Chinese visceral adiposity index, a novel indicator of visceral obesity for assessing the risk of incident hypertension in a prospective cohort study

Minghui Han1†, Ranran Qie2†, Quanman Li1, Leilei Liu1, Shengbing Huang1, Xiaoyan Wu2, Dongdong Zhang1, Cheng Cheng1, Yang Zhao1, Dechen Liu1, Chunmei Guo1, Qiongguai Zhou2, Gang Tian1, Yanyan Zhang2, Yuying Wu2, Yang Li2, Xingxin Yang1, Yang Zhao1, Yifei Feng1, Pei Qin2, Fulan Hu2, Ming Zhang2 and Dongsheng Hu1*†

1Department of Epidemiology and Health Statistics, College of Public Health, Zhengzhou University, Zhengzhou, Henan 450000, People’s Republic of China
2Department of Biostatistics and Epidemiology, School of Public Health, Shenzhen University Health Science Center, Shenzhen, Guangdong 518000, People’s Republic of China

(Submitted 6 August 2020 – Final revision received 7 October 2020 – Accepted 27 October 2020 – First published online 4 November 2020)

Abstract
The present study aimed to investigate the association of the Chinese visceral adiposity index (CVAI) and its 6-year change with hypertension risk and compare the ability of CVAI and other obesity indices to predict hypertension based on the Rural Chinese Cohort Study. Study participants were randomly recruited by a cluster sampling procedure, and 10,034 participants ≥18 years were included. Modified Poisson regression was used to derive adjusted relative risks (RR) and 95% CI. We identified 2072 hypertension cases during a median of 6.03 years of follow-up. The RR for the highest vs. lowest CVAI quartile were 1.29 (95% CI 1.05, 1.59) for men and 1.53 (95% CI 1.22, 1.91) for women. Per-SD increase in CVAI was associated with hypertension for both men (RR 1.09, 95% CI 1.02, 1.16) and women (RR 1.14, 95% CI 1.06, 1.22). Also, the area under the receiver operating characteristic curve value for hypertension was higher for CVAI than the four other obesity indices for both sexes (all P < 0.05). Finally, per-SD increase in CVAI change was associated with hypertension for both men (RR 1.26, 95% CI 1.16, 1.36) and women (RR 1.23, 95% CI 1.15, 1.30). Similar results were observed in sensitivity analyses. CVAI and its 6-year change are positively associated with hypertension risk. CVAI has better performance in predicting hypertension than other visceral obesity indices for both sexes. The current findings suggest CVAI as a reliable and applicable predictor of hypertension in rural Chinese adults.

Key words: Chinese visceral adiposity index; Hypertension; Receiver operating characteristic curves; Prospective cohort studies

Hypertension is the most important risk factor for CVD and the leading preventable cause of premature death and disability worldwide[1,2]. A pragmatic global screening campaign by the International Society of Hypertension detected hypertension in 502,079 (3.5-4%) individuals among 1,504,963 aged 18 years and older who were screened in 2018[3]. In China, a national survey from 2014 to 2017 including 1,738,886 participants showed that almost half of Chinese adults aged 35–75 years had hypertension[4]. Despite the high prevalence, the levels of awareness, treatment and control of hypertension among Chinese remain low[4]. Therefore, early and accurate identification of hypertension-related risk factors is urgently needed to effectively prevent its incidence and then reduce its disease burden.

Visceral adiposity index (VAI) was found as a reliable index for evaluating visceral fat dysfunction and to have better prediction value than traditional clinical parameters for metabolic disorders in Caucasians[5,6]. Considering the different characteristic of body fat in Asian populations as compared with Caucasians[7,8], recently, the Chinese visceral adiposity index (CVAI), which combines demographic (age), anthropometric (BMI and waist circumference (WC)) and metabolic characteristics (serum TAG and HDL-cholesterol), was developed in Chinese adults[9]. Cross-sectional study including 6495 participants showed that CVAI is superior to BMI, WC and VAI in predicting the metabolic syndrome, hypertension, diabetes and prediabetes[9]. There were also some prospective studies reporting a positive association between
CVs and risk of incident diabetes\(^{18-20}\). However, whether CVs is also positively associated with risk of incident hypertension remains unknown. In addition, the effect of CVs change on hypertension incidence and the performance of CVAI for predicting incident unknown. In addition, the effect of CVAI change on hypertension also positively associated with risk of incident hypertension remains age, BMI, WC, and TAG and HDL-cholesterol levels (\(t^{23}\)), hypertension at baseline (\(t^{24}\)) and missing data for follow-up age, BMI, WC, and TAG and HDL-cholesterol levels (\(t^{25}\)) among the 20 194 study participants; finally, a total of 10 304 non-hypertensive participants recruited by a cluster sampling procedure.

Methods

Study population

The Rural Chinese Cohort Study was a prospective cohort study, and participants were selected by cluster random sampling among people \(\geq\)18 years old who had lived for at least 10 years in a rural area of Henan Province in China. All participants were free of severe psychological disorders, physical disabilities, Alzheimer’s disease, dementia, tuberculosis, AIDS or other infectious diseases at the time of enrolment. Ultimately, a total of 20 194 participants were recruited at baseline during July to August 2007 and July to August 2008, and 17 265 participants (response rate 85.5\%) were successfully followed up during July to August 2013 and July to October 2014. Details of the study design and participant characteristics were described previously\(^{13,14}\). Written informed consent was obtained from each participant after a full explanation of the study, which was approved by the Ethics Committee of Zhengzhou University.

In the primary analysis, we excluded participants with hypertension at baseline (\(n\) 6229), hypertension status at baseline or follow-up unknown (\(n\) 3554) and missing data for baseline age, BMI, WC, and TAG and HDL-cholesterol levels (\(n\) 37) among the 20 194 study participants; finally, a total of 10 304 individuals were included to evaluate the association between baseline CVs and risk of hypertension. In the second analysis, we excluded participants with missing data for follow-up age, BMI, WC, and TAG and HDL-cholesterol levels (\(n\) 945) and therefore had data for 9359 participants to assess risk of incident hypertension with 6-year change in the CVAI (online Supplementary Fig. S1).

Baseline data collection

Questionnaires including items on demographic characteristics (age, sex, marital status and educational level), behavioural measures (smoking, alcohol drinking and physical activity) and medical history (anti-hypertensive medication and lipid-lowering medication history) were administered by trained research staff during face-to-face interviews. Drinking was defined as drinking alcohol at least 12 times during the last year\(^{19}\). Physical activity level was classified by the International Physical Activity Questionnaire scoring protocol\(^{16}\). Family history of hypertension was defined as having at least one first-degree family member with hypertension. For measuring anthropometric indices, participants were asked to wear light clothes and be barefoot. Height was measured to the nearest 0.1 cm with participants standing erect. Weight was measured to the nearest 0.5 kg by use of a vertical weight scale. WC was measured at the mid-point between the lowest rib and the iliac crest to the nearest 0.1 cm with participants gently breathing. Participants were measured twice, and the average was used for analyses. BMI was calculated as weight (kg) divided by height (m) squared. ABMI was defined as WC/(BMI\(^{0.5}\)) \times (height\(^{0.5}\))\(^{17}\).

Participants were instructed to refrain from smoking and consuming alcohol, coffee and tea before blood pressure (BP) measurement. They sat comfortably with the arm positioned at the level of the heart during the measurement. BP was measured with an electronic oscillometric BP measurement device (HEM-770 AFuzzy) during one visit by trained health workers, according to the American Heart Association’s standardised protocol\(^{18}\). The measurements were repeated three times with a 30-s interval, and the average was used for the analysis. Hypertension was defined as systolic BP (SBP) \(\geq\)140 mmHg and/or diastolic BP (DBP) \(\geq\)90 mmHg and/or use of antihypertensive medication\(^{19}\).

Blood samples were obtained after an overnight fast of at least 8 h. Levels of fasting plasma glucose, TAG, total cholesterol and HDL-cholesterol were measured using a HITACHI automatic clinical analyzer (model 7060). The CVAI\(^{20}\) and VAI\(^{21}\) were calculated as follows:

\[
\text{CVAI} (\{men}) = -267.93 + 0.68 \times \text{age} + 0.03 \times \text{BMI} + 4.00 \times \text{WC} + 22.00 \times \log_{10} \text{TAG} - 16.32 \\
 \times \text{HDL-cholesterol}
\]

\[
\text{CVAI} (\{women}) = -187.32 + 1.71 \times \text{age} + 4.23 \\
 \times \text{BMI} + 1.12 \times \text{WC} + 39.76 \times \log_{10} \text{TAG} - 11.66 \times \text{HDL-cholesterol}
\]

\[
\text{VAI} (\{men}) = (\text{WC}/(39.68 + (1.88 \times \text{BMI})) \times (\text{TAG}/1.05) \\
 \times (1/\text{HDL-cholesterol})
\]

\[
\text{VAI} (\{women}) = (\text{WC}/(36.58 + (1.89 \times \text{BMI})) \times (\text{TAG}/0.81) \\
 \times (1.52/\text{HDL-cholesterol})
\]

Follow-up examination

The same questionnaire interview, anthropometric measurements and laboratory measurements at baseline were performed during the follow-up visits. The same definitions for hypertension and CVAI were adopted in the follow-up.

Statistical analyses

The 6-year change in CVAI was calculated as CVAI at the end of follow-up minus that at baseline. Continuous variables are described with medians and interquartile ranges because of skewed distribution and were analysed by the Wilcoxon two-
sample test. Categorical variables are described with frequencies and percentages and were analysed by the χ² test. Sex-specific analyses were conducted for all results.

Modified Poisson regression is commonly used to derive adjusted relative risks (RR) and 95% CI for cohort studies. In the primary analysis, study participants were classified by four CVAI quartiles, with the lowest quartile as the reference. We also estimated risk of hypertension with per-SD increase in CVAI. Model 1 was adjusted for age at baseline, model 2 was adjusted for model 1 plus marital status, educational level, drinking, physical activity and family history of hypertension at baseline and model 3 was further adjusted for model 2 plus SBP, DBP and fasting plasma glucose and total cholesterol level at baseline. Sensitivity analysis was conducted by excluding participants with cancers, kidney disease, stroke, myocardial infarction or heart failure at baseline to minimise the potential influence on risk estimates in model 4 and further excluding participants with lipid-lowering medication history in model 5. We used restricted cubic splines analysis to explore the dose-response association between CVAI and risk of hypertension, with the knot at 25th percentile of the distribution as the reference. Finally, area under the receiver operating characteristic curve analysis was used to evaluate the predictive value of incident hypertension with baseline CVAI, VAI, ABSI, WC and BMI; differences between area under the receiver operating characteristic curve for these obesity indices were tested with the Z statistic.

In the second analysis, study participants were classified by four CVAI change quartiles, with the quartile containing 0 as the reference. We also estimated risk of hypertension with per-SD increase in CVAI change. Model 1 was adjusted for age at baseline, model 2 was further adjusted for model 1 plus marital status, educational level, drinking, physical activity and family history of hypertension at baseline and model 3 was further adjusted for model 2 plus SBP, DBP, fasting plasma glucose and total cholesterol levels, and CVAI at baseline. Sensitivity analysis was conducted by excluding participants with cancers, kidney disease, stroke, myocardial infarction or heart failure at baseline to minimise the potential influence on risk estimates in model 4 and further excluding participants with lipid-lowering medication history in model 5. The receiver operating characteristic curves were calculated using Medcalc version 9.3, and other analyses involved using SAS version 9.4 for Windows (SAS Institute). Two-sided P < 0.05 was considered statistically significant.

**Results**

**Demographic characteristics of the study participants**

A total of 10,304 participants (women 6,240) were included in the study. Median age for men and women was 51.00 (interquartile range 41.00–59.00) and 46.00 (interquartile range 39.00–55.00) years, respectively. Baseline characteristics of study participants with and without hypertension stratified by sex are presented in Table 1. For both men and women, participants with hypertension had higher WC, BMI, SBP, DBP, fasting plasma glucose and total cholesterol levels, ABSI and CVAI than those without hypertension (all P < 0.05). However, participants with hypertension had higher TAG level and VAI and lower proportion of married/cohabitating for women but not men (all P < 0.05). Participants without hypertension were more likely physically active for men but not women (P < 0.05).

**Association of baseline Chinese visceral adiposity index and hypertension risk**

During a mean of 6.03 (range 4.80–7.23) years of follow-up, hypertension developed in 839 of 4064 men and 1233 of 6240 women. The cumulative incidence of hypertension for participants in quartiles 1, 2, 3 and 4 of the CVAI was 13.08, 17.65, 22.52 and 29.33%, respectively, for men and 7.82, 16.22, 22.56 and 32.64%, respectively, for women (Table 2). With increasing CVAI quartile, hypertension risk increased for both men and women (all P < 0.05). In unadjusted models, with CVAI quartile 1 as the reference, with quartiles 2, 3 and 4, the RR for hypertension were 1.25 (95% CI 1.02, 1.54), 1.57 (95% CI 1.29, 1.90) and 2.03 (95% CI 1.69, 2.45), respectively, for men, and 1.69 (95% CI 1.37, 2.09), 2.11 (95% CI 1.71, 2.61) and 2.62 (95% CI 2.11, 3.26), respectively, for women. After adjusting for potential confounding factors, the positive association between CVAI and hypertension risk persisted only with the highest quartile for men (RR 1.29, 95% CI 1.05, 1.59, model 3). For women, CVAI quartiles 2, 3 and 4 were significantly associated with hypertension in model 3; the adjusted RR were 1.34 (95% CI 1.08, 1.65), 1.42 (95% CI 1.15, 1.76) and 1.53 (95% CI 1.22, 1.91), respectively.

Risk of hypertension was increased with per-SD increase in CVAI for both men and women. The adjusted RR were 1.09 (95% CI 1.02, 1.16) for men and 1.14 (95% CI 1.06, 1.22) for women in model 3. The positive association between CVAI and hypertension risk persisted on further excluding participants with cancers, kidney disease, stroke, myocardial infarction, heart failure or lipid-lowering medication history at baseline. Restricted cubic splines indicated a significant non-linear dose-response association between CVAI and hypertension risk for both men and women (all Pnon-linearity < 0.01, Figs. 1 and 2).

**Comparison of the association of Chinese visceral adiposity index, visceral adiposity index, a body shape index, BMI and waist circumference with hypertension risk**

The receiver operating characteristic curve analysis of the association between the five obesity indices and hypertension for men and women is in online Supplementary Figs. S2 and S3. The area under the receiver operating characteristic curves for CVAI, VAI, ABSI, WC and BMI were 0.611 (95% CI 0.595, 0.626), 0.542 (95% CI 0.526, 0.557), 0.567 (95% CI 0.552, 0.583), 0.591 (95% CI 0.576, 0.606) and 0.597 (95% CI 0.582, 0.612), respectively, for men, and 0.672 (95% CI 0.661, 0.684), 0.584 (95% CI 0.572, 0.597), 0.599 (95% CI 0.587, 0.612), 0.609 (95% CI 0.597, 0.621) and 0.586 (95% CI 0.574, 0.598), respectively, for women. The CVAI had the largest area under the receiver operating characteristic curve value for hypertension among the five obesity indices, and the differences were all statistically significant (all P < 0.05).
Table 1. Baseline characteristics of the study participants with and without hypertension by sex  
(Medians and interquartile ranges (IQR); numbers and percentages)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Men</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Women</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-hypertension  (n 3225)</td>
<td>Hypertension (n 839)</td>
<td></td>
<td></td>
<td></td>
<td>Non-hypertension  (n 5007)</td>
<td>Hypertension (n 1233)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>IQR</td>
<td>Median</td>
<td>IQR</td>
<td>P</td>
<td>Median</td>
<td>IQR</td>
<td>Median</td>
<td>IQR</td>
</tr>
<tr>
<td>Age (years)</td>
<td>50.00</td>
<td>40.00–58.00</td>
<td>55.00</td>
<td>45.00–63.00</td>
<td>&lt;0.01</td>
<td>45.00</td>
<td>38.00–54.00</td>
<td>52.00</td>
<td>43.00–60.00</td>
</tr>
<tr>
<td>Married/cohabitating (n and %)</td>
<td>2941</td>
<td>91.22</td>
<td>756</td>
<td>90.32</td>
<td>0.42</td>
<td>4729</td>
<td>94.45</td>
<td>1124</td>
<td>91.16</td>
</tr>
<tr>
<td>High school or higher (n and %)</td>
<td>538</td>
<td>16.68</td>
<td>120</td>
<td>14.30</td>
<td>&lt;0.01</td>
<td>401</td>
<td>8.01</td>
<td>61</td>
<td>4.95</td>
</tr>
<tr>
<td>Drinking (n and %)</td>
<td>1012</td>
<td>31.38</td>
<td>222</td>
<td>26.46</td>
<td>&lt;0.01</td>
<td>36</td>
<td>0.72</td>
<td>10</td>
<td>0.81</td>
</tr>
<tr>
<td>Physical activity (n and %)</td>
<td>Low</td>
<td>630</td>
<td>19.53</td>
<td>222</td>
<td>26.46</td>
<td>1510</td>
<td>30.16</td>
<td>373</td>
<td>30.25</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>643</td>
<td>19.94</td>
<td>134</td>
<td>15.97</td>
<td>1178</td>
<td>23.53</td>
<td>276</td>
<td>22.38</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>1952</td>
<td>60.53</td>
<td>483</td>
<td>57.57</td>
<td>2319</td>
<td>46.32</td>
<td>584</td>
<td>47.36</td>
</tr>
<tr>
<td>Family history of hypertension (n and %)</td>
<td>898</td>
<td>32.43</td>
<td>273</td>
<td>39.06</td>
<td>&lt;0.01</td>
<td>1459</td>
<td>32.90</td>
<td>399</td>
<td>38.33</td>
</tr>
<tr>
<td>WC (cm)</td>
<td>80.25</td>
<td>74.00–87.70</td>
<td>84.10</td>
<td>76.75–91.45</td>
<td>&lt;0.01</td>
<td>79.00</td>
<td>72.45–85.75</td>
<td>83.20</td>
<td>76.35–89.60</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>22.74</td>
<td>20.73–24.95</td>
<td>23.90</td>
<td>21.71–26.07</td>
<td>&lt;0.01</td>
<td>23.67</td>
<td>21.49–26.09</td>
<td>24.72</td>
<td>22.52–27.18</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>115.67</td>
<td>109.00–123.33</td>
<td>126.33</td>
<td>119.33–132.33</td>
<td>&lt;0.01</td>
<td>112.00</td>
<td>104.67–120.33</td>
<td>125.00</td>
<td>117.67–131.67</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>73.00</td>
<td>67.67–78.00</td>
<td>79.00</td>
<td>73.67–84.00</td>
<td>&lt;0.01</td>
<td>72.33</td>
<td>67.67–77.67</td>
<td>78.67</td>
<td>73.67–83.33</td>
</tr>
<tr>
<td>FPG (mmol/l)</td>
<td>5.26</td>
<td>4.92–5.66</td>
<td>5.37</td>
<td>5.02–5.81</td>
<td>&lt;0.01</td>
<td>5.27</td>
<td>4.94–5.66</td>
<td>5.44</td>
<td>5.09–5.91</td>
</tr>
<tr>
<td>TC (mmol/l)</td>
<td>4.21</td>
<td>3.69–4.80</td>
<td>4.34</td>
<td>3.79–4.95</td>
<td>&lt;0.01</td>
<td>4.27</td>
<td>3.73–4.93</td>
<td>4.53</td>
<td>3.97–5.18</td>
</tr>
<tr>
<td>TAG (mmol/l)</td>
<td>1.27</td>
<td>0.92–1.82</td>
<td>1.36</td>
<td>0.97–2.00</td>
<td>&lt;0.01</td>
<td>1.25</td>
<td>0.89–1.79</td>
<td>1.46</td>
<td>1.04–2.06</td>
</tr>
<tr>
<td>HDL-cholesterol (mmol/l)</td>
<td>1.09</td>
<td>0.95–1.26</td>
<td>1.08</td>
<td>0.93–1.24</td>
<td>0.05</td>
<td>1.18</td>
<td>1.03–1.37</td>
<td>1.16</td>
<td>1.00–1.33</td>
</tr>
<tr>
<td>ABSI</td>
<td>0.78</td>
<td>0.75–0.81</td>
<td>0.79</td>
<td>0.76–0.82</td>
<td>&lt;0.01</td>
<td>0.77</td>
<td>0.74–0.80</td>
<td>0.79</td>
<td>0.75–0.81</td>
</tr>
<tr>
<td>VAI</td>
<td>1.44</td>
<td>0.94–2.30</td>
<td>1.58</td>
<td>1.03–2.53</td>
<td>&lt;0.01</td>
<td>1.91</td>
<td>1.23–3.01</td>
<td>2.35</td>
<td>1.55–3.67</td>
</tr>
<tr>
<td>CVAI</td>
<td>71.78</td>
<td>42.98–104.86</td>
<td>91.41</td>
<td>60.95–123.30</td>
<td>&lt;0.01</td>
<td>72.54</td>
<td>46.77–100.15</td>
<td>96.56</td>
<td>73.55–120.09</td>
</tr>
</tbody>
</table>

WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; TC, total cholesterol; ABSI, a body shape index; VAI, visceral adiposity index; CVAI, Chinese visceral adiposity index.
Table 2. Association of baseline Chinese visceral adiposity index and risk of hypertension*  
(Relative risks (RR) and 95 % confidence intervals; numbers and ranges)

<table>
<thead>
<tr>
<th>Men</th>
<th>Quartile 1</th>
<th>RR</th>
<th>95 % CI</th>
<th>Quartile 2</th>
<th>RR</th>
<th>95 % CI</th>
<th>Quartile 3</th>
<th>RR</th>
<th>95 % CI</th>
<th>Quartile 4</th>
<th>RR</th>
<th>95 % CI</th>
<th>Per 1-sd</th>
<th>RR</th>
<th>95 % CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>&lt;46 28</td>
<td>46 28–75 58</td>
<td>75 58–109 65</td>
<td>≥109 65</td>
<td>298/1016</td>
<td>133/1017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of cases/participants</td>
<td>133/1017</td>
<td>179/1014</td>
<td>229/1017</td>
<td>298/1016</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>1 00</td>
<td>1 25</td>
<td>1 02, 1 54</td>
<td>1 57</td>
<td>1 29, 1 90</td>
<td>2 03</td>
<td>1 69, 2 45</td>
<td>&lt;0 01</td>
<td>1 30</td>
<td>1 23, 1 38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td>1 00</td>
<td>1 23</td>
<td>0 98, 1 55</td>
<td>1 55</td>
<td>1 25, 1 93</td>
<td>2 07</td>
<td>1 68, 2 55</td>
<td>&lt;0 01</td>
<td>1 30</td>
<td>1 22, 1 39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 3</td>
<td>1 00</td>
<td>1 05</td>
<td>0 85, 1 31</td>
<td>1 13</td>
<td>0 92, 1 39</td>
<td>1 29</td>
<td>1 05, 1 59</td>
<td>&lt;0 01</td>
<td>1 09</td>
<td>1 02, 1 16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 4</td>
<td>1 00</td>
<td>1 03</td>
<td>0 82, 1 30</td>
<td>1 13</td>
<td>0 91, 1 40</td>
<td>1 27</td>
<td>1 03, 1 58</td>
<td>0 01</td>
<td>1 09</td>
<td>1 01, 1 17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 5</td>
<td>1 00</td>
<td>1 01</td>
<td>0 80, 1 27</td>
<td>1 14</td>
<td>0 92, 1 41</td>
<td>1 29</td>
<td>1 03, 1 60</td>
<td>&lt;0 01</td>
<td>1 09</td>
<td>1 02, 1 18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Model 1: adjusted for age at baseline. Model 2: adjusted for model 1 as well as marital status, educational level, drinking, physical activity and family history of hypertension at baseline. Model 3: adjusted for model 2 as well as systolic blood pressure, diastolic blood pressure, fasting plasma glucose and total cholesterol at baseline. Model 4: adjusted for model 3 and further excluded participants with cancers, kidney disease, stroke, myocardial infarction or heart failure at baseline. Model 5: adjusted for model 4 and further excluded participants with lipid-lowering medication history at baseline.

Discussion

To our knowledge, this is the first prospective study to explore the association between the CVAI and risk of hypertension in Chinese populations. Our findings showed that the CVAI had the best performance as a predictor of hypertension among various obesity indices, followed by VAI, ABSI, WC and BMI. We observed dose-response associations between the CVAI, VAI, ABSI, WC and BMI in predicting incident hypertension, with the CVAI being the best predictor of hypertension for both sexes. Also, we compared the performance of CVAI, VAI, ABSI, WC and BMI in predicting hypertension for both sexes, and found that the CVAI had the highest predictive values than VAI, ABSI, WC and BMI for both sexes. Our findings indicate that CVAI may be a reliable index of body fat distribution and visceral adiposity in predicting incident hypertension.

Moreover, we have indicated that the association between the CVAI and risk of hypertension was increased with the highest quartile of CVAI change during the 6-year follow-up and hypertension risk. For men, risk of hypertension was increased 29 % for men with the highest quartile of CVAI change (≥109 65) compared with the lowest quartile (RR 26, 95 % CI 1 16, 1 19) (model 3). For women, risk of hypertension was increased 26 % for women with the highest quartile of CVAI change (≥109 65) compared with the lowest quartile (RR 23, 95 % CI 1 15, 1 30). Similar results were found in the sensitivity analyses.
found the CVAI with better predictive performance for hypertension than the VAI, WC and BMI in a Chinese population. Further research in other Asian populations may be needed to test the performance of the CVAI in predicting incident hypertension. As widely used and recommended obesity indices, WC and BMI are also good predictors for hypertension if data for blood lipid levels are not available.

Our analysis found a stronger association between baseline CVAI and hypertension for women than men ($P_{interaction} < 0.01$). Tang et al. also found that VAT was more strongly associated with SBP and DBP in women than men. The sex differences may be due to differences in fat distribution, sex hormones and the pathogenesis of hypertension. Further studies are needed to explore the potential mechanisms. Our analysis showed a positive association between CVAI gain and risk of hypertension for both men and women. Consistent with our findings, Chandra et al. found a 39% increased risk of hypertension with per-SD gain in VAT. Another study by Sullivan et al. observed a positive association between 5-year increase in intra-abdominal fat and risk of hypertension after adjusting for potential confounding factors. As compared with stable CVAI, decreased CVAI marginally lowered the risk of hypertension for men. The Framingham Heart Study Third Generation cohort gave similar findings, that decreasing VAT attenuation was positively associated with increased risk of hypertension after adjusting for BMI and WC. Also, Rosenquist et al. observed a positive association between CVAI gain and risk of hypertension for both men and women. Consistent with our findings, Chandra et al. found a 39% increased risk of hypertension with per-SD gain in VAT. Another study by Sullivan et al. observed a positive association between 5-year increase in intra-abdominal fat and risk of hypertension after adjusting for potential confounding factors. As compared with stable CVAI, decreased CVAI marginally lowered the risk of hypertension for men. The Framingham Heart Study Third Generation cohort gave similar findings, that decreasing VAT attenuation was positively associated with increased risk of hypertension after adjusting for BMI and WC. Also, Rosenquist et al. observed a positive association between CVAI gain and risk of hypertension for both men and women. Consistent with our findings, Chandra et al. found a 39% increased risk of hypertension with per-SD gain in VAT. Another study by Sullivan et al. observed a positive association between 5-year increase in intra-abdominal fat and risk of hypertension after adjusting for potential confounding factors. As compared with stable CVAI, decreased CVAI marginally lowered the risk of hypertension for men. The Framingham Heart Study Third Generation cohort gave similar findings, that decreasing VAT attenuation was positively associated with increased risk of hypertension after adjusting for BMI and WC.
Table 3. Association of 6-year change of Chinese visceral adiposity index during the 6-year follow-up and risk of hypertension* (Relative risks (RR) and 95 % confidence intervals; numbers and ranges)

<table>
<thead>
<tr>
<th>Quartile 1</th>
<th>Quartile 2</th>
<th>Quartile 3</th>
<th>Quartile 4</th>
<th>Per 1-SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR 95 % CI</td>
<td>RR 95 % CI</td>
<td>RR 95 % CI</td>
<td>RR 95 % CI</td>
<td>P_trend</td>
</tr>
</tbody>
</table>

**Men**

<table>
<thead>
<tr>
<th>No. of cases/participants</th>
<th>Range</th>
<th>RR 95 % CI</th>
<th>Range</th>
<th>RR 95 % CI</th>
<th>Range</th>
<th>RR 95 % CI</th>
<th>Range</th>
<th>RR 95 % CI</th>
<th>P_trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td>0.99</td>
<td>0.82, 1.19</td>
<td>1.04</td>
<td>0.86, 1.26</td>
<td>0.83</td>
<td>0.84, 1.26</td>
<td>0.85</td>
<td>0.84, 1.27</td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td>0.90</td>
<td>0.74, 1.11</td>
<td>0.98</td>
<td>0.75, 1.15</td>
<td>0.90</td>
<td>0.84, 1.24</td>
<td>0.86</td>
<td>0.84, 1.27</td>
</tr>
<tr>
<td>Model 3</td>
<td></td>
<td>0.85</td>
<td>0.71, 1.03</td>
<td>0.91</td>
<td>0.75, 1.15</td>
<td>0.83</td>
<td>0.84, 1.24</td>
<td>0.85</td>
<td>0.84, 1.27</td>
</tr>
<tr>
<td>Model 4</td>
<td></td>
<td>0.83</td>
<td>0.68, 1.01</td>
<td>0.91</td>
<td>0.76, 1.16</td>
<td>0.83</td>
<td>0.84, 1.24</td>
<td>0.85</td>
<td>0.84, 1.27</td>
</tr>
<tr>
<td>Model 5</td>
<td></td>
<td>0.85</td>
<td>0.69, 1.05</td>
<td>0.91</td>
<td>0.75, 1.16</td>
<td>0.83</td>
<td>0.84, 1.24</td>
<td>0.85</td>
<td>0.84, 1.27</td>
</tr>
</tbody>
</table>

**Women**

<table>
<thead>
<tr>
<th>No. of cases/participants</th>
<th>Range</th>
<th>RR 95 % CI</th>
<th>Range</th>
<th>RR 95 % CI</th>
<th>Range</th>
<th>RR 95 % CI</th>
<th>Range</th>
<th>RR 95 % CI</th>
<th>P_trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td>1.00</td>
<td>0.89, 1.20</td>
<td>1.01</td>
<td>0.86, 1.18</td>
<td>1.00</td>
<td>0.89, 1.22</td>
<td>1.00</td>
<td>0.89, 1.27</td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td>1.00</td>
<td>0.93, 1.16</td>
<td>0.99</td>
<td>0.84, 1.15</td>
<td>1.00</td>
<td>0.93, 1.22</td>
<td>1.00</td>
<td>0.93, 1.30</td>
</tr>
<tr>
<td>Model 3</td>
<td></td>
<td>1.00</td>
<td>0.95, 1.25</td>
<td>1.08</td>
<td>0.83, 1.30</td>
<td>1.00</td>
<td>0.90, 1.27</td>
<td>1.00</td>
<td>0.84, 1.19</td>
</tr>
<tr>
<td>Model 4</td>
<td></td>
<td>1.00</td>
<td>0.99</td>
<td>1.10</td>
<td>0.93, 1.22</td>
<td>1.00</td>
<td>0.94, 1.17</td>
<td>1.00</td>
<td>0.94, 1.19</td>
</tr>
<tr>
<td>Model 5</td>
<td></td>
<td>1.00</td>
<td>0.99</td>
<td>1.10</td>
<td>0.93, 1.22</td>
<td>1.00</td>
<td>0.94, 1.17</td>
<td>1.00</td>
<td>0.94, 1.19</td>
</tr>
</tbody>
</table>

* Model 1: adjusted for age at baseline. Model 2: adjusted for model 1 as well as marital status, educational level, drinking, physical activity and family history of hypertension at baseline. Model 3: adjusted for model 2 as well as systolic blood pressure, diastolic blood pressure, fasting plasma glucose, total cholesterol and Chinese visceral adiposity index at baseline. Model 4: adjusted for model 3 and further excluded participants with cancers, kidney disease, stroke, myocardial infarction or heart failure at baseline. Model 5: adjusted for model 4 and further excluded participants with lipid-lowering medication history at baseline.

**Conclusions**

Our results show higher baseline CVI and dynamic gain in CVI provide risk of incident hypertension in Chinese adults. The performance of CVI in predicting hypertension in Chinese adults is superior to other obesity indices, especially available in large prospective studies and randomised clinical trials. CVI may be used as a valuable, easily applicable and reliable clinical marker for identifying high risk of hypertension and promoting early intervention to reduce or delay the incidence of hypertension.

The present study was supported by the National Natural Science Foundation of China (grant number 81975186). The authors thank all the study investigators and staff and individuals who participated in the present study, especially Dr. JCYJ20170412110537191 and JCYJ20190808145805515.

We thank all the study investigators and staff and individuals who participated in the present study, especially Dr. JCYJ20170412110537191 and JCYJ20190808145805515.

Acknowledgements

We thank all the study investigators and staff and individuals who participated in the present study, especially Dr. JCYJ20170412110537191 and JCYJ20190808145805515.

We thank all the study investigators and staff and individuals who participated in the present study, especially Dr. JCYJ20170412110537191 and JCYJ20190808145805515.
M. H., R. Q. and D. H. designed and conducted the research; M. H. and R. Q. analysed the data and wrote the paper; Q. L., L. L., S. H., X. W., D. Z., C. C., Y. Z., D. L., C. G., Q. Z., G. T., Y. Z., Y. W., Y. L., X. Y., Y. Z., Y. F., P. Q., F. H. and M. Z. provided constructive suggestions and M. H. and R. Q. had primary responsibility for the final content. All authors read and approved the final manuscript for submission.

There are no conflicts of interest.

Supplementary material
For supplementary material referred to in this article, please visit https://doi.org/10.1017/S0007114520004298

References


