Introduction

The worldwide prevalence of obesity has increased rapidly in the past two decades, with more than doubled between 1980 and 2008 according to the World Health Organization. Increased body mass index (BMI) has been linked to death from many cancers (1). The fact that increased BMI negatively affects the diagnostic precision through assessment of serum concentrations of soluble tumor markers, might contribute, at least partly, to the increased risk of certain cancer-caused death in obese persons (2).

Carcinoembryonic antigen (CEA) is one of these serologic markers of malignant tumors, which is overexpressed in adenosarcomas in many organs. A recent study (3) has also shown that higher BMI is associated with lower CEA in patients with colorectal cancer, and that hemodilution from increased plasma volume may be responsible for the decreased serum CEA levels. Therefore, we designed a study in healthy Chinese males, to explore whether larger plasma volumes in obese men are associated with lower CEA concentrations. In consideration of the lack of ‘golden criterion’ for noninvasive plasma volume estimation, two plasma volume estimates were applied in the study: one is a commonly used equation based on height and weight; another is widely applied for drug administration based on weight and hematocrit. The influence of BMI status on interpretation of CEA value was additionally quantified.

Materials and Methods

Participants selection

The collected records of 2,359 consecutive healthy males presenting at our unit for health management from October 2012 to December 2012 were reviewed retrospectively. Analyses were confined to men with BMI > 16 kg/m², and a hematocrit from 0.37 to 0.54 (n = 2,304), as values out of these ranges are likely to represent data errors or to reflect underlying disease processes. We excluded men with missing BMI data (n = 54), no recorded hematocrit (n = 90) or CEA concentration (n = 157), and no data of smoking status (n = 74) or lack of the fecal occult blood test (n = 82). Participants with a history of inflammatory bowel disease (n = 17), or renal or liver insufficiency (n = 26) were additionally excluded. Abnormal liver function was defined as serum aspartate aminotransferase or alanine aminotransferase concentrations >80 IU/L. Abnormal kidney function was defined as serum creatinine concentration >133 μmol/L (1.5 mg/dL).

Methods

Of note, 1,915 healthy males were retrospectively collected, with ages ranging from 18 to 84 years. Two equations, a body surface area (BSA)–based and a hematocrit-based, were applied, respectively, for plasma volume and CEA mass calculation. Multivariate linear and logistic regression models were used to detect the associations of CEA concentration, and the two estimates of CEA mass with body mass index (BMI); possible confounding factors, including age, leucocyte count, and smoking status, were adjusted.

Results

CEA concentration significantly decreased with increasing BMI (P < 0.001); however, CEA mass remained consistent or increased by using the BSA- or hematocrit-based equation. A screening level of CEA 5.0 ng/mL in normal-weight men was found to correspond to 4.52 ng/mL in overweight and obese men.

Conclusions

CEA may be affected in obese individuals by several factors, including but not limiting to hemodilution, inflammatory conditions, and insulin resistance. The relationship between CEA concentration and BMI might be highly dependent on which factor or factors have been predominant.
History inquiry, physical examination, chest X-ray, abdominal ultrasound, and the above-mentioned laboratory tests were performed in all the remaining subjects. People with abnormal results were arranged for follow-up tests in local hospitals. We provided follow-up telephone calls to the participants in April 2013. People with cancers (n = 12) diagnosed previously or during follow-up were further excluded: colorectal cancer (n = 3), gastric cancer (n = 1), lung cancer (n = 3), kidney cancer (n = 2), and thyroid cancer (n = 3). There were overlaps among these missing data. The remaining 1,915 males were included in the present analysis. Our local Institutional Review Board approved the survey before it was conducted.

BMI was calculated as weight in kilograms divided by height in meters squared. Participants were weighed with emptied pockets and without shoes. Standing height was measured using a fixed stadiometer with a vertical backboard and a moveable headboard. Subjects were divided into three BMI categories of < 22.9, 23–27.5, and ≥ 27.5 according to the new Asian classification (4).

Subjects who had quit smoking for 1 month or less and those who had quit for more than 1 month before the time of the health screening were considered to be, respectively, current and former smokers, and those without a smoking history were considered to be never smokers.

The hematocrit was measured on a Hematology Analyzer (Beckman Coulter Gen-S System 2); alanine aminotransferase, aspartate aminotransferase, and serum creatinine on a Hitachi 7600 modular chemistry analyzer; serum CEA concentration on a Beckman Coulter DXI 800 Immunoassay Analyzer; fecal occult blood by the colloidal gold method using an anti-human hemoglobin monoclonal antibody (fecal occult blood gold gel strip; Beijing WanHuaPuMan Bio-Engineering Co., Ltd); chest X-ray by Digital Diagnost System (Philips), and abdominal ultrasound, and the above-mentioned laboratory tests were performed in all the remaining subjects. People with abnormal results were arranged for follow-up tests in local hospitals. We provided follow-up telephone calls to the participants in April 2013. People with cancers (n = 12) diagnosed previously or during follow-up were further excluded: colorectal cancer (n = 3), gastric cancer (n = 1), lung cancer (n = 3), kidney cancer (n = 2), and thyroid cancer (n = 3). There were overlaps among these missing data. The remaining 1,915 males were included in the present analysis. Our local Institutional Review Board approved the survey before it was conducted.

Next, multivariate linear regression regression models were conducted to examine the associations of serum CEA concentration, BSA-based and hematocrit-based plasma volume, and CEA mass with BMI categories. As according to the Kolmogorov–Smirnov statistic the CEA and CEA mass were not normally distributed, the values were logarithmically transformed to attain a normal distribution before multivariate linear regression analyses. Binary logistic regression models were additionally conducted with nontransformed data by using normal weight (BMI ≤ 22.9) as the reference to assess the associations with overweight and obesity. In all multivariable analyses, age (years), smoking status, and WBC counts (× 10⁹) were considered as potential confounders.

Finally, we developed a theoretical formula for estimating plasma CEA concentration in high-BMI participants corresponding to a reference value in normal-weight males. We reconstructed the multiple linear regression model, including BMI categories. The estimates obtained were then back transformed for ease of interpretation. Associations with P < 0.05 were considered statistically significant.

Results

Table 1 presents the characteristics of the 1,915 males included in the analysis by BMI category. The mean (SD) age of men was 46.54 (12.42) years. Mean (SD) BMI were 24.75 (3.03) kg/m². More than half of all men were classified as overweight and 17.81% as obese. About half of the participants were smokers. Continuous variables, including age, hematocrit, and WBC counts, seemed to be higher in the obese compared with normal-weight males (P < 0.05).

Table 2 shows the relationship between CEA concentration, plasma volume, CEA mass, and BMI categories. The median CEA concentration was 1.57 ng/mL. The mean CEA concentration decreased from 1.64 ng/mL in normal-weight men to 1.46 ng/mL in obese men (P < 0.001). Means of estimated plasma volumes by using BSA- and hematocrit-based equations, increased with increasing BMI category, from 2.91 L in normal-weight men to 3.10 L in obese men, and from 2.63 to 3.06 L, respectively (P < 0.001). Estimated CEA mass, however, did not show a significant association with BMI (P = 0.461) when BSA-based equation was applied. Whereas when hematocrit-based equation was induced, CEA mass significantly increased with BMI (P < 0.001), with mean CEA mass
values of 4.29, 4.55, and 5.14 μg across the three BMI categories (P < 0.001).

Results from logistic regression models were shown in Table 3. With normal-weight men as the reference group, the prevalence of the lowest CEA tertile was found to increase with BMI, with the OR of 1.35 [95% confidence interval (CI), 1.04–1.90] in overweight men and 1.40 (95% CI, 1.04–1.90) in the obese. Indeed, we found the ORs for the highest plasma volume tertile tended to get much higher in overweight and obese men by using both equations. The prevalence of the lowest or the highest CEA mass tertile and BMI (P = 0.048), in overweight or obese cohort, a specificity of 97.10% (96.4%–97.7%) was still obtained.

In this mathematical model, WBC count and age were continuous variables, smoking status was given a point from 1 to 3 (i.e., nonsmoker got point 1, former-smoker got point 2, and current smoker got point 3); BMI was given a point from 0 to 1 (i.e., normal-weight man got point 0 and overweight or obese man got point 1). Our model suggested that serum CEA of 4.52 (95% CI, 4.27–4.79) ng/mL in overweight or obese people were mathematically equivalent to 5.0 ng/mL in normal-weight men. When we put the predicted value back to our overweight or obese cohort, a specificity of 97.10% (96.4%–97.7%) was still obtained.

Discussion

In this study of nearly 1,915 healthy men with no clinical evidence of any cancer, after adjusting for potential confounding factors age, smoking status, and WBC count, men in the obese group had 11% lower serum CEA concentrations than normal-weight men, in line with the 3.8% decreased CEA concentration seen in another population-based studies of men without any cancer (9).

Table 1. Cohort characteristics of all men by BMI category

<table>
<thead>
<tr>
<th>BMI category</th>
<th>Age (y; SD)</th>
<th>WBC count (10⁹/L; SD)</th>
<th>Hematocrit (%; SD)</th>
<th>Smoking status</th>
<th>Current smoker</th>
<th>Former smoker</th>
<th>Nonsmoker</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI &lt; 22.9 kg/m² (n = 549)</td>
<td>45.22 (13.38)</td>
<td>6.27 (1.67)</td>
<td>40.1 (2.22)</td>
<td>Current smoker</td>
<td>315</td>
<td>22</td>
<td>212</td>
</tr>
<tr>
<td>BMI 23–27.4 kg/m² (n = 1,025)</td>
<td>47.14 (11.62)</td>
<td>6.49 (1.54)</td>
<td>40.6 (2.15)</td>
<td>Former smoker</td>
<td>589</td>
<td>61</td>
<td>24</td>
</tr>
<tr>
<td>BMI ≥ 27.5 kg/m² (n = 341)</td>
<td>47.09 (12.78)</td>
<td>6.74 (1.66)</td>
<td>41.0 (2.13)</td>
<td>Nonsmoker</td>
<td>375</td>
<td>105</td>
<td>0.068</td>
</tr>
</tbody>
</table>

Table 2. Linear regression models: CEA concentration, plasma volume, and CEA mass according to BMI category

<table>
<thead>
<tr>
<th>BMI category</th>
<th>CEA concentrationa (ng/mL; 95% CI)</th>
<th>Mean plasma volume (L; SD)</th>
<th>CEA massa (μg; 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI &lt; 22.9 kg/m² (n = 549)</td>
<td>1.64 (1.56–1.72)</td>
<td>2.91 (0.17)</td>
<td>4.75 (4.53–4.99)</td>
</tr>
<tr>
<td>BMI 23–27.4 kg/m² (n = 1,025)</td>
<td>1.49 (1.44–1.54)</td>
<td>3.10 (0.18)</td>
<td>4.62 (4.46–4.78)</td>
</tr>
<tr>
<td>BMI ≥ 27.5 kg/m² (n = 341)</td>
<td>1.46 (1.37–1.55)</td>
<td>3.31 (0.22)</td>
<td>4.81 (4.53–5.12)</td>
</tr>
</tbody>
</table>

aAdjusted for age, smoking status, and WBC count.
However, the cited study included only populations within a range of 0 to 5 ng/mL, which might be a reason for their findings of lower hemodilution effect.

Moreover, we observed obese men had greater plasma volume. When calculating CEA mass, i.e., the amount of CEA in the blood at the time of determination of CEA concentration, obese men had similar or higher CEA mass based on BSA- or hematocrit-based equation. Indeed, several small studies found that CEA concentrations increase acutely after dialysis (10, 11). This suggests that hemodilution from larger plasma volume may be responsible for the lower CEA values observed among obese men in our cohort. According to BSA-based equation for plasma volume calculation, we found that all men, regardless of BMI, had the same amount of circulating CEA, as reflected by the calculated CEA mass. When the hematocrit-based formula was applied, there was a significant trend for increasing CEA mass across BMI categories. Thus, we found no evidence that CEA mass was decreased among obese men. The greater CEA mass based on hematocrit suggests that obese men actually have more circulating CEA protein than do normal-weight men, but that this is diluted by their larger plasma volume.

The reason for the greater CEA mass is unclear. Because obesity is associated with some inflammation conditions and insulin resistance (12), which is also found in cancer development, we hypothesize two possible reasons:

First, obesity is known to promote an inflammatory state (13), and this proinflammatory condition may result in greater leakage of tumor marker into the serum (2). In our study, we confirmed that the circulating WBC count, a marker for systemic inflammation, was higher in obese men. We also observed both CEA and mass increased with increasing WBC count, even after age, BMI and smoking status were adjusted (data not shown). Second, insulin resistance might contribute to the increased CEA among obese men through insulin-like growth factor-I (IGF-I), because an antisense IGF-I gene that blocks the corresponding IGF sequences may be the reason for the decrease of CEA (14). Indeed, it was also reported that increased CEA was more commonly seen in men with metabolic syndrome or carotid atherosclerosis (15,16), which might indirectly support the hypothesized underlying mechanism.

Therefore, CEA may be affected in obese individuals by several factors, including but not limiting to hemodilution, inflammatory conditions, and insulin resistance. Interestingly, we found that though CEA levels were higher in overweight or obese men when compared with normal-weight men, no significant difference in CEA concentrations was found between overweight and obese men. The former result might suggest hemodilution predominates and the other two factors are rendered negligible. The latter result and some other conflicting findings might also be explained by this theory (17,18). In these studies no association was found between CEA concentrations and BMI in healthy cohorts. It might be due to the fact that in these cohorts none of these factors could be rendered negligible.

Park and colleagues (3) reported that increased BMI might negatively affect the diagnostic precision of the CEA test in patients with colorectal cancer. They consider it may be necessary to interpret the CEA concentrations of obese patients in a manner distinct from that of normal-weight patients. Here, we also developed a theoretical formula to estimate CEA values in overweight and obese men corresponding to a CEA value of 5.0 ng/mL (the reference value of our laboratory) in normal-weight

Table 3. Logistic regression models: adjusted associations of CEA, BSA-, and hematocrit-based CEA mass with BMI categories

<table>
<thead>
<tr>
<th>BMI</th>
<th>Prevalence of the lowest tertile of serum CEA level, n (%), and ORa (95% CI)</th>
<th>Prevalence of the highest tertile of plasma volume, n (%), and ORa (95% CI)</th>
<th>Prevalence of the highest tertile of CEA mass, n (%), and ORa (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 22.9 kg/m² (N = 549)</td>
<td>169 (30.8), 1.00 (reference)</td>
<td>356 (34.7), 1.35 (1.07–1.70)</td>
<td>117 (34.3), 1.40 (1.04–1.90)</td>
</tr>
<tr>
<td>22.9–27.4 kg/m² (N = 1,025)</td>
<td>38.41) 294 (86.2), 280.00 (148.16–529.11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 27.5 kg/m² (N = 341)</td>
<td>1.40) 102 (29.9), 0.96 (0.71–1.30)</td>
<td>1.16) 0.57 (0.42–0.78)</td>
<td>0.549</td>
</tr>
</tbody>
</table>

NOTE: BMI category as independent variable.
Reference group, normal-weight group.
*aAdjusted for age, smoking status, and WBC count.
subjects. The diagnostic accuracy of the CEA test might thus be improved by setting the reference value of the overweight and obese group about 4% to 15% lower than that of the normal-weight group.

Notably, in addition to the quantification of the effect of obesity on CEA concentration and the analysis of the possible underlying mechanisms, the third strength of our study is that both multivariate linear and logistic regression models were conducted to analyze the association of CEA level with BMI. Because logarithmic transformations conducted before multivariate linear regression analyses, might sometimes distort data (19), whereas dichotomization of the continuous dependent variable in the binary logistic regression models might yield a loss of information, our study fills in some of the blanks left by other studies in which linear or logistic regression analysis was applied alone. The additionally performed binary logistic regression analyses in our study using nontransformed data showed no conflicting results, though the corresponding significance does not seem to be as strong as that stated by using linear regression analyses with transformed data.

This study has several potential limitations. First, the reason for why the fact that CEA mass increased with increasing BMI was observed only when hematocrit-based equation was applied was not explained. We previously investigated the agreement between hematocrit- and BSA-based plasma volumes and found the dilution power of a plasma volume estimated by the hematocrit-based equation was much stronger than that calculated by BSA-based formula. Because of the absence of a plasma volume determined by "Golden criteria," we could not tell which equation is more suitable for clinical application. However, the discrepancies call for greater attention to further study on the problem (20). Second, because of the cross-sectional nature of the study, we cannot determine whether there is a causal or resultant relationship between the elevation of serum CEA and obesity. Third, we analyzed only men in this study, because the number of female subjects who had a smoking history was much smaller during the study period. Fourth, in addition to cigarette smoking, age, and WBC count, serum CEA levels may increase under some other nonmalignant conditions, for example, hypothyroidism and etc. We did not include these disorders as confounding variables because their prevalence is considered to be very low among the study population.

In conclusion, CEA may be affected in obese individuals by several factors, including but not limiting to hemodilution, inflammatory conditions, and insulin resistance. The relationship between CEA concentration and BMI might be highly dependent on which factor or factors have been predominant. Obesity might be one of the factors that affect CEA value, leading to loss of diagnostic accuracy in the CEA test.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

Authors' Contributions

Conception and design: F. Li

Development of methodology: F. Li

Acquisition of data (provided animals, acquired and managed patients, provided facilities, etc.): F. Li, Z. Shen, Y. Lu, L. Wang, W. Song

Analysis and interpretation of data (e.g., statistical analysis, biostatistics, computational analysis): F. Li

Writing, review, and/or revision of the manuscript: F. Li

Administrative, technical, or material support (i.e., reporting or organizing data, constructing databases): F. Li

Study supervision: F. Li

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References

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