Correlation and prediction of trunk fat mass with four anthropometric indices in Chinese males

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To increase our understanding of the relationships of trunk fat mass (FMtrunk) and four anthropometric indices in Chinese males, 1090 males aged 20–40 years were randomly recruited from the city of Changsha, China. Waist circumference (WC) and hip circumference (HC) were measured using standardized equipment, and three other anthropometric indices of BMI, waist:hip ratio (WHR) and conicity index (CoI) were calculated using weight, height, HC and WC. FMtrunk (in kg) was measured using a Hologic QDR 4500 W dual-energy X-ray absorptiometry scanner. There was an increasing trend of FMtrunk, %FMtrunk (percentage of FMtrunk) and BMI, WC, WHR, CoI in successively older age groups (e.g. the mean FMtrunk values were 4·63 (SD 2·58), 5·39 (SD 2·74), 5·93 (SD 2·82), 6·57 (SD 2·94) in four 5-year age groups, respectively). FMtrunk and %FMtrunk were significantly correlated with four anthropometric indices with the Pearson’s correlation coefficients ranging from 0·25 to 0·86. Principal component analysis was performed to form three principal components that interpreted over 99·5% of the total variation of four related anthropometric indices in all age groups, with over 65% of the total variation accounted by principal component 1. Multiple regression analyses showed that three principal components explained a greater variance (R² 70·0–80·1%) in FMtrunk than did BMI or WC alone (R² 57·8–74·1%). The present results suggest that there is an increasing trend of FMtrunk and four anthropometric indices in successively older age groups; that age has important effects on the relationships of FMtrunk and studied anthropometric indices; and that the accuracy of predicting FMtrunk using four anthropometric indices is higher than using BMI or WC alone.

Anthropometric index: Trunk fat mass: Percentage of trunk fat mass: Principal component analysis

The prevalence of obesity is increasing worldwide: there are about 250 million obese adults, with far larger numbers of overweight adults (James & Ralph, 1999). The preferential accumulation of adipose tissue in the central region, i.e. trunk fat mass (FMtrunk), is clearly associated with increased risk of human chronic diseases, such as diabetes and CVD (Van Pelt et al. 2002; Pi-Sunyer, 2004), although the potential mechanisms remain to be elucidated fully. In addition, there are ethnic and sex-specific distributions of body fat mass. Compared with Caucasians, the Asian population accumulates central fat mass at lower body weight (McKeigue et al. 1992). Observations have shown that the risks of excess central fat mass emerge stronger and the hazards of even modest weight gain seem more drastic in the Asian population (James & Ralph, 1999). Men have been shown to have higher risks of disease for a given weight than women, which may be attributed to the propensity of depositing fat mass centrally in men (Vague et al. 1985; Pi-Sunyer, 2004). Therefore, the measure of fat mass at trunk is of clinical significance in Chinese males to identify who is at risk of such diseases.

A number of techniques have been developed to allow an accurate estimation of body fat mass, such as dual-energy X-ray absorptiometry (DXA). However, it is difficult to apply these complex techniques widely for clinical measurement of total or regional fat mass in developing countries, including China, because the measurement approaches depending on such technologies incur relatively high cost. On the other hand, the anthropometric indices, with their simple and cheap characteristics, continue to play an important role in assessing overall and regional fat mass in clinical practice. Dozens of studies have used several anthropometric indices, such as

Abbreviations: CoI, conicity index; DXA, dual-energy X-ray absorptiometry; FMtrunk, trunk fat mass; %FMtrunk, percentage of FMtrunk; HC, hip circumference; PC1, principal component 1; WC, waist circumference; WHR, waist:hip ratio.

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BMI, waist circumference (WC), waist:hip ratio (WHR) and conicity index (CoI), as predictors of central body fat mass (Taylor et al. 1998, 2000; Janssen et al. 2002; Brambilla et al. 2006), whereas the studies generally employed only one anthropometric index to predict fat mass, which may partially account for the current inconsistent results of the accuracy of the prediction, due to the potential confounders of adipose distribution.

To date, relatively few data on the correlations between anthropometric indices and truncal region fat mass measured by sophisticated methods, such as DXA, have been accumulated in the Chinese population. DXA is a safer and quicker method which typically has been used to assess bone mineral mass but also has been a valuable tool in assessing overall and regional body composition (Svendsen et al. 1993; Kohrt, 1995) than other technically complicated methods. However, to the best of our knowledge, there are no data on simultaneously employing the four anthropometric indices to assess trunk adipose tissue in either Chinese or Caucasians. Therefore, the current study was undertaken in Chinese males with three major aims: (1) to evaluate the effects of age on FMtrunk and anthropometric indices; (2) to investigate the correlations between FMtrunk and anthropometric indices; (3) to evaluate the ability of predicting FMtrunk using the four anthropometric indices (BMI, WC, WHR and CoI) and to develop four age-specific equations to predict FMtrunk by the four anthropometric indices.

Material and methods

Subjects

The project was approved by the Research Administration Departments of Hunan Normal University. The subjects were from a large population that was randomly recruited, through the use of fliers and posters advertising in the surrounding communities of Hunan Normal University (located in the central south area of China), for genetic studies searching for genes underlying peak bone mass variation in the Chinese population. After the subjects signed informed consent documents, a questionnaire was given to obtain the subject’s individual data including age, medical history, family history, physical activity, alcohol use, dietary habits and smoking history. We adopted the exclusion criteria detailed by Deng et al. (2002) to screen and recruit ‘healthy’ subjects. A total of 1090 healthy Chinese males, aged 20–40 years, were finally included in the study.

Measurements

Weight and height were measured using standardized equipment. BMI (kg/m²) was calculated as weight (kg) divided by height squared (m²). WC and HC were measured using an anthropometric tape over light clothing, with measurement of WC and HC at the minimum circumference between the iliac crest and the rib cage, and at the maximum protuberance of the buttocks. WHR was calculated as WC divided by HC. CoI was calculated using the following formula: CoI = (WC - 0.109 × √(weight/height)) / (WC and height in m; weight in kg) (Valdez et al. 1993; Taylor et al. 2000). Fat mass, lean mass and bone mineral mass were measured by Hologic QDR 4500 W DXA scanner (Hologic Corp., Waltham, MA, USA). Body regions are distinguished using specific anatomic landmarks. The truncal region consists of the area bordered by a horizontal line below the chin, vertical borders lateral to the ribs and oblique lines passing through the femoral necks. The percentage of FMtrunk (%FMtrunk) was calculated as [FMtrunk/(FMtrunk + trunk lean mass + trunk bone mineral content)].

Statistical analysis

Statistical analyses were performed with the SAS package (SAS Institute Inc., Cary, NC, USA). To investigate the effects of age, we divided the individuals into four 5-year age groups (20–24 years, 25–29 years, 30–34 years and 35–39 years). Pearson’s correlation coefficients were used to investigate the linear correlation of FMtrunk and %FMtrunk with each anthropometric index. Because of the disturbance of the colinearity when simultaneously modelling four strongly correlated anthropometric indices (BMI, WC, WHR and CoI) in the multiple regression analysis, to avoid these confused effects, a principal component analysis was performed to form three principal components accounting for most of the variation of the four anthropometric indices, as well as eigenvalues of the matrix and eigenvectors. Subsequently, the three principal component values were calculated by eigenvalues of the matrix and eigenvectors (Green, 1978; Vapnik, 1998), and then they were used to estimate their regression coefficients and the proportion of the variance (R²) of FMtrunk predicted by these principal components by multiple regression analysis. Regression analyses were also conducted to determine whether the three principal components explained a greater variance (R²) of FMtrunk than did BMI or WC alone and also to investigate the correlation coefficients of the measured FMtrunk and the predicted FMtrunk by the three principal components and by BMI or WC alone. Finally, we developed four age-specific equations to predict FMtrunk by the measured values of four anthropometric indices. The equations were calculated as follows:

The predicted FMtrunk (kg) = intercept + RCPCI × PC1 (EPC1BMI × S_BMI) + EPC1WC × S_WC + EPC1WHR × SWHR + EPC1CoI × S_CoI) + RCPC2 × PC2 (EPC2BMM × S_BMI) + EPC2WC × S_WC + EPC2WHR × SWHR + EPC2CoI × S_CoI) + RCPC3 × PC3 (EPC3BMM × S_BMI) + EPC3WC × S_WC + EPC3WHR × SWHR + EPC3CoI × S_CoI).
Results

Age was significantly correlated with FM\textsubscript{trunk}, %FM\textsubscript{trunk} and the four studied anthropometric indices in the whole group, but was not significantly associated with them in each 5-year age group (data not shown). The subject characteristics for total and each of four groups are summarized in Table 1. There was an increasing trend of FM\textsubscript{trunk}, %FM\textsubscript{trunk}, BMI, WC, WHR and CoI, with the correlation coefficients ranging from 0.25 to 0.86. In each age group, the correlation of BMI, WC, WHR and CoI, with the correlation coefficients generally higher than those between %FM\textsubscript{trunk} and the four studied anthropometric indices in each age group, respectively. Correlations between FM\textsubscript{trunk} and the four anthropometric indices were generally higher than those between %FM\textsubscript{trunk} and the studied anthropometric indices in each age group (Table 2). The higher correlations resulted in more accurate predictions, and thus the following analyses focused on the prediction of FM\textsubscript{trunk} with the four anthropometric indices. FM\textsubscript{trunk} and %FM\textsubscript{trunk} were significantly correlated with BMI, WC, WHR and CoI, with the correlation coefficients ranging from 0.25 to 0.86. In each age group, the correlation coefficients of BMI and WC with FM\textsubscript{trunk} were significantly higher than those of WHR or CoI with FM\textsubscript{trunk} (e.g. the correlation coefficients between FM\textsubscript{trunk} and BMI, WC, CoI and WHR in the 20–24 age group were 0.84, 0.81, 0.48 and 0.26, respectively).

As shown in Table 3, the three principal components interpreted over 99.5% of the total variation of four relative anthropometric indices by principal component analysis, with over 65% of the total variation accounted for by PC1. Regression analyses (Table 4) showed that the three principal components explained a greater variance ($R^2$ 70.0–80.1%) of FM\textsubscript{trunk} than did BMI or WC alone ($R^2_{ BMI }$ 57.8–74.1%) (e.g. in the 20–24 age group, the proportions were 65.0, 70.9 and 75.6% by WC, BMI and the three principal components, respectively). Although the three principal components or BMI, WC, WHR and CoI were strongly correlated with FM\textsubscript{trunk}, approximately more than 20% of the variance in FM\textsubscript{trunk} remained unexplained by them. Figure 1 intuitively illuminates the simple correlation coefficients between the measured FM\textsubscript{trunk} and the predicted FM\textsubscript{trunk} by the three principal components, single BMI or WC in regression analyses. Obviously, the correlations of the measured FM\textsubscript{trunk} and the predicted FM\textsubscript{trunk} by three principal components were higher than by BMI or WC alone, indicating that the three principal components predicted a more precise FM\textsubscript{trunk} than did BMI or WC alone. We also developed four age-specific simple equations to predict FM\textsubscript{trunk} using measured values of the four anthropometric indices (Table 5), which were detailed in the statistical analyses. Then, to investigate the external validation of predicting FM\textsubscript{trunk}, we determined the equations to predict FM\textsubscript{trunk} in half of the randomly collected subjects and tested the prediction equations in the other half. The prediction equations in half of the randomly collected samples were very similar to those in the whole samples (data not shown), and then the predicted FM\textsubscript{trunk} using these equations in the other half were highly correlated with the measured FM\textsubscript{trunk} ($r$ 0.71–0.89).

Discussion

The major observation of the present study is that, independent of age, the use of BMI, WC, WHR and CoI in combination is better than using them alone for the prediction of FM\textsubscript{trunk} in Chinese males. The present study also confirms the finding that age has a significant influence on the truncal region fat mass and four anthropometric indices, all of which increase in ageing groups. The central adipose tissue was a widely used predictor of health risk. Thus, the results of the present study may imply the importance and a more accurate pattern of incorporating these four anthropometric indices into routine clinical practice.

Table 1. Basic statistical characteristics of the studied sample of Chinese males*

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–24 (n 415)</td>
<td>23.7</td>
<td>1.05</td>
<td>26.9</td>
<td>1.44</td>
</tr>
<tr>
<td>25–29 (n 472)</td>
<td>26.1</td>
<td>0.55</td>
<td>29.9</td>
<td>1.30</td>
</tr>
<tr>
<td>30–34 (n 159)</td>
<td>32.0</td>
<td>1.41</td>
<td>35.3</td>
<td>1.60</td>
</tr>
<tr>
<td>35–39 (n 44)</td>
<td>37.3</td>
<td>1.60</td>
<td>41.0</td>
<td>1.95</td>
</tr>
<tr>
<td>Total (n 1090)</td>
<td>27.2</td>
<td>4.17</td>
<td>32.6</td>
<td>4.71</td>
</tr>
</tbody>
</table>

* For details of procedures, see p. 950.
Central fat mass was demonstrated to be strongly related with many chronic diseases (Folsom et al. 1990; Rexrode et al. 1998; Van Pelt et al. 2002), and in routine clinical practice, the inexpensive and convenient anthropometric index was commonly used for assessing central adipose tissue, especially in developing countries. However, compared with Caucasians, few data on the relationships of anthropometric indices with fat mass in the truncal region have been reported in the Chinese population. The apparent differences in energy expenditure and body build among various ethnic groups may lead to ethnic-specific relationships (Deurenberg et al. 1998; Duncan et al. 2004). Additionally, the higher incidence of some diseases, such as CHD, in men compared to women, may partially result from the more central distribution of fat mass in men (Freedman et al. 1990; Larsson et al. 1992; Pi-Sunyer, 2004). Therefore, to increase our understanding of the ethnic-specific correlation and prediction of $F_{\text{Mtrunk}}$ with four anthropometric indices, we conducted the present study in a large cohort of Chinese males with ages ranging from 20 to 40 years.

Consistent with previous studies (Shimokata et al. 1989; Lemieux et al. 1995; Zamboni et al. 1997), the present results showed a progressive trend toward increasing central fat mass deposition with ageing, which gives support to the earlier finding that age had an effect on upper-body fat mass in males (Horber et al. 1997). It may be partially credited to blunted growth hormone and testosterone secretion in old men (Corpas et al. 1993; Bjorntorp, 1996; Johansson et al. 1997; Harman & Blackman, 2004). Johansson et al. (1997) found that growth hormone treatment in adult men with abdominal obesity had favourable effects on abdominal fat mass and several obesity-related diseases. Declining physical activity with ageing may also enhance a more central shape (Mitchell et al. 2003; Parsons et al. 2005). Thus, to try to decrease the disturbance of age on the estimation of relationships between four anthropometric indices and $F_{\text{Mtrunk}}$, it was appropriate to divide our sample into four 5-year age groups, because age was significantly correlated with $F_{\text{Mtrunk}}$ and four anthropometric indices in all samples, but was not associated with them in each divided age group.

We have confirmed that the four anthropometric indices were highly correlated with $F_{\text{Mtrunk}}$ and $\%F_{\text{Mtrunk}}$, and BMI and WC were better predictors of $F_{\text{Mtrunk}}$ than were WHR and Col (Lean et al. 1995; Taylor et al. 2000; Snijder et al. 2004). However, more importantly, the present results indicated that the three principal components from four anthropometric indices assessed $F_{\text{Mtrunk}}$ more accurately than did BMI, WC, WHR and Col alone, explaining at least an additional 2.6% of the variation of $F_{\text{Mtrunk}}$. It was also supported by the simple correlation coefficients between the measured $F_{\text{Mtrunk}}$ and the predicted $F_{\text{Mtrunk}}$ by the three principal components, which were higher than those between the measured $F_{\text{Mtrunk}}$ and the predicted $F_{\text{Mtrunk}}$ by BMI or WC alone (Fig. 1). In past years, numerous studies have been striving for the accuracy of a single anthropometric index for estimating central fat mass, but the results have been largely inconsistent among the studies (Ross et al. 1994; Taylor et al. 1998, 2000; Kamel et al. 1999, 2000; Lindsay et al. 2001).

| Table 2. Correlation coefficients of trunk fat mass ($F_{\text{Mtrunk}}$) and percentage of trunk fat mass ($\%F_{\text{Mtrunk}}$) with anthropometric indices |
|-----------------|--------|--------|--------|--------|
| Age group (years) | $F_{\text{Mtrunk}}$ (kg) | BMI | WC | WHR | Col |
| 20–24 | 0.84 | 0.81 | 0.26 | 0.48 | 0.76 | 0.76 | 0.25 | 0.47 |
| 25–29 | 0.86 | 0.79 | 0.31 | 0.40 | 0.78 | 0.70 | 0.39 | 0.40 |
| 30–34 | 0.79 | 0.76 | 0.74 | 0.42 | 0.70 | 0.32 | 0.32 | 0.42 |
| 35–39 | 0.85 | 0.84 | 0.74 | 0.62 | 0.72 | 0.71 | 0.71 | 0.61 |

Col, conicity index; WC, waist circumference; WHR, waist:hip ratio.

| Table 3. Eigenvalues of the correlation matrix and eigenvectors in the principal component analysis for four anthropometric indices |
|-----------------|--------|--------|--------|--------|
| Age group (years) | Eigenvector | BMI | WC | WHR | Col |
| 20–24 | PC1 2.602 0.651 | 0.478 | 0.603 | 0.374 | 0.518 |
| | PC2 0.813 0.203 | −0.561 | −0.212 | 0.773 | 0.206 |
| | PC3 0.570 0.143 | 0.507 | −0.135 | 0.512 | −0.680 |
| 25–29 | PC1 2.898 0.728 | 0.418 | 0.567 | 0.498 | 0.506 |
| | PC2 0.849 0.212 | 0.755 | 0.216 | −0.410 | −0.464 |
| | PC3 0.240 0.060 | 0.159 | −0.294 | 0.763 | −0.653 |
| 30–34 | PC1 2.796 0.699 | 0.408 | 0.577 | 0.480 | 0.519 |
| | PC2 0.862 0.215 | 0.773 | 0.192 | −0.443 | −0.411 |
| | PC3 0.326 0.082 | 0.219 | −0.297 | 0.756 | −0.541 |
| 35–39 | PC1 3.139 0.785 | 0.466 | 0.552 | 0.495 | 0.483 |
| | PC2 0.546 0.136 | 0.755 | 0.068 | −0.173 | −0.630 |
| | PC3 0.297 0.074 | −0.108 | −0.325 | 0.851 | −0.398 |

Col, conicity index; PC1, PC2, PC3, principal components derived from the four anthropometric indices by principal component analysis; WC, waist circumference; WHR, waist:hip ratio.
WC is a commonly and widely used tool for central adipose tissue assessment (Taylor et al. 1998, 2000; Snijder et al. 2004). However, the use of WC as the predictor of central fat mass has been criticized (Ross et al. 2004). However, the use of WC as the predictor of central fat mass has been criticized (Ross et al. 2004; Kamel et al. 2000) for the relatively low correlation coefficients between WC and central fat mass. Adipose distribution may partially disturb the accuracy of assessment as anatomic adipose distribution in the central region has been demonstrated to be different among individuals with different BMI (Ross et al. 1994; Han et al. 1997; Kamel et al. 2000). Thus there are limitations in only using one anthropometric index to evaluate regional fat mass. In Janssen et al. 2002, demonstrated that the combined use of WC and BMI substantially increased the variance explained in abdominal subcutaneous and visceral fat mass than did either variable alone. Their results support our belief that it may be more significant and accurate to evaluate fat mass in the truncal region using combined anthropometric indices. BMI, WC, WHR and Col were all useful and accurate tools for assessing central adipose tissue (Taylor et al. 1998, 2000; Janssen et al. 2002; Brambilla et al. 2006). However, as those indices were highly related, they cannot simply be involved in multiple regression analysis to predict FMtrunk. A principal component analysis was adopted in the present study to attempt to extract useful information from these four related indices. To the best of our knowledge, the present study is the first effort to use four anthropometric indices simultaneously to predict FMtrunk in Chinese adult males with age varying from 20 to 40 years.

With the aim of predicting FMtrunk with a simple method, in the present study we developed four age-specific equations using the measured values of four anthropometric indices which have practical significance for routine clinical assessment in Chinese males. The validation of predicting FMtrunk is very high. The correlation coefficients between the measured FMtrunk and predicted FMtrunk by the three principal components using multiple regression analysis were high, ranging from 0·83 to 0·88 (Fig. 1). Although predictive equations have been developed and proposed for estimating central fat mass by combining anthropometric indices with DXA data in Caucasians (Jensen et al. 1995; Bertin et al. 2000), several studies have reported the limitations when the generalized formulas based on Caucasians were used to estimate the body composition of non-white populations (Vickery et al. 1988; Jakicic et al. 1998). Furthermore, the assessment of adipose tissue with measurement of anthropometric indices is much cheaper and technically easier than using DXA, computed tomography or magnetic resonance imaging. Therefore, it is of very important clinical implication to develop ethnic-specific equations for accurately assessing central fat mass using simple and costless anthropometric indices, especially in developing countries like China. This is the primary motive for performing the present study in the Chinese population.

However, the present study has some limitations. First, although DXA as a three-component model is becoming increasingly popular for the measurement of soft tissue composition as well as bone mineral mass, it cannot distinguish between visceral and subcutaneous adipose tissue and is less accurate compared with computed tomography or magnetic resonance imaging. But research has illustrated strong correlations between the fat mass at trunk measured by DXA and abdominal fat mass measured with computed tomography or

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**Table 4.** The $R^2$ and standard error of estimation (SEE) of the three principal components (PC), BMI or waist circumference (WC) and the regression coefficients of the PC.

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>Variations</th>
<th>Regression coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R^2$ (PC)</td>
<td>SEE (PC)</td>
</tr>
<tr>
<td>20–24</td>
<td>75·6</td>
<td>1·27</td>
</tr>
<tr>
<td>25–29</td>
<td>76·7</td>
<td>1·32</td>
</tr>
<tr>
<td>30–34</td>
<td>70·0</td>
<td>1·57</td>
</tr>
<tr>
<td>35–39</td>
<td>80·1</td>
<td>1·31</td>
</tr>
</tbody>
</table>

$R^2$ is the percentage of the variance of trunk fat mass explained by the three PC, BMI and WC.

**Fig. 1.** Simple correlation coefficients, using regression analysis, between trunk fat mass (FMtrunk) and the predicted FMtrunk by the three principal components (■), BMI (□) and waist circumference (◆). For details of procedures, see pp. 950–951.
magnetic resonance imaging (Treuth et al. 1995; Goran et al. 1998; Glickman et al. 2004). Second, the present results from a healthy population with normal body weight might be inappropriate for obese populations or other patients with chronic diseases and conditions. But, central fat mass is an undeniable necessity for accessing disease risk in non-obese populations as well. Goodpaster et al. (2005) demonstrated that apart from general fat mass, the abdominal adipose tissue was independently associated with the metabolic syndrome in men and women, particularly among those of normal body weight. Third, the subjects were aged between 20 and 40 years. Therefore, it may not be possible to generalize the results of the present study to older or younger Chinese males. Fourth, the small number of men in the 35–39 age group (only forty-sent study to older or younger Chinese males. Fourth, the small number of men in the 35–39 age group (only forty-

In conclusion, the present study explored the complex relationships between four anthropometric indices and FMtrunk in a very large sample of Chinese males with ages varying from 20 to 40 years. The results obtained added to our understanding of the relationships of anthropometric indices and fat mass in the trunk region, as well as the effects of age on them.

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