Comparison of waist circumference percentiles versus body mass index percentiles for diagnosis of obesity in a large cohort of children

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Abstract

Context. Waist circumference may offer improved diagnosis of obesity in youth compared with body mass index (BMI), but empirical evidence is limited. Objective. To compare the ability of BMI percentile using UK reference data and waist circumference percentile using UK reference data to diagnose high fat mass in English children. Design and Methods. In 7,722 9–10-year-olds (3,809 boys, 3,913 girls) sensitivity and specificity were calculated and receiver operator characteristic (ROC) analyses undertaken to determine the diagnostic accuracy of BMI and waist circumference z-scores to define high fat mass measured by dual energy x-ray absorptiometry (DXA). High fat mass was defined as being in the top decile of fatness for each sex (359 boys and 367 girls). Results. The area under the ROC curve was slightly higher for BMI percentile (0.92 in boys, 95% CI: 0.91–0.93; 0.94 in girls, 95% CI: 0.93–0.95) than waist circumference percentile (0.89 in boys, 95% CI: 0.86–0.91; 0.81 in girls, 95% CI: 0.73–0.90). Specificity of BMI percentile was slightly but significantly higher than that of waist circumference percentile for both sexes (p<0.05 in each case). Conclusions. The present study suggests that waist circumference percentile has no advantage over BMI percentile for the diagnosis of high fat mass in children.

Key words: ALSPAC, BMI, children, dual energy x-ray absorptiometry, waist, obesity

Introduction

Body mass index (BMI) is well established as a simple means to define or diagnose obesity, a state of excess body fatness associated with increased risk of disease (1), in children and adolescents (1–6). In the UK for example, a high BMI percentile denotes high body fatness in children with moderately high sensitivity and very high specificity (4). Evidence of high specificity (low false positive rate) has long been recognized as being of greatest clinical importance, because of the need to avoid incorrect diagnosis of obesity in the non-obese child or adolescent (2,3).

Waist circumference in youth has been of increasing interest as an alternative, and possibly superior, simple index of high body fatness and/or the comorbidities of high fatness (7–9). The widespread availability of population reference charts for waist circumference has also made it easier to use waist circumference for diagnosis of obesity and may tend to increase variation in clinical diagnostic practice in future. In adults, waist circumference may offer improvement over BMI to diagnose both high fat mass and the cardiovascular co-morbidities of high fat mass (10,11). Associations between waist and body fatness are stronger than those between BMI and body fatness in some pediatric studies (9), indicating a possible benefit of using waist over BMI to diagnose excessive body fatness in youth, but to date only one study (of 17-year-olds) compared the diagnostic ability of BMI versus waist for the assessment of high fat mass in youth (12) so empirical pediatric evidence is lacking.
Guidelines for the management of pediatric obesity have concluded consistently that there is insufficient evidence to recommend waist as the basis of diagnosis of obesity at present, but have noted the potential benefits of using waist circumference in diagnosis and called for more research comparing the diagnostic ability of waist versus BMI in children and adolescents (1,13–16).

The aim of the present study was therefore to make a direct comparison of the ability of waist circumference percentiles versus BMI percentiles to diagnose high fatness, as measured by dual energy X-ray absorptiometry (DXA), in a large cohort of children from the Avon Longitudinal Study of Parents and Children (ALSPAC) (17).

Methods

Sample and design

The initial ALSPAC sample consisted of 14,541 pregnancies. Of the initial 14,541 pregnancies, all but 69 had known birth outcome and 195 were twin, three triplet and one quadruplet pregnancy, which meant that there were 14,676 fetuses in the original ALSPAC sample. Of these 14,676 fetuses, 14,062 were live births and 13,988 were alive at age 1 year. Data have been obtained from study participants using a variety of sources: linkage to medical records, questionnaires, and measurements made at research clinics, including an invitation to participate in annual research clinics from age 7 onwards (17). The potential sample for the present study consisted of healthy children participating in the age 9-year ALSPAC research measurement clinic. Ethical approval for the study was obtained from the ALSPAC Law and Ethics Committee and Local Health Service Research Ethics Committees, and informed written consent was obtained. Children were eligible for the present study if they had measures of height, weight, waist circumference, and DXA-measured fat mass during the age 9-year research clinic. After excluding 57 children with missing measurements, 7,722 were available for the analyses reported in the present study (3,809 boys and 3,913 girls).

Anthropometry and body composition

All anthropometric measurements were made by trained staff following the procedures described in the anthropometric measurement standardization manual (18) and data were double-entered into a database to minimise errors. Height was measured with shoes and socks removed using a Harpenden Stadiometer (Holtain, Wales). Weight was measured using a TANITA TBF 305 Body Fat Analyser/weight-scaling scale (TANITA, Tokyo) with children wearing hospital gowns. BMI was calculated as weight (kg) divided by height$^2$ (m$^2$), and expressed as a standard deviation score (z-score) and percentile relative to UK 1990 reference data (19) using software provided by the Child Growth Foundation (London, England). Waist circumference was expressed as a z-score and percentile relative to UK 1988 reference data (20) using software provided by the Child Growth Foundation. In the present study percentiles relative to UK population reference data were therefore used, though in the UK different datasets have been used to derive the BMI and waist circumference reference data. Whole-body DXA scans were performed to measure body fatness using a Lunar Prodigy Scanner (GE Medical Systems; www.ge healthcare.com) with Encore pediatric software (21). Precision of DXA measurement of body fatness is reasonably high in children, as also found in adults (22,23).

Statistical analyses

DXA measures of fatness provided the ‘true positives’ for the present study and excess fat mass was defined as being in the top decile of fatness for boys (n = 359) and girls (n = 367). The DXA measures of fat mass were adjusted for age and height using regression (21). The definition of excessive fat mass used here is biologically meaningful: when expressed as a simple, unadjusted, percentage of body weight as fat in the top decile of fatness all boys had at least 34% of body weight as fat, and all girls at least 39% of body weight as fat. These levels of body fat exceed the body fat percentage values shown to be associated with increased risk of adverse metabolic and cardiovascular risk factor profiles in previous pediatric studies (24,25).

Sensitivity and specificity of BMI and waist circumference were calculated with 1 percentile increments using the appropriate UK population reference data. Receiver operator characteristic curves (ROC curves) were also used (4), and ROC data and related statistics (sensitivity, specificity, predictive values) expressed using standard definitions (26). Area under the curve (AUC) was calculated using SPSS version 16.0 and differences in AUC for waist circumference versus BMI percentiles examined using their respective 95% confidence intervals.

Results

Characteristics of study participants

Descriptive characteristics of study participants are shown in Table I. Prevalence of overweight (including
Diagnosis of obesity

Obesity, defined conventionally as ≥85th percentile relative to UK 1990 reference data, was 25.8% in boys and 25.2% in girls. Prevalence of obesity, defined conventionally as ≥95th percentile relative to UK 1990 reference data, was 13.9% in boys and 12.3% in girls.

Comparison of waist versus BMI: Sensitivity

Sensitivity of BMI was high in both sexes (Table II for boys; Table III for girls), increasing with lower cut-off points in the distribution as expected (4): 100.0% in boys (359/359) and 99.7% (366/367) in girls at the 85th percentile; 96.4% (346/359) in boys and 94.3% (346/367) in girls at the conventional obesity definition of the 95th percentile; 50.1% in boys (180/359) and 39.5% in girls (145/367) at the 99th percentile. The AUC for BMI was 0.92 (95% CI: 0.91–0.93) in boys and 0.94 (95% CI: 0.93–0.95) in girls.

Sensitivity of waist circumference was high in both sexes (Table II for boys; Table III for girls), increasing with lower cut-off points in the distribution: sensitivity was 99.4% in boys (357/359) and 99.2% (364/367) in girls at the 85th percentile, declining to 75.3% (271/359) in boys and 76.5% (281/367) in girls at the 99th percentile. The AUC for waist circumference in boys was 0.89 (95% CI: 0.86–0.91), and in girls, 0.81 (95% CI: 0.73–0.90). Differences in AUCs between waist and BMI percentiles were significant in both sexes (p<0.05).

Comparison of waist versus BMI: Specificity

Specificity of BMI was high in both sexes (Table II for boys; Table III for girls), increasing with higher cut-off points in the distribution as expected (4). At the 85th percentile for BMI, specificity was 81.9% (2 826/3 450) in boys and 76.8% in girls (2 722/3 546); at the conventional obesity definition of the 95th percentile for BMI, specificity in boys was 94.7% (3 268/3 450) and 96.2% (3 411/3 546) in girls; at the 99th percentile specificity was 99.7% in both sexes.

Specificity of waist circumference ranged from moderately high to high in both sexes (Table II for boys; Table III for girls), increasing at higher cut-off points: at the 85th percentile specificity was 68.7% (2 364/3 450) in boys and 61.6% (2 184/3 546) in girls; at the 99th percentile specificity was 97.4% (3 360/3 450) in boys and 94.8% (3 361/3 546) in girls.

Discussion

Main findings and study implications

The present study suggests that waist circumference is unlikely to offer improved diagnosis of high fat mass over that provided by BMI in children. For clinical applications, high specificity in the diagnosis of excess fatness is considered paramount (2,3), and in the present study BMI out-performed waist circumference with higher specificity, most marked at the lower end of the range of cut-off points tested. The present study is therefore supportive of recommendations from recent pediatric obesity manage-

Table I. Characteristics of participants; Mean (standard deviation).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Boys</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>9.9  (0.5)</td>
<td>9.9  (0.5)</td>
</tr>
<tr>
<td>BMI z-score</td>
<td>0.30 (1.10)</td>
<td>0.29 (1.10)</td>
</tr>
<tr>
<td>Waist z-score</td>
<td>0.80 (1.10)</td>
<td>0.90 (1.11)</td>
</tr>
<tr>
<td>Body fat, percentage of body weight (DXA)</td>
<td>20.1 (8.8)</td>
<td>26.7 (8.4)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>34.4 (7.1)</td>
<td>35.1 (7.8)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>139.7 (6.1)</td>
<td>139.2 (6.5)</td>
</tr>
</tbody>
</table>

Table II. Comparison of diagnostic accuracy of waist circumference percentiles versus body mass index (BMI) percentiles in 3 809 boys, n (%).

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Sensitivity</th>
<th>-ve Predictive Value</th>
<th>+ve Predictive Value</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>BMI Waist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>85th</td>
<td>359/359 357/359</td>
<td>2 826/3 450 2 364/3 450</td>
<td>359/83 357/1 435</td>
</tr>
<tr>
<td></td>
<td>(100.0%) (99.4%)</td>
<td>(81.9%) (68.7%)</td>
<td>(36.5%) (24.8%)</td>
</tr>
<tr>
<td>91st</td>
<td>359/359 357/359</td>
<td>3 074/3 450 2 712/3 450</td>
<td>359/735 357/1 093</td>
</tr>
<tr>
<td></td>
<td>(100.0%) (99.4%)</td>
<td>(90.2%) (78.6%)</td>
<td>(48.8%) (32.7%)</td>
</tr>
<tr>
<td>95th</td>
<td>346/359 350/359</td>
<td>3 268/3 450 2 788/3 450</td>
<td>346/528 350/792</td>
</tr>
<tr>
<td></td>
<td>(96.4%) (97.5%)</td>
<td>(94.7%) (80.8%)</td>
<td>(65.5%) (44.1%)</td>
</tr>
<tr>
<td>99th</td>
<td>180/359 271/359</td>
<td>3 441/3 450 3 360/3 450</td>
<td>180/189 271/362</td>
</tr>
<tr>
<td></td>
<td>(50.1%) (75.3%)</td>
<td>(99.7%) (97.4%)</td>
<td>(95.2%) (74.9%)</td>
</tr>
</tbody>
</table>

DXA: Dual energy x-ray absorptiometry.

Body mass index (BMI) and waist circumference z-scores calculated relative to UK population reference data.

Indicates a significant difference between the sexes (p<0.05).
ment guidelines (1,2,13–16) that BMI percentiles rather than waist circumference percentiles should be used for clinical diagnostic purposes.

Comparisons with other evidence

Only one other study appears to have compared BMI versus waist for diagnosis of high body fat content in youth: Neovius (12) found little difference in the diagnostic accuracy of waist or BMI for high fatness in 17-year-old Swedes (n = 474), consistent with the present study. Recent evidence from studies that compared the ability of waist versus BMI to diagnose adverse cardiovascular disease risk factor profiles in children and adolescents (distinct from fatness) is not entirely consistent, but is not supportive of waist over BMI for diagnosis of cardiovascular risk factors (6,8,9,27), which is perhaps surprising given the evidence from adults. The BMI is a practical and evidence-based option for diagnosis of obesity in youth (1–6), and the balance of evidence from the present study and other recent diagnostic studies of comparisons with waist provides no strong indication to support the replacement of BMI by waist as the most appropriate simple option for diagnosis and definition of obesity.

Study strengths and weaknesses

The sample in the present study derived from an ongoing cohort study and there was inevitable loss of study participants from study inception. The influence of dropout from the cohort may be a minor concern for the present diagnostic study, particularly given the sample size, which is the largest of any pediatric obesity diagnostic study to date. The large sample size available from cohort studies suggests that they offer a practical and efficient opportunity to carry out diagnostic studies of obesity in youth, which could be used more widely in future.

Measurement of body fatness by DXA is prone to both random and systematic errors (28,29), but is a fairly precise approach to measurement of body fatness, which has been used only rarely in diagnostic studies of obesity in children to date (1). Multi-component models of body composition are the most accurate approach to measurement of body fatness (28) but would be impractical with very large samples. No diagnostic studies in pediatric obesity to date have used multi-component models to define excessive fatness.

The present study tested the ability of BMI and waist circumference to diagnose excessive fat mass, one element of the standard definition of obesity, the other being co-morbidities associated with excessive fatness. Ideally, diagnostic evidence should consider both elements in the definition of obesity, but the diverse range of co-morbidities and differences in definitions of the same co-morbidity make a more comprehensive approach to diagnosis problematic, and almost all previous diagnostic studies have considered just body fatness or cardiovascular co-morbidities, not both (1). As noted above, the existing evidence from pediatric diagnostic studies, which have used fatness and cardiovascular risk factors, is fairly consistent in suggesting no improvement in use of waist over BMI. Moreover, many co-morbidities arise directly from excess fat mass and this means that a focus on diagnostic accuracy for excess fat mass is adequate. Measurement of cardiovascular mortality would be ideal, but appropriate for adults, not children. An additional complication is the possibility of ‘metabolically healthy’ obese individuals who would meet body fatness criteria for obesity but not criteria based on cardio-metabolic complications.

In other studies on the ALSPAC cohort, which used DXA at age 9 years, total fat mass and abdominal fat mass (measured as a specified region of interest) were extremely highly correlated (30) and this high degree of correlation may have limited the scope for improvement in diagnosis by waist over BMI in the present study. It is possible that in participants older than those in the present study, greater amounts of visceral adipose tissue might shift the balance of

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>+ve Predictive Value</th>
<th>−ve Predictive Value</th>
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<tr>
<td></td>
<td>BMI</td>
<td>Waist</td>
<td>BMI</td>
<td>Waist</td>
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<tr>
<td>85th</td>
<td>366/367</td>
<td>364/367</td>
<td>2 722/3 546</td>
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<td></td>
<td>(99.7%)</td>
<td>(99.2%)</td>
<td>(76.8%)</td>
<td>(61.6%)</td>
</tr>
<tr>
<td>91st</td>
<td>366/367</td>
<td>362/367</td>
<td>3 207/3 546</td>
<td>2 532/3 546</td>
</tr>
<tr>
<td></td>
<td>(99.7%)</td>
<td>(98.6%)</td>
<td>(90.4%)</td>
<td>(71.4%)</td>
</tr>
<tr>
<td>95th</td>
<td>346/367</td>
<td>358/367</td>
<td>3 411/3 546</td>
<td>2 865/3 546</td>
</tr>
<tr>
<td></td>
<td>(94.3%)</td>
<td>(97.0%)</td>
<td>(96.2%)</td>
<td>(80.8%)</td>
</tr>
<tr>
<td>99th</td>
<td>145/367</td>
<td>281/367</td>
<td>3 536/3 546</td>
<td>3 361/3 546</td>
</tr>
<tr>
<td></td>
<td>(39.5%)</td>
<td>(76.5%)</td>
<td>(99.7%)</td>
<td>(94.8%)</td>
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diagnostic evidence away from BMI and in favor of waist circumference because of associations between visceral adiposity and cardiovascular risk factors. However, an MRI study on a sub-sample of the ALSPAC cohort at age 13 years (31) suggested that the amount of intra-abdominal adipose tissue was still highly correlated with total adiposity, and this biological feature of child and adolescent growth may limit the usefulness of indices based on waist in children and adolescents.

In the present study the standard external reference data for BMI and waist recommended for clinical and public health use in the UK were tested. It is possible that conclusions of the study might have differed had the two sets of external reference data been generated from the same sample or population, or if non-UK reference data had been used to generate percentiles.

A number of issues other than diagnostic accuracy will influence decisions about the appropriateness of BMI or waist circumference as a simple means of providing a definition or diagnosis of pediatric obesity. Such issues are beyond the scope of the current manuscript, and are dealt with elsewhere (1,2,5–9,32), but include comparisons of waist versus BMI for the precision and accuracy of measurement, practical utility, and ease of explaining obesity diagnosis to patients and their families.

Conclusions

The present study provides no evidence to support the replacement of BMI percentile with waist circumference percentile as a simple clinical means of identifying children with excess fat mass.

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