Prediction of a new body shape index and body adiposity estimator for development of type 2 diabetes mellitus: The Rural Chinese Cohort Study

Chengyi Han1,2,3, Yu Liu2, Xizhuo Sun2, Xinpeng Luo1, Lu Zhang1,4, Bingyuan Wang1,4, Yongcheng Ren1,4, Junmei Zhou1, Yang Zhao1,4, Dongdong Zhang1,4, Xuejiao Liu1,4, Ming Zhang1 and Dongsheng Hu1,2*  
1Department of Preventive Medicine, Shenzhen University Health Sciences Center, 3688 Nantai Avenue, Shenzhen, Guangdong 518060, People’s Republic of China  
2The Third Affiliated Hospital of Shenzhen University, 47 Youyi Road, Shenzhen, Guangdong 518001, People’s Republic of China  
3Department of Infection Control, The First Affiliated Hospital of Henan University of TCM, 19 Renmin Road, Zhengzhou, Henan 450003, People’s Republic of China  
4Department of Epidemiology and Health Statistics, College of Public Health, Zhengzhou University, 100 Kexue Avenue, Zhengzhou, Henan 450001, People’s Republic of China

(Submitted 11 March 2017 – Final revision received 9 September 2017 – Accepted 26 September 2017 – First published online 16 November 2017)

Abstract
To compare the ability of a body shape index (ABSI) and body adiposity estimator (BAE) to BMI, waist circumference (WC) and waist:height ratio (WHtR) for predicting development of type 2 diabetes mellitus (T2DM) in rural adult Chinese. The prospective cohort study included 11 687 eligible participants who were free of T2DM at baseline. The risk of new-onset T2DM for ABSI, BAE, BMI, WC and WHtR quintiles was substantially increased (\(P_{\text{trend}} < 0.0001\)). After adjustment for multi-covariates, risk of T2DM was increased from the second to fifth quintile as compared with first quintile for ABSI (1.27; 95% CI 0.95, 1.69; 1.35; 95% CI 1.00, 1.82; 1.75; 95% CI 1.33, 2.32 and 1.87; 95% CI 1.40, 2.49; \(P_{\text{trend}} < 0.0001\)); BAE (1.82; 95% CI 1.38, 2.41; 1.93; 95% CI 1.38, 2.68; 2.73; 95% CI 1.94, 3.84 and 4.18; 95% CI 2.98, 5.87; \(P_{\text{trend}} < 0.0001\)); BMI (1.42; 95% CI 1.03, 1.97; 1.62; 95% CI 1.18, 2.23; 2.59; 95% CI 1.92, 3.50 and 3.90; 95% CI 2.90, 5.20; \(P_{\text{trend}} < 0.0001\)); WC (1.53; 95% CI 1.08, 2.17; 1.66; 95% CI 1.18, 2.33; 2.72; 1.97, 3.76 and 4.09; 95% CI 2.97, 5.62; \(P_{\text{trend}} < 0.0001\); and WHtR (1.40; 95% CI 0.98, 1.99; 2.06; 95% CI 1.47, 2.88; 2.90; 95% CI 2.10, 4.01 and 4.22; 95% CI 3.05, 5.85; \(P_{\text{trend}} < 0.0001\)). ABSI, BAE, BMI, WC and WHtR were effective and comparable in discriminating cases from non-cases of T2DM. Risk of T2DM was increased with elevated ABSI and BAE, but the predictive ability for T2DM did not differ than that of BMI, WC and WHtR in a rural Chinese population.

Key words: A body shape index: Body adiposity estimator: BMI: Waist circumstance: Waist:height ratio: Type 2 diabetes mellitus

In 2015, the International Diabetes Federation demonstrated that China has the highest number of adults with diabetes (109.6 million), and type 2 diabetes mellitus (T2DM) is the most common1. However, many people with T2DM remain unaware of their condition for a long time because the symptoms are usually less marked than with type 1 diabetes mellitus and may take years to be recognised2-4. As a result, many people already have complications when they receive a diagnosis of T2DM5. About 80% of T2DM could be prevented by behaviour and lifestyle intervention5. Therefore, identifying people at high risk of T2DM is indispensable for effective prevention strategies, which could help halt the inexorable increase in T2DM incidence.

Obesity is a confirmed risk factor of premature mortality6,7 and T2DM8. To predict premature mortality better, Krakauer & Krakauer9, proposed a body shape index (ABSI) based on waist circumference (WC) adjusted for height and weight. ABSI could predict premature mortality better than traditional anthropometric measurements (BMI or WC)10. Recently, a prospective cohort study based on 687 urban Chinese found that ABSI was a weaker predictor of diabetes mellitus than traditional anthropometric measurements (BMI or WC), but the study participants were from a smaller urban population11. In addition, some studies concluded that excess adiposity but not excess body weight was the real culprit of T2DM12,13. To respond to the condition of unavailable body fat information in some studies, an estimation equation based on a large white population that accounted for BMI, sex and age to body fat has been developed14. However, the predictive power of estimated body adiposity estimator (BAE) based on the equation for T2DM was not assessed in the Chinese population.

Abbreviations: ABSI, a body shape index; BAE, body adiposity estimator; T2DM, type 2 diabetes mellitus; WC, waist circumstance; WHtR, waist:height ratio.

* Corresponding author: D. Hu, fax +86 755 8667 1906, email hud@szu.edu.cn
The current study aimed to compare the power of ABSI and BAE with traditional anthropometric measurements (BMI, WC and waist-height ratio (WHtR)) for predicting new-onset T2DM in an adult Chinese population.

Methods

Study design and participants

A total of 19,443 participants 18 to 74 years old were recruited from a rural Chinese population between July and August 2007 and July and August 2008; 16,627 (85.5%) participants completed the follow-up between July and August 2013 and July and October 2014. A questionnaire interview was used to collect data on demographic characteristics (sex and age), behavioural variables (smoking and drinking), physical activity and medical and family history by interviewing all participants face to face at baseline and follow-up. Among the 16,627 participants who completed the follow-up, we excluded people who died (n = 881), had T2DM (n = 1260) and type 1 diabetes mellitus (n = 11), lacked fasting plasma glucose (FPG) values (n = 10) and anthropometric measurements (n = 4), had BMI <18.5 kg/m² (n = 446) at baseline; and lacked FPG values (n = 2328) at follow-up. Ultimately, 11,687 participants were included in the analysis.

Covariate measurement and definition

A smoker was defined as having smoked 100 or more cigarettes during the lifetime. An alcohol drinker was defined as having consumed alcohol twelve or more times in the past year. Physical activity level was classified as high, moderate and low according to the International Physical Activity Questionnaire score. Body weight and height were measured twice by procedures involving human subjects were approved by the Medical Ethics Committee of Shenzhen University Health Sciences Center. Written informed consent was obtained from all participants.

Definition of type 2 diabetes mellitus

A diagnosis of T2DM was considered with a history of diabetes mellitus, currently using anti-diabetic agents, or FPG level ≥7.0 mmol/l. We excluded participants with type 1 diabetes mellitus, gestational diabetes and other diabetes types. The time of onset of T2DM was collected by dedicated survey staff who used a specially designed questionnaire with face-to-face interviews for participants. Person-years of follow-up were computed as the date of onset of T2DM or follow-up minus the date of baseline examination.

Statistical analysis

The Shapiro–Wilk test was used to evaluate normality of continuous variables. Data are presented as medians and interquartile ranges for continuous variables according to result of normality test and numbers and percentages for categorical variables. Wilcoxon’s rank sum and χ² tests were used to evaluate differences in continuous and categorical variables, respectively. The trend of T2DM incidence with increased ABSI, BAE, WC, BMI and WHtR was assessed by Cochran–Mantel–Haenszel test. Cox proportional-hazards regression analysis was used to estimate the risk of T2DM by anthropometric measurements (ABSI, WC, BMI and WHtR) and BAE adjusted for sex, age, smoking, alcohol consumption, physical activity, SBP and DBP, and TC, TAG and HDL-cholesterol levels. Simultaneously, the receiver operating characteristic (ROC) curve was used to identify cut-off values that balanced both sensitivity and specificity well for the anthropometric measurement in terms of the specific T2DM risk factor, with respective sensitivity and specificity values reported. All statistical analyses involved use of SAS 9.1 (SAS Institute), and a two-tailed P < 0.05 was considered statistically significant. Software of Sample Size Calculations (Mark Woodward, The George Institute International Health; Lesley Francis, MIS Consultants Pty Ltd) was used estimated sample size. Statistical power was considered typically 80%, two-sided significance level typically 0.05, T2DM incidence of unexposed group 0.5%, relative risk 2.0 and exposed/unexposed 0.3. These parameters were set to criteria from previous studies (incidence of unexposed group: >0.5%; relative risk: >2.0,(9,20) and overweight: 30.1% (Report on nutrition and non-communicated diseases in Chinese population (2015)). Calculated result demonstrated the study need 12,136 participants. Therefore, sample size was adequate in the study.

Results

The baseline characteristics of study participants with and without T2DM during follow-up are in Table 1. During a median of 6.01 years (interquartile range: 5.49–6.06) of follow-up, we recorded 749 new-onset T2DM. Data for age, BMI, WC, WHtR,
Absi, BAЕ, SBР, DBР and TC, TAG and FPG levels were higher and HDL-cholesterol level was lower with T2DМ than non-T2DМ (P<0.0001), the groups did not differ by sex, smoking, alcohol consumption or physical activity (P>0.05).

Fig. 1 summarises the incidence and hazard ratios and 95% CI for T2DМ by Absi, BAЕ, BMI, WC and WHR (P<0.0001). As compared with the first quintile, with the second to fifth quintiles, the risk of T2DМ increased for ABSI (1-53; 95% CI 1-16, 2-03; 1-85; 95% CI 1-38, 2-47; 2-67; 95% CI 2-05, 3-48 and 3-55; 95% CI 2-72, 4-64; P<0.0001); BAЕ (1-97; 95% CI 1-50, 2-59; 1-53; 95% CI 1-15, 2-05; 2-36; 95% CI 1-81, 3-09 and 4-44; 95% CI 3-46, 5-71; P<0.0001); BMI (1-59; 95% CI 1-51, 2-21; 2-08; 95% CI 1-52, 2-84; 3-51; 95% CI 2-62, 4-69 and 5-95; 95% CI 4-51, 7-86; P<0.0001); WC (1-78; 95% CI 1-26, 2-53; 2-19; 95% CI 1-57, 3-07; 4-03; 95% CI 2-95, 5-51 and 7-00; 95% CI 5-19, 9-43; P<0.0001); and WHR (1-63; 95% CI 1-14, 2-31; 2-67; 95% CI 1-93, 3-71; 4-27; 95% CI 3-14, 5-82 and 7-24; 95% CI 5-38, 9-75; P<0.0001). After adjustment for sex, age, smoking, alcohol consumption, physical activity, SBР, DBР and TC, TAG and HDL-cholesterol levels, the association was consistent across the second to fifth quintiles for ABSI (1-27; 95% CI 0-95, 1-69; 1-35; 95% CI 1-00, 1-82; 1-75; 95% CI 1-33, 2-32 and 1-87; 95% CI 1-40, 2-49; P<0.0001); BAЕ (1-82; 95% CI 1-38, 2-41; 1-93; 95% CI 1-38, 2-68; 2-73; 95% CI 1-94, 3-84 and 4-18; 95% CI 2-98, 5-87; P<0.0001); BMI (1-42; 95% CI 1-03, 1-97; 1-62; 95% CI 1-18, 2-23; 2-59; 95% CI 1-92, 3-50 and 3-90; 95% CI 2-90, 5-26; P<0.0001); WC (1-53; 95% CI 1-48, 2-17; 1-72; 95% CI 1-18, 2-83; 2-7; 95% CI 1-97, 3-76 and 4-99; 95% CI 2-97, 5-62; P<0.0001); and WHR (1-40; 95% CI 0-98, 1-93; 2-06; 95% CI 1-47, 2-88; 2-9095 95% CI 95% CI 2-10, 4-01 and 4-22; 95% CI 3-05, 5-85; P<0.0001). As continuous variables for Absи, BAЕ, BMI, WC and WHR, the risk of T2DМ also increased in unadjusted and adjusted models (P<0.0001).

Baseline Absи, BAЕ, BMI, WC and WHR had moderate predictive ability for T2DM (AUC (ROC)), sensitivity and specificity but high negative predictive value and low positive predictive value (Fig. 2 and Table 2). Specificity for Absи and BAЕ for predicting T2DМ was higher than traditional anthropometric measurements (BMI, WC and WHR), but sensitivity, positive and negative predictive values, and AUC were lower (Fig. 2 and Table 2).

**Discussion**

We found risk of T2DM increased with elevated Absи and BAЕ. However, for predicting development of T2DМ, the ability of Absи and BAЕ did not differ from traditional anthropometric measurements (BMI, WC and WHR).
Like traditional anthropometric measures (BMI, WC and WHR), elevated ABSI was associated with increased T2DM incidence. To our knowledge, only three cohort studies have evaluated the association of ABSI and diabetes mellitus (13, 31, 32). One 15-year prospective cohort study of urban Chinese (n 687) found ABSI independently associated with development of diabetes mellitus (13). The 4-year retrospective cohort study of a Japanese population (n 37 581) demonstrated elevated ABSI as an independent risk factor of diabetes mellitus but not a better predictor than BMI and WC (31). Recently, the Atherosclerosis Risk in Communities (ARIC) study, with data for more than 11 years of follow-up, demonstrated that ABSI had a lower association and was an inferior discriminator of incident T2DM among all race-sex groups in a US population (32). A cross-sectional study based on 9555 Iranian adults suggested increased ABSI as an independent risk factor of abnormal glucose homeostasis but not a better predictor than BMI, WHR and BAE (33). Previous studies indicated higher WC and BMI as an independent risk factor of T2DM (22, 34). ABSI is based on WC and BMI (31). Recently, the Atherosclerosis Risk in Communities study (n 47 581) demonstrated elevated ABSI as an independent risk factor of abnormal glucose homeostasis but not a better predictor than BMI, WHR and BAE (33). ABSI was based on WC and BMI adjusted for height and weight. Therefore, high ABSI would be associated with increased T2DM incidence. A multicultural community-health assessment trial in Canada based on computed tomography demonstrated different amounts of abdominal adipose tissue among ethnic groups (35). Development of ABSI, combining WC (mainly measurement of abdominal adipose tissue), height and strain indices, might explain the weak predictive ability of ABSI for T2DM incidence.

We found general obesity (elevated BMI level) and central obesity (elevated WC) derived from excess adipose tissue as independent risk factors of T2DM incidence (35), which is the best explanation for the relationship of increased BAE and T2DM incidence. Although the risk of T2DM did not differ with high BAE, WC or WHR, BAE was not a better predictor of T2DM than WC and WHR in our study. The predictive power of BAE for T2DM might be affected by some confounding factors for identifying type 2 diabetes mellitus (T2DM). Elevated ABSI was associated with increased T2DM incidence. To our knowledge, only three cohort studies have evaluated the association of ABSI and diabetes mellitus (13, 31, 32). One 15-year prospective cohort study of urban Chinese (n 687) found ABSI independently associated with development of diabetes mellitus (13). The 4-year retrospective cohort study of a Japanese population (n 37 581) demonstrated elevated ABSI as an independent risk factor of diabetes mellitus but not a better predictor than BMI and WC (31). Recently, the Atherosclerosis Risk in Communities (ARIC) study, with data for more than 11 years of follow-up, demonstrated that ABSI had a lower association and was an inferior discriminator of incident T2DM among all race-sex groups in a US population (32). A cross-sectional study based on 9555 Iranian adults suggested increased ABSI as an independent risk factor of abnormal glucose homeostasis but not a better predictor than BMI, WHR and BAE (33). Previous studies indicated higher WC and BMI as an independent risk factor of T2DM (22, 34). ABSI is based on WC and BMI adjusted for height and weight. Therefore, high ABSI would be associated with increased T2DM incidence. A multicultural community-health assessment trial in Canada based on computed tomography demonstrated different amounts of abdominal adipose tissue among ethnic groups (35). Development of ABSI, combining WC (mainly measurement of abdominal adipose tissue), height and weight, was based on the adult American (10). Hence, ethnic differences might explain the weak predictive ability of ABSI for T2DM incidence.

We found general obesity (elevated BMI level) and central obesity (elevated WC) derived from excess adipose tissue as independent risk factors of T2DM incidence (35), which is the best explanation for the relationship of increased BAE and T2DM incidence. Although the risk of T2DM did not differ with high BAE, WC or WHR, BAE was not a better predictor of T2DM than WC and WHR in our study. The predictive power of BAE for T2DM might be affected by some confounding

<table>
<thead>
<tr>
<th>Variables</th>
<th>No. of T2DM</th>
<th>Person-years of follow-up</th>
<th>Incidence (/1000 person-years)</th>
<th>HR 95 % CI</th>
<th>HR 95 % CI*</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSI (m11/6 kg–23)</td>
<td>74</td>
<td>14 112.79</td>
<td>5.24</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>WC (cm)</td>
<td>81</td>
<td>14 203.11</td>
<td>5.78</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>WHtR</td>
<td>142</td>
<td>13 946.39</td>
<td>10.18</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>BAE</td>
<td>105</td>
<td>13 811.42</td>
<td>7.68</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>BMI (kg/m2)</td>
<td>157</td>
<td>13 770.90</td>
<td>11.40</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>WHR</td>
<td>248</td>
<td>13 487.85</td>
<td>19.57</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>WC (cm)</td>
<td>749</td>
<td>69 219.66</td>
<td>10.82</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Fig. 1. Cox proportional-hazards analysis of predictors of type 2 diabetes mellitus (T2DM) incidence. ABSI, a body shape index; BAE, body adiposity estimator; HR, hazard ratio; WC, waist circumference; WHtR, waist-height ratio. * Adjusted for baseline sex, age, smoking, alcohol consumption, physical activity, systolic and diastolic blood pressure and total cholesterol, TAG and HDL-cholesterol levels.

Fig. 2. Adjusted receiver operating characteristic (ROC) curves for baseline factors for identifying type 2 diabetes mellitus (T2DM). Adjusted waist circumference (AUC 0.632); adjusted BMI (AUC 0.618); adjusted waist-height ratio (AUC 0.633); adjusted body adiposity estimator (AUC 0.618); adjusted a body shape index (AUC 0.584). Adjusted for baseline sex, age, smoking, alcohol consumption, physical activity, systolic and diastolic blood pressure and total cholesterol, TAG and HDL-cholesterol levels.
may facilitate the development and promotion of preventive strategies aimed at obesity to reduce T2DM incidence. ABSI and BAE, but these factors are not better predictors of T2DM warranted when interpreting and comparing the sex, which might suggest follow-up bias. Therefore, caution is status. The results showed significantly between

This analysis has several strengths, including its novel evaluation, relatively large sample size, community-based participants and face-to-face interviews. However, all participants were from rural areas, which might decrease the representativeness. We used only FPG to detect undiagnosed T2DM in this study, which may underestimate the incidence of T2DM. Many factors affect T2DM incidence. Because of lack of information on some factors, their potential effect on T2DM may not be fully eliminated, although we adjusted for multi-covariates by Cox regression analysis. Considering a 14.5% lost to follow-up, statistical analysis was performed on baseline demographic characteristics by response status. The results showed significant differences between responding and non-responding participants for age but not sex, which might suggest follow-up bias. Therefore, caution is warranted when interpreting and comparing the findings.

In conclusion, the risk of T2DM may be increased with elevated ABSI and BAE, but these factors are not better predictors of T2DM than BMI, WC or WHtR in rural Chinese population. Our findings may facilitate the development and promotion of preventive strategies aimed at obesity to reduce T2DM incidence.

Acknowledgements

The investigators are grateful to the dedicated participants and all research staff of the study.

This work was supported by the National Natural Science Foundation of China (grant nos 81373074, 81402752, 81673260); and the Science and Technology Development Foundation of Shenzhen (grant no. JCYJ20160307155707264). C. H. and D. H.: design of the study. C. H., Y. L., X. S., X. L., L. Z., Y. R., B. W., J. Z. and Y. Z.: researched and analysed the data. C. H.: wrote the manuscript. D. Z., X. L., M. Z. and D. H.: contributed to the discussion and reviewed/edited the manuscript. All authors read and approved the final manuscript.

The authors declare that there are no conflicts of interest.

References


