marital status (unmarried)	0.05	0.02	[0.02, 0.09]

Model R^2 = 0.124, F(10, 13587) = 192.45, p < .001. Class 1 (Persistently low BMR) served as the reference group. β = unstandardized regression coefficient; S

Figures

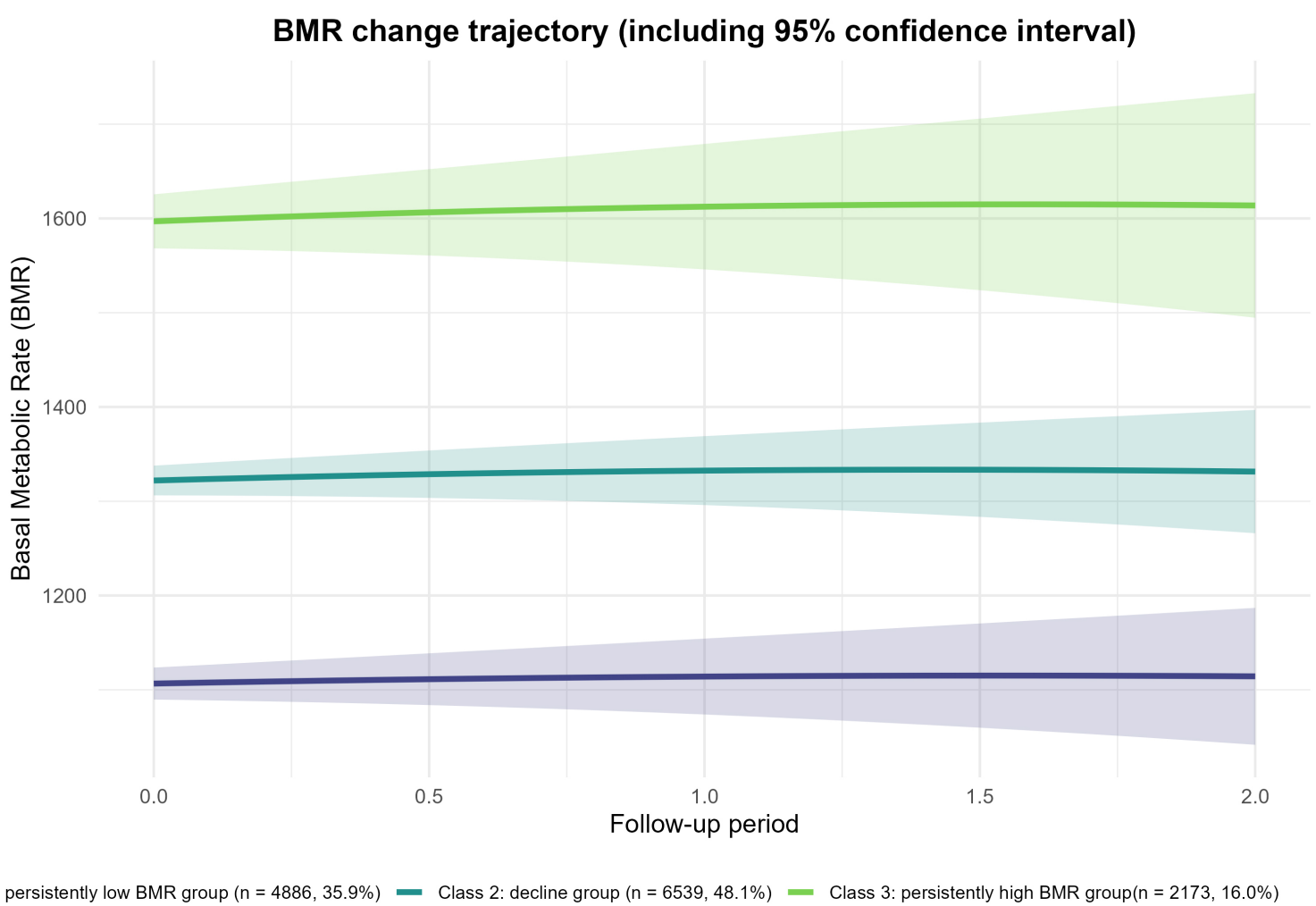


Figure 1

BMR change trajectory from 2011 to 2015.

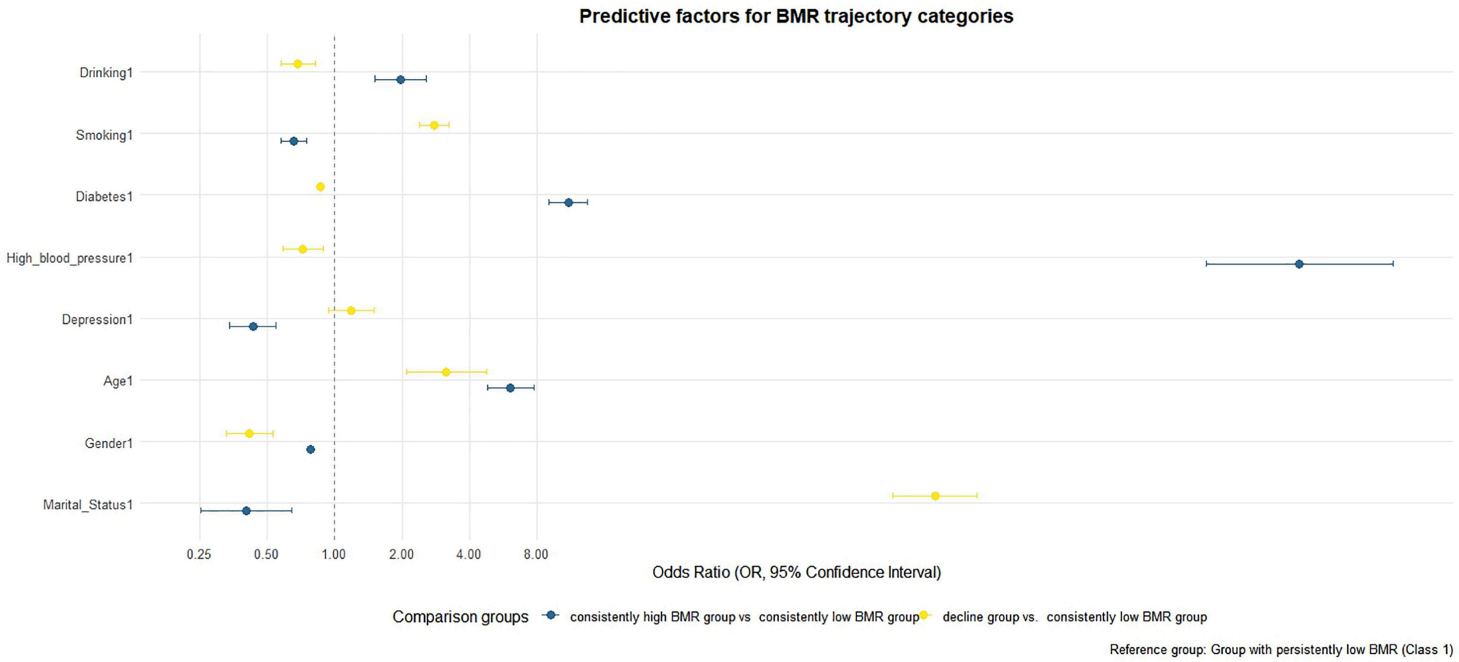


Figure 2

Prective factors for BMR trejactory categories.

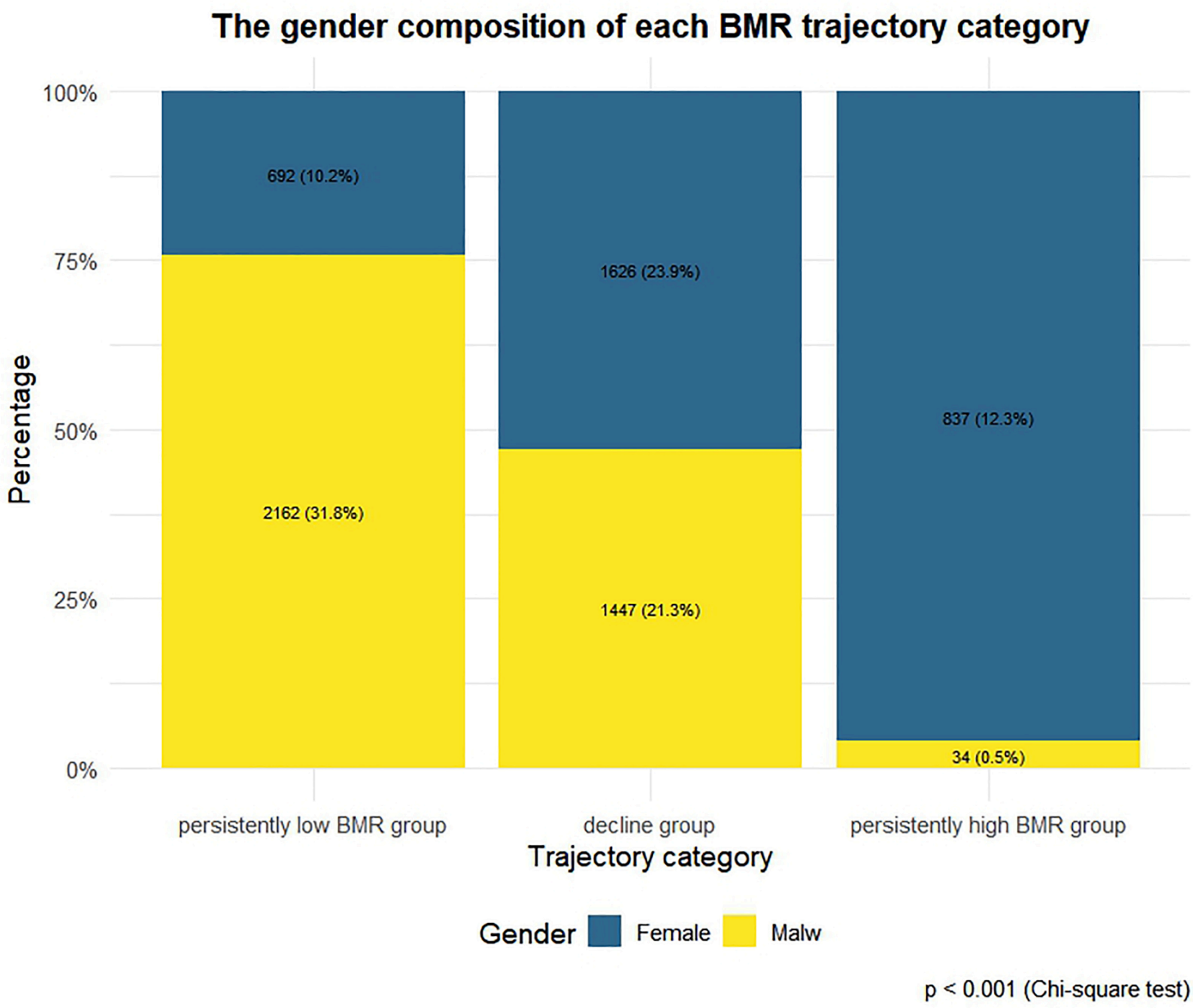


Figure 3

The gender of each BMR trejactory categories.

Supplementary Files

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