Association of predicted fat mass, predicted lean mass and predicted percent fat with diabetes mellitus in Chinese population: a 15-year prospective cohort

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ABSTRACT

Objectives With body mass index (BMI) failing to distinguish the mass of fat from lean, several novel predicted equations for predicted fat mass (FM), predicted lean mass (LM) and predicted per cent fat (PF) were recently developed and validated. Our aim was to explore whether the three novel parameters could better predict diabetes mellitus (DM) than the commonly used obesity indicators, including BMI, waist circumference, hip circumference and waist-hip ratio.

Design A 15-year prospective cohort was used.

Setting It was a prospective cohort, consisting of a general Chinese population from 1992 to 2007.

Participants This cohort enrolled 711 people. People suffering from DM at baseline (n=24) were excluded, and 687 non-diabetics with complete data were included in the analysis.

Primary outcome New-onset DM.

Results After the follow-up, 74 (48 men and 26 women) incidences of DM were documented. For men, the adjusted HRs were 1, 5.19 (p=0.003) and 7.67 (p<0.001) across predicted PF tertiles; 1, 2.86 (p=0.029) and 5.60 (p<0.001) across predicted FM tertiles; 1, 1.21 (p=0.646) and 2.27 (p=0.025) across predicted LM tertiles. Predicted FM performed better than other commonly used obesity indicators in discrimination with the highest Harrell’s C-statistic among all the body composition parameters.

Conclusion Predicted PF, predicted LM and predicted FM could independently predict the risk of DM for men, with predicted FM performing better in discrimination than other commonly used obesity indicators. For women, larger samples were further needed.

INTRODUCTION

Diabetes mellitus (DM) is a collection of chronic metabolic conditions, characterised by elevated blood glucose levels resulting from the body’s inability to produce insulin or resistance to insulin action or both.1 There are two primary forms of DM, insulin-dependent DM (type 1 diabetes mellitus, T1DM) and non-insulin-dependent DM (type 2 diabetes mellitus, T2DM). T2DM is the most common form, making up 90%–95% of all patients with diabetes.1 DM and its complications can result in disability and premature death,2 as well as enormous economic and social burdens.3 There is no cure for DM; thus, prevention is the best intervention.

Among the well-known modifiable risk factors, obesity, defined as an excess accumulation of body fat, is regarded as a major risk factor.4 Body mass index (BMI) has been mostly used as a simple and reasonable measure of general adiposity in clinical and public health settings. However, since it is defined as the result of weight in kilogram divided by height in metre squared, BMI is in poor discrimination of metabolically distinct components such as fat mass (FM) and lean mass (LM).5 Direct measurement of FM and LM is impractical in large epidemiological studies for sophisticated and expensive technologies such as dual-energy X-ray absorptiometry (DXA) or imaging techniques (ie, MRI and CT).

Recently, Lee et al developed anthropometric prediction equations for FM, LM
and per cent fat (PF) from the large population samples of the non-institutionalized civilians in the USA from National Health and Nutrition Examination Survey. In the original study, the validation tests showed robust and consistent results without evident substantial bias, and comparable abilities to predict obesity-related biomarkers with direct DXA measurements. Later, based on two large US prospective cohorts, predicted FM and predicted PF were both estimated to have a stronger association than BMI with T2DM. However, body compositions differ across ethnic groups. Healthy Chinese and South Asian individuals were measured to have a greater amount of visceral adipose tissue than Europeans with the same BMI or waist circumference (WC). Therefore, we aimed to evaluate if these equations could better predict the risk of DM in comparison with BMI and other obesity indicators, including WC, hip circumference (HC) and waist-hip ratio (WHR), in a 15-year prospective cohort consisting of Chinese people.

MATERIALS AND METHODS

Study population
In 2007, supported by the Mega-projects of Science Research for China’s 11th Five-Year Plan (Trends in the incidence of metabolic syndrome and integrated control in China), a group of 711 people, from an urban community situated in Chengdu, China, underwent a health examination. They also had a health examination in 1992 as part of the Chinese Multi-provincial Cohort Study approved by Beijing Institute of Heart, Lung, and Blood Vessel Disease that investigated cardiovascular risk factors across the country. Therefore, we picked up the data, and more details have been described elsewhere. People suffering from DM at baseline (n=24) were excluded. No one had missing data. Finally, the remaining 687 people with complete data were included in the analysis. All of them provided written informed consent. The study was approved by the Ministry of Health of China, as well as the Ethics Committee of West China Hospital of Sichuan University.

Evaluation

Definition
DM was defined by self-reported history or fasting plasma glucose (FPG) ≥7.0 mmol/L. Hypertension was a conventional blood pressure of ≥140 mm Hg systolic, ≥90 mm Hg diastolic or the use of antihypertensive drugs. DM family history was determined with a diagnosis of DM in the first-grade relatives. Smoking was defined as an average cigarette consumption of at least one per day. Frequent previous alcohol intake and present alcohol intake were both defined as alcohol consumption. Activity was defined as at least twice 20 min moderately intensive physical activity per week.

Data collection
Baseline data in 1992 included medical history, physical examination and biochemical tests. Questionnaires containing demographic information and cardiovascular disease risk factors were collected by well-trained investigators. WC was measured at the midpoint between the lower border of the rib cage and the iliac crest at the end of a normal exhalation. HC was measured at the maximum protrusion of the gluteal region. WHR was calculated by WC in centimetre divided by HC in centimetre. Height was measured without shoes. Weight was measured in light clothing. Blood pressure was measured in a sitting position after at least 15 min of rest, and the mean blood pressure of three measurements taken by a standardised mercury sphygmomanometer was used as a participant’s blood pressure. Blood samples were drawn from participants in the morning after 12-hour overnight fasting. FPG, total cholesterol (TC) and triglyceride (TG) levels were determined in an enzymatic method, and high-density lipoprotein cholesterol (HDLC) was measured by the phosphotungstic acid/MgCl2 precipitation method. Low-density lipoprotein cholesterol (LDLC) was measured using a standard kit.

Equation profiles

\[\text{Equations for predicted FM (kg)}\]

For men:
\[-18.592 + 0.089 \times \text{age (year)} - 0.889 \times \text{height (cm)} + 0.226 \times \text{weight (kg)}
+ 0.387 \times \text{WC (cm)} + 0.090 \times \text{Mexican} - 0.188 \times \text{Hispanic} - 0.485
\times \text{Black} + 1.050 \times \text{other ethnicity}\]

For women:
\[11.817 + 0.041 \times \text{age (year)} - 0.199 \times \text{height (cm)} + 0.610 \times \text{weight (kg)}
+ 0.044 \times \text{WC (cm)} + 0.388 \times \text{Mexican} - 0.073 \times \text{Hispanic} - 1.187
\times \text{Black} + 0.525 \times \text{other ethnicity}\]

\[\text{Equations for predicted LM (kg)}\]

For men:
\[19.565 + 0.001 \times \text{age (year)} + 0.064 \times \text{height (cm)} + 0.756 \times \text{weight (kg)}
- 0.366 \times \text{WC (cm)} - 0.066 \times \text{Mexican} + 0.231 \times \text{Hispanic} + 0.432
\times \text{Black} - 1.087 \times \text{other ethnicity}\]

For women:
\[-10.685 - 0.039 \times \text{age (year)} + 0.186 \times \text{height (cm)} + 0.383 \times \text{weight (kg)}
- 0.043 \times \text{WC (cm)} - 0.359 \times \text{Mexican} - 0.059 \times \text{Hispanic} + 1.085
\times \text{Black} - 0.54 \times \text{other ethnicity}\]

\[\text{Equations for predicted PF (\%)}\]

For men:
\[0.02 + 0.00 \times \text{age (year)} - 0.07 \times \text{height (cm)} - 0.08 \times \text{weight (kg)}
+ 0.48 \times \text{WC (cm)} + 0.32 \times \text{Mexican} + 0.02 \times \text{Hispanic} - 0.65
\times \text{Black} + 1.12 \times \text{other ethnicity}\]

For women:
\[50.46 + 0.07 \times \text{age (year)} - 0.26 \times \text{height (cm)} + 0.27 \times \text{weight (kg)}
+ 0.10 \times \text{WC (cm)} + 0.89 \times \text{Mexican} + 0.49 \times \text{Hispanic} - 1.57
\times \text{Black} + 0.43 \times \text{other ethnicity}\]

Patient and public involvement
Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Statistical analyses
For descriptive results, variables were expressed as the mean±SD, median and IQR, or counts and percentages as appropriate. Smoking, alcohol intake, activity, hypertension and family history of DM were expressed as dummy variables (presence=1, absence=0). Differences
in baseline characteristics between participants with and without new-onset DM were tested by independent t-test for normally distributed variables and by the non-parametric Mann-Whitney U test for skewed variables. Interactions between categorical variables were evaluated with the Pearson’s χ² test, and Fisher’s exact probabilities were used if necessary. Correlations between different variables were determined using Pearson’s or Spearman’s analysis.

We treated all the parameters as sex-specific tertiles. The cumulative incidences of DM across tertiles were graphically displayed according to the method of Kaplan-Meier, with comparisons among groups by the log-rank test. Cox proportional hazards regression models were used to assess the impact of the variables on the incidence rate of DM. Furthermore, restricted cubic spline analysis was used to visualise the relations between variables and incident DM. To quantify and compare the discriminative ability of different parameters, Harrell’s c-index was calculated. A generally accepted approach suggests that the C-index of less than 0.60 reflects poor discrimination; 0.60–0.75, possibly helpful discrimination, and more than 0.75, clearly useful discrimination.¹⁴

All statistical tests were two sided, and p value <0.05 was considered statistically significant. Statistical analyses were performed using R V.3.6.3.

RESULTS

Baseline characteristics

After excluding people suffering from DM at baseline (n=24), the remaining 687 (399 men and 288 women) people free of DM at baseline with complete data were included in the analysis.

Those who had subsequent DM were associated with higher baseline levels of FPG, weight, BMI, WC, HC, predicted FM, predicted LM and predicted PF for men; associated with higher baseline levels of TC, TG, height, BMI, WC, HC, predicted FM and predicted PF, and lower baseline level of HDL-C for women. At baseline, age was not of significance between the two groups both in men and women, but there was still a trend that people suffering incident DM were older. Other details of baseline information are shown in table 1.

As shown in online supplemental table S1, predicted FM was strongly correlated with WC (r=0.98), followed

| Table 1 | Basic characteristics of people with or without subsequent DM |
|---------|---------------------------------------------------------------|
| Variables | Men (N=399) | Women (N=288) | P value | Men (N=399) | Women (N=288) | P value |
| Age (years) | 50.6±5.0 | 49.0 (45.0–53.0) | 0.079 | 48.4±6.8 | 46.0 (42.0–50.0) | 0.127 |
| Smoking (%) | 32 (66.7) | 213 (60.7) | 0.425 | 10 (0.8) | 1.000 |
| Hypertension (%) | 9 (18.8) | 50 (14.2) | 0.410 | 7 (26.9) | 38 (14.5) | 0.150 |
| DM family history (%) | 3 (6.3) | 9 (2.6) | 0.165 | 3 (11.5) | 18 (6.9) | 0.418 |
| SBP (mm Hg) | 118.1±14.5 | 110.0 (105.0–120.0) | 0.061 | 119.0 (103.0–132.5) | 110.0 (102.0–120.0) | 0.240 |
| DBP (mm Hg) | 74.0 (70.0–80.0) | 72.0 (70.0–80.0) | 0.292 | 76.4±12.1 | 70.0 (71.0–80.0) | 0.226 |
| FPG (mmol/L) | 4.6±0.8 | 4.0 (3.8–4.7) | <0.001 | 5.0±0.7 | 4.4 (3.9–5.0) | 0.052 |
| TC (mmol/L) | 4.4 (4.1–4.8) | 4.3 (3.9–4.8) | 0.049 | 5.0±0.7 | 4.4 (3.9–5.0) | 0.006 |
| TG (mmol/L) | 1.9 (1.7–3.0) | 1.9 (1.5–2.4) | 0.014 | 1.9 (1.5–2.3) | 1.8 (1.4–2.2) | <0.001 |
| HDL-C (mmol/L) | 1.2 (1.0–1.4) | 1.2 (1.1–1.4) | 0.193 | 1.2±0.2 | 1.3 (1.1–1.5) | 0.009 |
| LDL-C (mmol/L) | 2.2±0.8 | 2.1 (1.7–2.7) | 0.556 | 2.4±1.0 | 2.3 (1.8–2.8) | 0.460 |
| Height (cm) | 165±4.9 | 165±3.6 | 0.895 | 151.9±4.4 | 151.0 (155.0–159.0) | 0.006 |
| Weight (cm) | 68.5 (61.3–74.8) | 62.9±8.2 | <0.001 | 58.6±9.0 | 56.4±7.5 | 0.168 |
| BMI (kg/m²) | 24.8 (23.0–26.6) | 23.0 (20.9–24.8) | <0.001 | 25.3±3.3 | 24.2±2.6 | 0.001 |
| WC (cm) | 83.6±8.2 | 78.0 (72.0–83.0) | <0.001 | 79.9±7.6 | 73.5±7.1 | <0.001 |
| HC (cm) | 95.0 (90.0–97.0) | 91.0 (87.0–95.0) | <0.001 | 95.4±7.4 | 92.6±5.8 | 0.021 |
| WHR | 0.89±0.05 | 0.85±0.06 | 0.001 | 0.84±0.04 | 0.79±0.05 | <0.001 |
| FM (kg) | 16.4±5.2 | 13.3 (9.6–16.2) | <0.001 | 21.8±5.4 | 19.6±4.3 | 0.014 |
| LM (kg) | 50.2±5.0 | 48.1±4.5 | 0.004 | 34.3±3.8 | 34.4±3.4 | 0.894 |
| PF (%) | 24.0±3.4 | 21.9±3.1 | <0.001 | 36.9±2.9 | 36.4±2.4 | <0.001 |

BMI, body mass index; DBP, diastolic blood pressure; DM, diabetes mellitus; FM, fat mass; FPG, fasting plasma glucose; HC, hip circumference; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; LM, lean mass; PF, per cent fat; SBP, systolic blood pressure; TC, total cholesterol; TG, triglyceride; WC, waist circumference; WHR, waist-hip ratio.
by BMI ($r_s=0.88$) and HC ($r_s=0.82$) in men; strongly correlated with BMI ($r_s=0.94$), followed by HC ($r_s=0.87$) and WC ($r_s=0.83$) in women. Predicted LM had a strong correlation with predicted FM ($r_s=0.83$) in women and a relatively strong correlation with HC ($r_s=0.71$) in men, but relatively weakly with WHR both in men ($r_s=0.15$) and women ($r_s=0.29$). Predicted PF was strongly correlated with WC ($r_s=0.97$) in men and BMI ($r_s=0.95$) in women, but relatively weakly with predicted LM both in men ($r_s=0.35$) and women ($r_s=0.51$).

**Survival analysis**

All the body composition parameters were divided into tertiles. Tertile 1 had the lowest estimated values, while tertile 3 had the highest. The category boundaries of all the parameters were displayed by gender in online supplemental table S2. After the follow-up of 15 years, 74 (48 men and 26 women) incidences of DM were documented (incidence rate: 0.74 per 100 person-years; 95% CI: 0.57 to 0.91). As figure 1A–C present, for men, the cumulative incidences of DM evaluated by Kaplan-Meier analysis were significantly different across the tertiles of predicted FM ($A$, log-rank $p=0.001$), predicted LM ($B$, log-rank $p=0.030$) and predicted PF ($C$, log-rank $p<0.001$). For women ($n=288$), the cumulative incidence of DM evaluated by Kaplan-Meier analysis was just significantly different across the tertiles of predicted PF ($D$, log-rank $p=0.028$). People in the top tertile had the highest cumulative incidence of DM. DM, diabetes mellitus; FM, fat mass; LM, lean mass; PF, per cent fat.

![Figure 1](attachment:image.png) Cumulative incidence of DM across tertiles of novel predicted body composition during follow-up. Survival curves were presented as Kaplan-Meier curves, and the log-rank tests were used for comparison among tertiles. For men ($n=399$), the cumulative incidences of DM evaluated by Kaplan-Meier analysis were significantly different across the tertiles of predicted FM ($A$, log-rank $p=0.001$), predicted LM ($B$, log-rank $p=0.030$) and predicted PF ($C$, log-rank $p<0.001$). For women ($n=288$), the cumulative incidence of DM evaluated by Kaplan-Meier analysis was just significantly different across the tertiles of predicted PF ($D$, log-rank $p=0.028$). People in the top tertile had the highest cumulative incidence of DM. DM, diabetes mellitus; FM, fat mass; LM, lean mass; PF, per cent fat.
Relation to risk of DM

Univariable Cox regression analysis is shown in online supplemental table S3. Predicted FM, predicted PF, BMI, WC, HC and WHR were risk factors of DM both for men and women, and predicted LM was a risk factor for men only. Variables showing statistical significance in univariable analysis or clinical relevance (p<0.1) were entered into multivariable analysis.

In multivariable analysis, we adjusted potential confounders including hypertension (yes/no), DM family history (yes/no), smoking (yes/no), alcohol (yes/no), activity (yes/no), TG, TC, HDL-C, LDL-C and FPG in men; hypertension (yes/no), DM family history (yes/no), smoking (yes/no), alcohol (yes/no), activity (yes/no), SBP, TG, TC, HDL-C and FPG in women.

As table 2 shows, in men, predicted FM (p<0.001), predicted LM (p=0.043) and predicted PF (p<0.001) were all the significantly independent predictors with the top tertiles associated with the highest risk of DM. Compared with the other parameters we studied, predicted PF in higher level was more strongly associated with increased risk of DM, since it showed a positive association with the risk of DM with the adjusted HR for tertile 2 and tertile 3 estimated as 5.19 (95% CI: 1.77 to 15.20, p=0.003) and 7.67 (95% CI: 2.64 to 22.35, p<0.001), respectively. There was a positive association between predicted FM and the risk of DM (HR: 2.86, 95% CI: 1.12 to 7.33, p=0.029 for tertile 2; HR: 5.60, 95% CI: 2.27 to 13.80, p<0.001 for tertile 3, respectively) as well. Other commonly used parameters such as BMI (p<0.001), WC (p<0.001), HC (p=0.004) and WHR (p<0.001) were also significant predictors (online supplemental table S4), and WC and WHR showed a positive association across tertiles.

As for the women, however, none of the three novel parameters was significantly independent after adjustment (table 2), as well as other commonly used obesity indicators but WHR, which (p<0.001) remained stable and significant (online supplemental table S4).

Furthermore, as table 2 shows, we treated the predicted FM, predicted LM and predicted PF as continuous variables. In men, all of them were independent risk factors and it is true of the restricted cubic splines used to flexibly model and visualise the relations with risk of DM (online supplemental figure S1). With the medians as reference points, all the three novel parameters showed an overall positive association with DM in men (figure 1); while in women, only predicted PF was independently associated with DM (table 2; HR: 1.34 per 1-SD increase, 95% CI: 1.15 to 1.57, p<0.001), and the restricted cubic spline shows the similar relationship, especially after the median (online supplemental figure 2).

Discrimination

Table 3 shows discriminative abilities evaluated by Harrell’s c-index of different body composition parameters. In the male group, predicted FM had the highest Harrell’s c-index of 0.679 (95% CI: 0.606 to 0.752), and predicted LM had the lowest Harrell’s c-index of 0.619
In the female group, since WHR was the only significantly independent risk factor of DM both as continuous variable and categorical variable, we just estimated Harrell’s c-index of WHR (0.768, 95% CI: 0.697 to 0.839), and it showed a clearly useful discriminative ability in predicting DM.14

To our knowledge, this was the first study in a Chinese prospective cohort to evaluate the associations of three novel body composition parameters with the incidence of DM. BMI has been preferred as a measure indicating overall obesity for a long time to identify people at increased risk of DM.15 However, BMI was not thought as a good indicator of obesity recently.5 16 It fails to distinguish the mass of fat from lean and had no gender distinction as well. For example, in common sense, athletes or someone liking exercise always had heavier weight for the mass of lean, they have greater BMI but they are not obese. Besides, ageing is associated with an accumulation of visceral fat and a progressive loss of muscle mass.16 With the same BMI, an old man has more mass of fat with less mass of muscle than a younger man.

Recently, Lee et al6 developed equations predicting FM, LM and PF to better reflect body composition. The predicted equations had a simple calculation and just require the information of gender, age, height, weight, WC and ethnicity, which are easily measurable and accessible in clinical settings or even at home. Lee et al later investigated the association between predicted FM and risk of DM in two large prospective cohorts of US men and women.7 They found predicted FM, as well as predicted PF, had a stronger association with DM than BMI both in men and women. Similarly, in our study consisting of Chinese population, in the male group, both predicted FM

| Variables | Men | Women |
|-----------|-----|-------|
| FM        | 0.679 | 0.606 to 0.752 |
| LM        | 0.619 | 0.537 to 0.701 |
| PF        | 0.670 | 0.598 to 0.742 |
| BMI       | 0.675 | 0.599 to 0.751 |
| WC        | 0.673 | 0.600 to 0.746 |
| WHR       | 0.652 | 0.578 to 0.726 |
| HC        | 0.636 | 0.560 to 0.712 |

BMI, body mass index; FM, fat mass; HC, hip circumference; LM, lean mass; PF, per cent fat; WC, systolic blood pressure; T, tertile; TC, total cholesterol; TG, triglyceride.
and predicted PF could independently predict incident DM and predicted FM had the highest Harrell’s value. Higher predicted PF was more strongly associated with increased risk of DM than other parameters. 

Besides in prediction of DM, predicted FM and predicted PF were also explored in association with risk of heart failure and myocardial infarction in adults with T2DM. The results showed a decline in predicted FM but not predicted LM, over 1 year was significantly associated with lower risk of overall heart failure (adjusted HR per 10% decrease in predicted FM: 0.80; 95% CI: 0.68 to 0.95); decline in predicted FM was significantly associated with lower risk of both heart failure subtypes (with preserved or reduced ejection fraction).

In a post hoc analysis of data from the Action to Control Cardiovascular Risk in Diabetes (ACCORD) study, researchers modified the two parameters, FM index and lean BMI, calculated by predicted FM and predicted LM, respectively, in kilograms divided by the square of height in metres. They found that in patients with T2DM, FM index had a strong positive association with a higher risk of a major adverse cardiovascular event, while predicted lean BMI was not associated with major cardiovascular events (p=0.34).

In a large prospective US cohort study of men, there was a strong positive association between predicted FM and mortality from all causes, cardiovascular disease and cancer. Compared with those in the lowest fifth of predicted FM, men in the highest fifth had an HR of 1.35 (95% CI: 1.26 to 1.46) for all-cause mortality. In contrast, predicted LM showed a U-shaped association with all-cause mortality that men in the second to fourth-fifths had 8%–10% lower risk. The U-shaped associations were also found with deaths from cardiovascular disease and cancer. However, there was a strong inverse association between predicted LM and mortality from respiratory disease.

Lean body mass accounts for most of the human body mass, and it is essential not only in the stress response but also in metabolism. Muscle loss may have negative effects. Son et al previously conducted a 2-yearly prospective assessment in middle-aged and older Korean adults, and reported that low muscle mass was associated with an increased risk of T2DM, independent of general obesity. In contrast, in our research, for the development of DM, the protective role of predicted LM could not be concluded. Instead, the top tertile of predicted LM had an increased risk in the male group. Since there is a lack of randomised clinical trial studies that directly assess the role of increased muscle mass in the prevention of new onset DM, the association between predicted LM and risk of DM needs further explorations. After all, increased LM was not always simply reported as the protective factor of diseases or mortality.

There are certainly some limitations in our study. First, 687 was a relatively small sample size, possibly leading to a statistical power decrease, for example, the results in women. Nevertheless, we still observed that as a continuous variable, predicted PF could independently predict the risk of incident DM in women. Maybe in a larger population, the relationships and comparisons would be more accurate. Second, due to the absence of oral glucose tolerance tests and haemoglobin A1c data in our study, some people might not be adequately diagnosed. Third, only one follow-up examination was carried out, so that there was no guarantee whether some ‘interval censoring’ might have occurred.

In conclusion, in the general Chinese population, predicted FM, predicted LM and predicted PF could independently predict the risk of DM in men, and predicted FM performed better in discrimination than other commonly used obesity indicators including BMI, WC, HC and WHR. For women, however, predicted FM, predicted LM, predicted PF, as well as other obesity indicators, but WHR, could not remain stable and independent in multivariable analysis, which might be attributed to the relatively small sample size with the corresponding few endpoints. Therefore, the conclusion of these findings should be extrapolated with caution, and larger samples from different races are needed to explore the predictive abilities of the three novel equations reflecting body composition on incident DM and other diseases.

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Patient consent for publication Obtained.

Ethics approval This study involves human participants and was approved by Ministry of Health of China and the Ethics Committee of West China Hospital of Sichuan University. We inquired the source of the original data, and the literature (Chin J Cardiol 1999;27:5–8) did not give the reference number of the ethical units. Participants gave informed consent to participate in the study before taking part.

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**REFERENCES**

1. Wu Y, Ding Y, Tanaka Y, et al. Risk factors contributing to type 2 diabetes and recent advances in the treatment and prevention. *Int J Med Sci* 2014;11:1185–200.
2. Zheng Y, Ley SH, Hu FB. Global aetiology and epidemiology of type 2 diabetes mellitus and its complications. *Nat Rev Endocrinol* 2018;14:88–98.
3. Zhao Y, Jiang Z, Guo C. New hope for type 2 diabetics: targeting insulin resistance through the immune modulation of stem cells. *Autoimmun Rev* 2011;11:137–42.
4. Klein S, Sheard NF, Pi-Sunyer X, et al. Weight management through lifestyle modification for the prevention and management of type 2 diabetes: rationale and strategies. A statement of the American diabetes association, the North American association for the study of obesity, and the American Society for clinical nutrition. *Am J Clin Nutr* 2004;80:257–63.
5. Prentice AM, Jebb SA. Beyond body mass index. *Obes Rev* 2002;1:141–7.
6. Lee DH, Keum N, Hu FB, et al. Development and validation of anthropometric prediction equations for lean body mass, fat mass and percent fat in adults using the National health and nutrition examination survey (NHANES) 1999-2006. *Br J Nutr* 2017;118:858–66.
7. Lee DH, Keum N, Hu FB, et al. Comparison of the association of predicted fat mass, body mass index, and other obesity indicators with type 2 diabetes risk: two large prospective studies in US men and women. *Eur J Epidemiol* 2018;33:1113–23.
8. Lear SA, Humphries KH, Kohli S, et al. Visceral adipose tissue accumulation differs according to ethnic background: results of the multicultural community health assessment trial (M-CHAT). *Am J Clin Nutr* 2007;86:353–9.
9. Lear SA, Humphries KH, Kohli S, et al. The use of BMI and waist circumference as surrogates of body fat differs by ethnicity. *Obesity* 2007;15:2817–24.
10. Chan JCN, Malik V, Jia W, et al. Diabetes in Asia: epidemiology, risk factors, and pathophysiology. *JAMA* 2009;301:2129–40.
11. Ren J, Grundy SM, Liu J, et al. Long-Term coronary heart disease risk associated with very-low-density lipoprotein cholesterol in Chinese: the results of a 15-year Chinese Multi-Provincial cohort study (CMCS). *Atherosclerosis* 2010;211:327–32.
12. Liu J, Hong Y, D’Agostino RB, et al. Predictive value for the Chinese population of the Framingham CHD risk assessment tool compared with the Chinese Multi-Provincial cohort study. *JAMA* 2004;291:2391–9.
13. Alberti KG, Zimmet PZ, Definition ZPZ. Definition, diagnosis and classification of diabetes mellitus and its complications. Part 1: diagnosis and classification of diabetes mellitus provisional report of a who consultation. *Diabet Med* 1998;15:539–53.
14. Albo AC, Agoritsas T, Walsh M, et al. Discrimination and calibration of clinical prediction models: users’ guides to the medical literature. *JAMA* 2017;318:1377–84.
15. Vazquez G, Duval S, Jacobs DR, et al. Comparison of body mass index, waist circumference, and waist/hip ratio in predicting incident diabetes: a meta-analysis. *Epidemiol Rev* 2007;29:115–28.
16. Wannamethee SG, Atkins JL. Muscle loss and obesity: the health implications of sarcopenia and sarcopenic obesity. *Proc Nutr Soc* 2015;74:405–12.
17. Patel KV, Bahnsen JL, Gaussouin SA, et al. Association of baseline and longitudinal changes in body composition measures with risk of heart failure and myocardial infarction in type 2 diabetes: findings from the look ahead trial. *Circulation* 2020;142:2420–30.
18. Xing Z, Tang L, Chen J, et al. Association of predicted lean body mass, fat mass and fat mass with cardiovascular events in patients with type 2 diabetes mellitus. *CMAJ* 2019;191:E1042–8.
19. Lee DH, Keum N, Hu FB, et al. Predicted lean body mass, fat mass, and all cause and cause specific mortality in men: prospective US cohort study. *BMJ* 2019;362:k2575.
20. Wolfe RR. The underappreciated role of muscle in health and disease. *Am J Clin Nutr* 2006;84:475–82.
21. Ruiz JR, Sui X, Lobelo F, et al. Association between muscular strength and mortality in men: prospective cohort study. *BMJ* 2008;337:a1439.
22. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *J Am Geriatr Soc* 2002;50:889–96.
23. Son JW, Lee SS, Kim SR, et al. Low muscle mass and risk of type 2 diabetes in middle-aged and older adults: findings from the KoGES. *Diabetologia* 2017;60:865–72.
24. de Sousa MV, da Silva Soares DB, Caraça ER, et al. Dietary protein and exercise for preservation of lean mass and perspectives on type 2 diabetes prevention. *Exp Biol Med* 2019;244:992–1004.