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Long-term time in target range for body mass index (BMI) and diabetes incidence: insights from CHARLS

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BACKGROUND: Body mass index (BMI) is strongly associated with the development of type 2 diabetes. However, the association between long-term time in target range (TTR) for BMI and the incidence of new-onset diabetes remains unclear.
METHODS AND RESULTS: This study utilized a non-diabetic population aged 45 years or older from the China Health and Retirement Longitudinal Study (CHARLS). BMI-TTR was assessed in Waves 1, 2, and 3 over a 5-year period, with the target range defined as 18.5 kg/m^2 ≤ BMI < 23 kg/m^2. New-onset diabetes in Waves 2, 3, and 4 over a 6-year follow-up served as the study endpoint. After applying exclusion criteria, 6662 participants (3143 men and 3519 women; mean age 58.93 ± 8.85 years) were enrolled. Participants were categorized into four groups (TTR1–TTR4) based on the number of times BMI was within the target range (0–3 times). The risk of new-onset diabetes decreased progressively with increasing BMI-TTR during follow-up. Compared with the TTR1 group, participants in the TTR4 group exhibited a significantly lower risk of diabetes (adjusted HR: 0.577, 95% CI: 0.463–0.720, $P < 0.001$), even after adjusting for baseline BMI (adjusted HR: 0.685, 95% CI: 0.537–0.872, $P = 0.002$). This effect was even more pronounced in female subgroup and in individuals aged under 60 years of age.
CONCLUSION: In adults aged 45 years or older, regardless of baseline BMI, maintaining BMI within the target range over time was associated with a reduced risk of new-onset diabetes, particularly among women and individuals under 60 years of age. These findings highlight the importance of long-term weight management in diabetes prevention.

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BACKGROUND

Type 2 diabetes mellitus (T_2DM) is a major public health concern and a leading cause of mortality and disability worldwide. Studies have shown that body mass index (BMI) is a commonly used measure of obesity and that obese individuals (as measured by BMI) have a significantly higher risk of T_2DM [1, 2]. This association is particularly pronounced among the elderly, especially those over 50 years of age [3].

Several studies have indicated that a normal BMI, not too low nor too high, is significantly associated with a reduced risk of T_2DM, cardiovascular disease events, and death [4–6]. Time in target range (TTR) metrics, such as those for blood glucose and blood pressure, have been employed to predict complications and clinical outcomes in diabetes and hypertension [7–12]. Elevated BMI has also been independently associated with an increased incidence of cardiovascular disease incidence and mortality [13, 14]. However, the association between BMI-TTR and the risk of new-onset diabetes remains underexplored.

In this study, we utilized the China Health and Retirement Longitudinal Study (CHARLS), which initially recruited a middle-aged and older cohort aged 45 years and older and has followed them over time, to investigate the association between BMI-TTR and risk of the long-term risk of diabetes in a middle-aged and elderly population.

PARTICIPANTS AND METHODS

Study design and participants

CHARLS is a longitudinal cohort study that collects high-quality microdata on households and individuals aged 45 years and older in China, and the study is ongoing. For a detailed description of CHARLS, please refer to the relevant literature and its official website [15, 16]. Participants included in this analysis had BMI measurements from CHARLS Wave 1 (2011), Wave 2 (2013), and Wave 3 (2015). Individuals under 45 years of age, those with diabetes mellitus (DM) at baseline, and those with a fasting blood glucose ≥7 mmol/L or glycated hemoglobin ≥6.5% at baseline were excluded. Ultimately, a total of 6662 participants were included in the BMI-TTR analysis (Flow Diagram was shown in Fig. 1). The study was approved by the Ethical Review Committee of Peking University. The studies were in accordance with the STROBE Statement, and informed consent was obtained from each participant.

Assessment of BMI and definition of BMI-TTR

BMI was calculated as weight (kg) divided by height squared (m^2). The target range for BMI was defined as 18.5 kg/m^2 ≤ BMI < 23 kg/m^2, based on World Health Organization (WHO) recommendations for Asian populations. Participants were stratified into four groups (TTR1–TTR4) based on the number of times their BMI fell within the target range (0–3 times). The TTR1–TTR4 categories are mutually exclusive. The TTR1 group consists of participants whose BMI was outside the normal range in all three Waves. The TTR2 group refers to participants whose BMI fell within the normal range in any one of the three Waves. The TTR3 group refers to participants whose BMI fell within the normal range in any two of the three Waves. The

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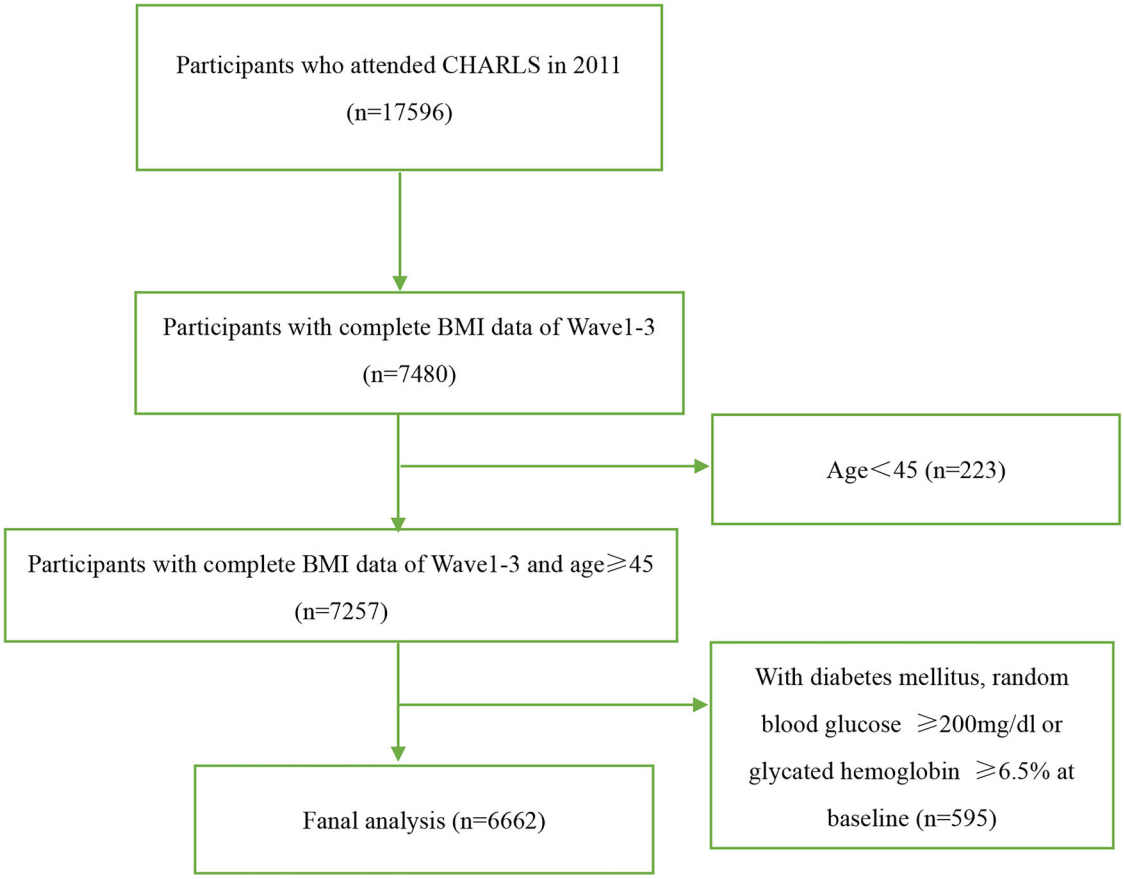

Fig. 1 Flow diagram. Flow diagram showing the selection of the study population.

TTR4 group includes participants whose BMI remained within the normal range across all three Waves.

Incident diabetes

New-onset diabetes, defined as self-reported physician-diagnosed diabetes, was assessed in Waves 2 (2013), 3 (2015), and 4 (2018) over a 6-year period.

Statistical analysis

Statistical analyses were performed using SPSS 26.0 (SPSS Inc. Chicago, IL) and R software (version 4.3.3, R Foundation for Statistical Computing, Austria). Categorical variables were expressed as percentages, and continuous variables as means ± SD. Group comparisons were performed using Student *t*-tests, ANOVA, nonparametric tests, Chi-square tests, or Fisher's exact tests, as appropriate. Cox regression models and binary logistic regression models were employed to calculate hazard ratios (HR) and odds ratios (OR) with 95% confidence intervals (CI). Kaplan–Meier curves illustrated the incidence of outcomes. Multivariate Cox models and binary logistic regression models adjusted for covariates including age, gender, hypertension, smoking, and other relevant factors.

The COX regression models included the following:

Model 1: Age, gender, hypertension, smoking, systolic blood pressure (SBP), heart rate (HR), hyperlipidemia, physical activity, marital status, education, high-density lipoprotein cholesterol (HDL-C), glycated hemoglobin A1c (HbA1c), high sensitivity C-reactive protein (hsCRP), estimated glomerular filtration rate (eGFR), and BMI-TTR.

Model 2: Age, gender, hypertension, smoking, SBP, HR, hyperlipidemia, physical activity, marital status, education, HDL-C, hsCRP, HbA1c, eGFR, BMI-TTR, and BMI of waves 1.

Model 3: Age, sex, hypertension, smoking, SBP, HR, hyperlipidemia, physical activity, marital status, education, HDL-C, hsCRP, HbA1c, eGFR, BMI-TTR, and BMI from waves 1, 2, and 3. The covariates included in the models were selected based on the results of univariate analysis, previously identified risk factors for diabetes in the literature, and established risk factors recognized as associated with diabetes, including age >45 years, overweight, cardiovascular disease, hypertension, dyslipidemia, and other features of metabolic syndrome, such as sex, pollution, chronic kidney disease (CKD, which affects HbA1c), obesity-related inflammation (CRP and IL-6) [17–20]. Restricted cubic spline (RCS) analysis was used to explore the nonlinear relationship between baseline BMI and diabetes incidence. Subgroup analyses were conducted by gender and age, with interaction effects assessed. Missing data were addressed using multiple imputation (see S-Table 1). A p-value < 0.05 was considered statistically significant.

RESULTS

Basic characteristics

A total of 6662 participants (3143 men and 3519 women, aged 58.93 ± 8.85 years) from the CHARLS were included. The basic characteristics of the different groups are presented in Table 1. From TTR 1 to TTR 4, baseline BMI levels gradually decreased, as did blood pressure, HR, blood glucose, glycosylated hemoglobin levels, and the proportion of individuals with a history of hypertension. Conversely, age, the proportion of males, and the proportions of smokers and alcohol drinkers gradually increased.

Association between TTR and diabetes incidence

Table 1 shows the number and proportion of incident diabetes cases during the 6-year follow-up period. In total, 655 participants developed diabetes, resulting in a prevalence of 9.83%. The incidence rates across TTR groups were: TTR1, 413 (13.6%); TTR2, 73 (8.6%); TTR3, 58 (6.8%); and TTR4, 111 (5.8%) ($p < 0.001$ for trend). Compared to TTR1, TTR4 was associated with a significantly reduced risk of diabetes in both unadjusted (HR 0.414, 95% CI 0.335–0.51, $p < 0.001$) and adjusted: Model 1 (HR 0.577, 95% CI 0.463–0.720, $p < 0.001$), and Model 2 (HR 0.685, 95% CI

Table 1. Basic characteristics according to TTR-BMI.

Variable	TTR1 $N = 3041$	TTR2 $N = 847$	TTR3 $N = 853$	TTR4 $N = 1921$	*P* value
BMI, kg/m²	25.74 ± 3.94	22.38 ± 2.86	21.28 ± 2.93	20.73 ± 1.12	<0.001
Age, years	57.87 ± 8.55	59.18 ± 9.42	60.48 ± 8.96	59.82 ± 8.80	<0.001
Female, *n* (%)	1805 (59.4)	467 (55.1)	415 (48.7)	832 (43.3)	<0.001
Marital status, *n* (%)					<0.001
Married or partnered	2647 (87.0)	696 (82.2)	694 (81.4)	1592 (82.9)	
Other marital status	394 (13.0)	151 (17.8)	159 (18.6)	329 (17.1)	
Education, *n* (%)					0.005
Below high school	2731 (89.8)	782 (92.3)	781 (91.6)	1786 (93.0)	
High or vocational school	283 (9.3)	61 (7.2)	63 (7.4)	120 (6.2)	
College or above	27 (0.9)	4 (0.5)	9 (1.1)	15 (0.8)	
Ever smoking, *n* (%)	986 (32.4)	346 (40.9)	366 (42.9)	928 (48.3)	<0.001
Ever drinking, *n* (%)	1063 (35.0)	316 (37.3)	331 (38.8)	852 (44.4)	<0.001
Hypertension, *n* (%)	932 (30.6)	173 (20.4)	164 (19.2)	273 (14.2)	<0.001
Dyslipidemia, *n* (%)	334 (11.0)	50 (5.9)	36 (4.2)	71 (7.4)	<0.001
Cancer or malignant, *n* (%)	26 (0.9)	6 (0.7)	5 (0.6)	10 (0.5)	0.556
Chronic lung disease, *n* (%)	273 (9.0)	84 (9.9)	100 (11.7)	188 (9.8)	0.118
Liver disease, *n* (%)	97 (3.2)	26 (3.1)	30 (3.5)	67 (3.5)	0.898
Kidney disease, *n* (%)	165 (5.4)	62 (7.3)	48 (5.6)	95 (4.9)	0.090
Digestive disease, *n* (%)	656 (21.6)	193 (22.8)	201 (23.6)	472 (24.6)	0.098
Arthritis or rheumatism, *n* (%)	1059 (34.8)	280 (33.1)	290 (34.0)	619 (32.2)	0.286
Asthma, *n* (%)	143 (4.7)	45 (5.3)	46 (5.4)	78 (4.1)	0.336
Memory-related disease, *n* (%)	41 (1.3)	8 (0.9)	18 (2.1)	21 (1.1)	0.123
Psychosomatic disease, *n* (%)	33 (1.1)	15 (1.8)	12 (1.4)	25 (1.3)	0.448
Physical exercise, *n* (%)	461 (15.2)	151 (17.8)	151 (17.7)	359 (18.7)	0.008
SBP, mmHg	132.29 ± 21.04	129.55 ± 21.34	127.73 ± 20.89	126.69 ± 20.97	<0.001
DBP, mmHg	77.97 ± 12.25	74.47 ± 11.45	73.12 ± 11.61	72.84 ± 11.81	<0.001
HR, bmp	72.90 ± 10.08	71.42 ± 10.26	71.31 ± 10.50	70.97 ± 10.39	<0.001
BUN, mg/dl	15.51 ± 4.41	15.84 ± 4.57	15.80 ± 4.50	15.94 ± 4.55	0.007
Glucose, mg/dl	105.69 ± 19.70	105.02 ± 19.68	102.25 ± 18.89	102.11 ± 19.74	<0.001
Creatinine, mg/dl	0.77 ± 0.18	0.77 ± 0.19	0.78 ± 0.19	0.79 ± 0.18	0.117
TC, mg/dl	195.49 ± 36.93	191.16 ± 36.69	190.91 ± 36.52	189.71 ± 35.59	<0.001
HDL, mg/dl	48.36 ± 14.30	53.37 ± 15.19	54.32 ± 15.54	55.82 ± 15.53	<0.001
LDL, mg/dl	118.89 ± 34.25	113.93 ± 32.92	115.27 ± 32.48	113.65 ± 32.17	<0.001
UA, mg/dl	4.49 ± 1.25	4.41 ± 1.21	4.37 ± 1.24	4.35 ± 1.20	0.001
eGFR, mL/min/1.73m^2	108.28 ± 29.57	109.28 ± 32.29	109.38 ± 32.05	109.98 ± 37.71	0.343
HbA1c, %	5.16 ± 0.44	5.12 ± 0.45	5.09 ± 0.42	5.08 ± 0.45	<0.001
hsCRP, mg/L	1.44 (0.70-3.41)	1.21 (0.60-3.86)	1.07 (0.54-3.58)	1.00 (0.49-3.01)	<0.001
New-onset DM, %	413 (13.6)	73 (8.6)	58 (6.8)	111 (5.8)	<0.001

TTR time in target range, *DM* diabetes mellitus, *BMI* body mass index, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *HR* heart rate, BUN blood urea nitrogen, *TC* total cholesterol, *HDL* high-density cholesterol, *LDL* low-density cholesterol, *UA* uric acid, *HbA1c* glycated hemoglobin A1c, *hsCRP* high sensitivity C-reactive protein, *eGFR* estimated glomerular filtration rate.

0.537–0.872, $p = 0.002$). Only when all BMIs of three Waves are included in the model will this significant effect of TTR disappear (Model 3). Baseline BMI was independently associated with diabetes risk (HR 1.037, 95% CI 1.017–1.057, $p < 0.001$) (Table 2). Binary logistic regression produced similar results (S-Table 2). Survival curves are presented in Fig. 2, with a log-rank p-value < 0.001. We developed an RCS model to examine the nonlinear relationship between baseline BMI and new-onset diabetes. The model revealed a significant nonlinear association (overall $p < 0.0001$, nonlinear $p = 0.0003$) (S-Fig. 1).

Additionally, we conducted an analysis comparing participants with persistently high TTR across all periods to those whose TTR improved over time (S-Tables 4 and 5). The total population was divided into three groups: the sustained normal BMI group (Group 1: normal BMI across all three waves, $n = 1921$), the BMI improvement group (Group 2: abnormal in wave 1 but normal in at least one of waves 2 or 3, $n = 590$), and the other group (Group 3, $n = 4151$). We found that both the BMI improvement group and the BMI consistently normal group exhibited lower long-term diabetes risk compared to the group with no improvement or persistently abnormal BMI. However, there was no significant difference in long-term diabetes risk between the BMI improvement group and the BMI consistently normal group.

Table 2. The association of BMI-TTR with diabetes incidence.

Variable	Crude HR (95% CI)	*P* value	Adjusted HR[a] (95% CI)	*P* value	Adjusted HR[b] (95% CI)	*P* value	Adjusted HR[c] (95% CI)	*P* value
TTR1								
TTR2	0.622 (0.485–0.797)	<0.001	0.752 (0.584–0.968)	0.027	0.844 (0.650–1.096)	0.203	0.904 (0.692–1.182)	0.461
TTR3	0.490 (0.372–0.645)	<0.001	0.633 (0.478–0.838)	0.001	0.736 (0.549–0.987)	0.040	0.822 (0.605–1.116)	0.209
TTR4	0.414 (0.335–0.510)	<0.001	0.577 (0.463–0.720)	<0.001	0.685 (0.537–0.872)	0.002	0.775 (0.597–1.007)	0.057
BMI of wave 1					1.037 (1.017–1.057)	<0.001	1.014 (0.986–1.043)	0.324
BMI of wave 2							1.045 (1.010–1.081)	0.011
BMI of wave 3							1.002 (0.975–1.030)	0.871

TTR time in target range, *DM* diabetes mellitus, *BMI* body mass index, *HR* hazard ratio, *CI* confidence interval, *SBP* systolic blood pressure, *HR* heart rate, *HDL* high-density cholesterol, *HbA1c* glycated hemoglobin A1c, *hsCRP* high sensitivity C-reactive protein, *eGFR* estimated glomerular filtration rate.
[a]Adjusted For age, sex, hypertension, smoking, SBP, HR, hyperlipidemia, physical exercise, marital status, education, HDL-C, hsCRP, HbA1c, eGFR.
[b]Adjusted For age, sex, hypertension, smoking, SBP, HR, hyperlipidemia, physical exercise, marital status, education, HDL-C, hsCRP, HbA1c, eGFR, and BMI of wave 1.
[c]Adjusted For age, sex, hypertension, smoking, SBP, HR, hyperlipidemia, physical exercise, marital status, education, HDL-C, hsCRP, HbA1c, eGFR, BMI of wave 1, 2, and 3.

Subgroup analysis

To further validate the association between TTR and the risk of new-onset diabetes, we repeated the regression analyses in gender and age subgroups. As shown in Table 3 and S-Table 3, the results regarding the association between new-onset diabetes and TTR were consistent with those observed in the whole population. However, the association was more pronounced in women and individuals aged 45–60 years. Interaction analyses were non-significant ($p > 0.05$).

DISCUSSIONS

This study based on CHARLS data from 2011 to 2018, explores the association between middle-aged and older adults' TTR and the risk of incident diabetes. A higher BMI-TTR was associated with a lower risk of diabetes, independent of baseline BMI, particularly among women and those aged 45–60 years. These findings highlight the importance of sustained BMI management within the target range to mitigate the risk of diabetes.

Obesity is well-known for its strong association with insulin resistance and the incidence of type 2 diabetes, with BMI being the classic measure of obesity. DM is a serious chronic condition that can lead to severe complications in multiple systems, including the heart, brain, kidneys, eyes, and nervous system. TTR has been widely used in studies examining the association between blood pressure or blood sugar and long-term outcomes. For example, higher SBP-TTR has been associated with a lower risk of adverse renal and cardiovascular events in hypertensive adults, and in older adults with hypertension, a higher long-term SBP-TTR correlates with a lower risk of cardiovascular events, regardless of their mean SBP [21–23]. TTR for blood glucose and the glycated hemoglobin has been shown to be significantly associated with adverse outcomes, such as complications and mortality, and is used as an important indicator for prognostic monitoring [7, 9, 10, 24, 25]. However, the association between long-term BMI attainment and the risk of developing diabetes remains unclear.

Although BMI is a relatively stable parameter in the short term (e.g., within hours or days), it can still exhibit meaningful changes over extended periods (e.g., months or years) [26, 27]. BMI-TTR is a valuable parameter for assessing the attainment of BMI over time. Our study is the first to examine the association between BMI-TTR and the long-term risk of diabetes. Our findings suggest a significant association between higher TTR and a lower risk of new-onset diabetes, even after controlling for baseline BMI levels. These results emphasize the importance of managing BMI not only to achieve the target range but also to maintain it as much as possible over a long follow-up period, in order to reduce the risk of developing diabetes and avoid a range of adverse clinical events associated with diabetes development.

In reference to the use of TTR in blood pressure and glucose monitoring, a higher TTR reflects lower variability in BMI and a greater chance of staying within the "healthy BMI" range over time. Previous studies have suggested that weight fluctuations may indicate underlying metabolic dysfunction, such as insulin resistance and inflammation [28–30]. Animal experiments have highlighted the significance of BMI variability: weight-cycling animals (those with fluctuating weight gain, loss, and recovery) exhibit similar adverse metabolic consequences as those with lifelong obesity, including higher levels of impaired fasting glucose and glucose intolerance [31]. It is hypothesized that neuroendocrine dysregulation of appetite and satiety hormones, as well as aseptic inflammation, may contribute to these effects [32, 33]. Furthermore, weight changes may promote increased lipogenic enzymes, such as myristic acid, palmitic acid, palmitoleic acid, and stearic acid, which can impair glucose metabolism and increase the risk of diabetes [34, 35]. These studies focused on BMI variability and did not address the percentage of BMI attainment, which is a key aspect of our study and its innovation.

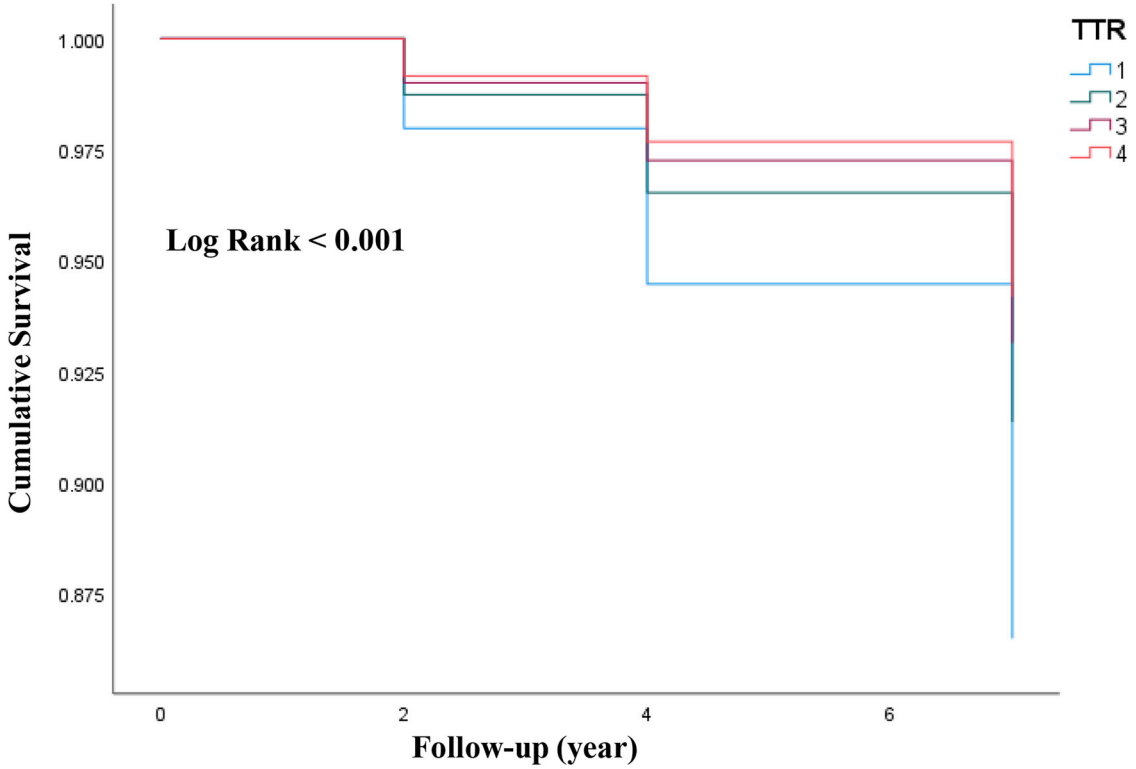

Fig. 2 Survival analysis. Kaplan–Meier survival curves for TTR from the 6-year incidence of new-onset DM.

Our findings were particularly robust in the female subgroup and among individuals aged 45–60 years. Changes in BMI are closely related to diet and exercise. It has been found that women are more likely to feel full than men, owing to gender-specific differences in hormones and neuronal activation [36]. There is also a gender-specific association between female estrogen and male hormone-sensitive lipase variants, as well as blood glucose concentrations, which may lead to different susceptibilities to metabolic diseases [37]. Males and females differ in body composition, with females generally having a higher body fat percentage and higher leptin levels. In addition, males have a marked preference for strength training, and high muscle mass in men facilitates glucose uptake and optimizes metabolic reactions [38, 39]. In summary, women may be more susceptible to changes in BMI. Regarding age, physical activity declines significantly with age, accompanied by a loss of muscle mass and a decrease in hormone levels, resulting in less pronounced benefits of maintaining BMI within the target range in older adults compared to younger ones [40].

BMI is a weight-related index, and since height remains relatively stable after adulthood, changes in BMI can effectively reflect changes in weight. With the increasing awareness of the dangers of obesity, many individuals strive to maintain a healthy weight. Additionally, beauty-conscious individuals often aim to control their weight to achieve an ideal body. Although our study focused on the impact of TTR on the development of diabetes, it did not examine the influence of weight loss, whether intentional or unintentional. Studies have shown that intentional weight loss can significantly reduce mortality, cancer risk, and cardiovascular disease risk, as well as increase remission rates in diabetic patients. However, unintentional weight loss, which differs metabolically from intentional weight loss, is often associated with chronic diseases, low muscle mass, and poor appetite, and tends to be associated with poor outcomes [41–43]. Unfortunately, this study only examined the number of times BMI was within the normal range. Although the statistical results are significant, the study did not explore the chronological order of BMI attainment or consider whether the weight loss was intentional or unintentional. Our conclusions provide evidence and motivation for individuals seeking to lose weight. Future studies with a prospective design are needed to explore the TTR-related effects whereas considering both intentional and unintentional weight loss.

Of course, there are some limitations in our study. First, the diagnosis of DM was based on self-reported physician-diagnosed information, which may introduce bias. Second, this study was conducted solely within a Chinese geriatric cohort, limiting the generalizability of the finding to other population. Third, the number of BMI measurements in our study was limited to three, which is significantly fewer than the numerous blood pressure measurements in the Blood Pressure TTR studies, and the method of TTR calculation was also different. Therefore, studies with more frequent and shorter intervals of BMI measurements and more precise TTR calculations are urgently needed to further validate our findings. Forth, the sample size in our study was relatively small, particularly in the TTR2 and TTR3 groups, which included only more than 800 individuals, and even fewer were available for subgroup analyses by gender and age. Fifth, the confounding effects of weight loss (whether intentional or unintentional) were not considered in the analysis of the association between TTR and diabetes onset. Sixth, although we controlled for confounding variables in the regression model, we were unable to entirely eliminate potential biases, such as survival bias and selection bias. Seventh, additional analysis comparing participants with sustained normal BMI across all periods to those whose BMI improved later showed no significant difference in DM incidence. Finally, whereas we have proposed potential mechanisms, they do not fully explain the findings, and further research is needed to explore these mechanisms more thoroughly.

Table 3. The association of BMI-TTR with diabetes incidence by subgroups.

Variable	Adjusted HR[a] (95% CI) Male ($n = 3143$)	*P* value	Adjusted HR[b] (95% CI)	*P* value	Adjusted HR[a] (95% CI) Age < 60 ($n = 3727$)	*P* value	Adjusted HR[b] (95% CI)	*P* value
TTR1								
TTR2	0.981 (0.663–1.451)	0.924	1.089 (0.725–1.636)	0.681	0.624 (0.434–0.897)	0.011	0.722 (0.495–1.054)	0.091
TTR3	0.753 (0.494–1.147)	0.186	0.853 (0.549–1.327)	0.481	0.494 (0.320–0.762)	0.001	0.601 (0.381–0.949)	0.029
TTR4	0.580 (0.411–0.818)	0.002	0.675 (0.461–0.988)	0.043	0.457 (0.329–0.634)	<0.001	0.570 (0.396–0.822)	0.003
BMI of wave 1			1.036 (1.000–1.074)	0.050			1.043 (1.013–1.074)	0.004
	Female (n=3519)				Age ≥ 60 (n=2935)			
TTR1								
TTR2	0.646 (0.461–0.903)	0.011	0.719 (0.509–1.016)	0.061	0.953 (0.667–1.363)	0.792	1.041 (0.720–1.506)	0.830
TTR3	0.567 (0.387–0.831)	0.004	0.660 (0.443–0.983)	0.041	0.808 (0.554–1.176)	0.265	0.902 (0.610–1.335)	0.607
TTR4	0.601 (0.449–0.803)	<0.001	0.707 (0.516–0.970)	0.032	0.725 (0.533–0.985)	0.040	0.822 (0.589–1.146)	0.247
BMI of wave 1			1.033 (1.010–1.057)	0.005			1.031 (1.002–1.060)	0.035
P for interaction	0.225		0.285		0.403		0.425	

TTR time in target range, *DM* diabetes mellitus, *BMI* body mass index, HR hazard ratio, *CI* confidence interval, *SBP* systolic blood pressure, *HR* heart rate, HDL high-density cholesterol, *HbA1c* glycated hemoglobin A1c, *hsCRP* high sensitivity C-reactive protein, *eGFR* estimated glomerular filtration rate.
[a]Adjusted For age, sex, hypertension, smoking, SBP, HR, hyperlipidemia, physical exercise, marital status, education, HDL-C, hsCRP, HbA1c, eGFR.
[b]Adjusted For age, sex, hypertension, smoking, SBP, HR, hyperlipidemia, physical exercise, marital status, education, HDL-C, hsCRP, HbA1c, eGFR, and BMI of wave 1.

CONCLUSIONS

Higher BMI-TTR was significantly associated with a reduced risk of long-term diabetes in non-diabetic middle-aged and older adults aged 45 and above, with the association being more pronounced in men and individuals under 60 years of age. Long-term monitoring and maintenance of body weight within the normal range can significantly reduce the risk of developing diabetes in the long term.

DATA AVAILABILITY

Data supporting the results of this study are available from official websites tttp://charls.pku.edu.cn and https://g2aging.org/.

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AUTHOR CONTRIBUTIONS

L.Z. conceived and designed the study; L.Z. and C.C. performed the study; L.Z. analyzed the data and drafted the paper, Y.Z., and F.D. helped to study. All authors read, critically revised, and approved the final manuscript.

COMPETING INTERESTS

The authors declare no competing interests.

CONSENT TO PUBLISH

All authors have reviewed the final version of the manuscript and approved it for publication.

ETHICAL APPROVAL

The China Health and Retirement Longitudinal Study was approved by the Ethics Review Committee of Peking University. Informed consent was obtained from each subject.

ADDITIONAL INFORMATION

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