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SHAPECODER: a new method for visual quantification of body mass index in young children

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Summary

Background: Few tools exist to quantify body mass index visually.

Objective: To examine the inter-rater reliability and validity (sensitivity and specificity for overweight/obesity and obesity) of a three-dimensional visual rating system to quantify body mass index (BMI) in young children.

Methods: Children ($n = 242$, mean age 5.9 years, 50.0% male; 40.5% overweight/ obese) participated in a videotaped protocol and weight and height were measured. Research staff applied a novel three-dimensional computer-based figure rating system (SHAPECODER) to the child's videotaped image. Inter-rater reliability was calculated, as well as correlation with measured body mass index (BMI) and sensitivity, specificity, positive predictive value and negative predictive value for overweight/obesity and obesity.

Results: Inter-rater reliability was excellent (intraclass correlation coefficient = 0.98). The correlation of SHAPECODER-generated BMI with measured BMI was 0.89. For overweight/obesity, the sensitivity, specificity, positive predictive value and negative predictive value were 62%, 97%, 94% and 79% respectively. For obesity, these values were 65%, 99%, 97% and 92% respectively.

Conclusion: SHAPECODER provides a method to quantify child BMI from video images with high inter-rater reliability, fair sensitivity and good specificity for overweight/obesity and obesity. The approach offers an improvement over existing two-dimensional rating scales for BMI.

Keywords: Anthropometry, body image, obesity.

Introduction

Estimating the body mass index (BMI) of adults by using a rating scale of two-dimensional (2-D) silhouette drawings is possible with reasonable validity (e.g. $r = 0.70$ to 0.80).(1–3) However, estimating the BMI of children by using 2-D silhouette drawings has proven to be more challenging. A child's selection of one of seven 2-D photographic images of children of varying BMIs correlated with the image that their measured BMI would match only modestly ($r = 0.43$ in one study(4) and 0.56 among girls and 0.29 among boys in another study(5)). In one study, only 40.3% of mothers were able to correctly match their child's measured BMI to one of seven 2-D silhouette drawings.(6) In another study with a separate set of seven 2-D drawings, sensitivity of the drawings for overweight/obesity based on parental selection was 70% and specificity was 79%.(7)

To address the limited validity of 2-D silhouette rating scales as an estimation of children's BMI, SHAPECODER, a new software tool based on three-dimensional (3-D) laser scans of child body shape, was developed. SHAPECODER guides a rater through a series of rotatable, 3-D figures of standing children generated from a Statistical Body Shape Model (SBSM).(8) At each of four levels, the rater chooses the SHAPECODER figure that best matches the body shape of the subject. The underlying SBSM associates each presented figure with a BMI.

This study sought to determine the reliability and validity of SHAPECODER for predicting child BMI from videotaped images of children. We hypothesized that SHAPECODER could be applied with acceptable inter-rater reliability, that it would be capable of generating

BMI values that closely correlate with actual measured BMIs, and that it would be highly sensitive and specific for child overweight/obesity and obesity by measured BMI. Although BMI has well-known limitations as an index of body fat,(9) it is easy to measure and calculate and is commonly used to define overweight/obesity and obesity. We therefore used BMI as the index of child adiposity against which to validate SHAPECODER.

Methods

Participants

A non-probability convenience sampling method was used to recruit participants. The study population included 242 children recruited from Head Start programmes (free, federally subsidized preschool programmes for children from families earning a low income) in the Midwestern region of the USA who were part of a longitudinal study examining stress, eating behaviour and children's growth. Those meeting the following criteria were eligible for inclusion: caregiver had less than a 4-year college degree, caregiver fluent in English, child born at 35 weeks of gestation or more and without significant perinatal or neonatal complications, child without serious medical problems and child not in foster care. To be included in this analysis, children also needed to have a measured BMI, which resulted in the exclusion of one child who declined anthropometry. In addition, one child whose measured BMI was a significant outlier at 38.46 was excluded. The work described here represents a secondary analysis of videotaped parent–child interactions around feeding which were part of a follow-up study of this cohort occurring 2 years later that included an extensive data collection protocol focused on maternal feeding beliefs and practices. For the overall protocol, families attended two 2-h study visits in a private room at a local community centre and provided three videotapes of mealtimes in their home. During study visits, the families completed interviews, questionnaires and the videotaped protocol described in the succeeding texts. The participants were each compensated $150. All parents gave written informed consent, the children provided assent, and the University of Michigan Institutional Review Board approved the study. The sample of children was 50.0% male and 43.8% Hispanic or not white, and the mean child age was 5.91 years (SD 0.71, range 4.0 to 8.1). The majority (90%) were from families earning a low income, defined as having an income-to-needs ratio less than 185% of the federal poverty line.

Videotaping protocol

The children were videotaped seated at a table with their parent while participating in a protocol designed to examine eating and feeding behaviours, which has been previously described.(10) Briefly, each parent–child dyad was presented with a series of servings of food, invited to taste them if they wished, and then left alone in the room with the food for 4 min, during which the parent–child interaction was videotaped. The researcher returned to the room after each 4-min period and asked the parent and child a series of standardized questions about their impressions of the food. In total, each videotape lasted about 20 min. The vast majority of children sat next to the parent throughout the task, generally engaging in a conversation with the parent about the food and often moving around frequently in their chairs. Some children occasionally stood up next to their chairs. The camera was set up to capture the child's entire body on video, while also being as close as possible in order to allow assessment of facial expressions for other elements of the study.

Anthropometry

Research staff participated in a half-day training in research-grade anthropometry, were certified for appropriate technique, participated in quarterly refresher sessions regarding appropriate technique, and were recertified annually. A Detecto Portable Scale Model no. DR550 was used to weigh the children, and a Seca 217 portable stadiometer was used to measure the children's height. A standard weight was used to check the calibration of the scale monthly. The children were measured according to the following procedures: shoes and heavy clothing were removed. The children were weighed twice, and if the readings differed by more than 0.1 kg, then they were weighed two additional times. The children's heights were measured twice after verifying appropriate position and posture, and if the measurements were inconsistent by more than 0.5 cm, then they were measured two more times. The average of the final two measures was used for analysis. BMI was calculated as weight in kilograms divided by height in metres squared [BMI = weight in kilograms / (height in metres)^2], and BMI z-scores were derived from the age-specific and sex-specific US Centers for Disease Control growth charts.(11) We elected to use these growth charts given that they provide a reference for US children, consistent with the nationality of children enrolled in this study. Child overweight/obese was defined as BMI ≥ 85th percentile, and obese was defined as BMI ≥ 95th percentile for age and sex.

SHAPECODER software

SHAPECODER software was developed by the authors based on data drawn from a separate sample of 73 boys and 67 girls' ages 3 to 11 years with a height range of 100 to 166 cm and a BMI from 12 to 27 kg/m^2. High-resolution body surface data were obtained in a standing posture by using a laser scanner. A standardized template was fit to the data, and a principal component analysis was conducted to obtain a reduced-dimension representation.(12) Linear regression analysis was conducted to predict body size and shape by using standard anthropometric values as predictors. The age range of the subject pool (3 to 11 years old) was determined based on developmental maturity sufficient to stand still for 15 s at a time. The selected children were free of evident skeletal deformities, musculoskeletal injuries or disabilities.

The SHAPECODER software generates 3-D figures by using an SBSM[17] based on these data (Fig. 1). At each of four levels, five figures are shown, and the rater chooses the one most similar to the study participant. At the first level, the figures are generated based on evenly spaced heights from 100 to 160 cm. The figures are always shown with the same vertical dimension on the screen, so height is visible as body proportions rather than vertical extent on the screen (i.e. how much of the computer screen is occupied by the figure). The second level uses the height selected at the first level and presents five figures with BMIs ranging from 10 to 30 kg/m^2. The third level presents a narrower range of height (±10 cm) based on the initial selection in Level 1, with the BMI held at the level selected in Level 2. In Level 4, the refined height selected in Level 3 is fixed and BMI is varied ±3 kg/m^2 relative to the value selected in Level 2. Hence, the best possible precision of SHAPECODER is 0.75 kg/m^2, or half of the final BMI interval. SHAPECODER exports the height and BMI associated with the figure selected in Level 4 for subsequent analysis. Supplementary information (a demonstration of SHAPECODER) is available at http://shapecoder.org.

Application of SHAPECODER

Two research staff members applied SHAPECODER to the videotaped images. Coders reviewed the SHAPECODER program manual and used it for a practice set of five videos independently, and then together, to gain experience by using the program. A total of 15 videos (6% of all videos) were coded by these two raters, from which inter-rater reliability on SHAPECODER was calculated. It took 3 to 4 min to code each participant's body shape from the videotaped image.

Statistical analyses

Data were analysed with SAS 9.3 (SAS Institute, Cary, NC, USA). To test the hypothesis that SHAPECODER could be applied with acceptable inter-rater reliability, we calculated intraclass correlation coefficients for the SHAPECODER-generated BMIs resulting from each of the two coders' application of the program.

Validity of SHAPECODER was assessed by examining the correlation of SHAPECODER-generated BMI with BMI by anthropometry, as well as the sensitivity and specificity for overweight/obesity and obesity. To test the hypothesis that SHAPECODER would generate a BMI value that closely correlated with the actual measured BMI, we calculated Pearson's correlation coefficient for the SHAPECODER-generated BMI against the measured BMI. To test the hypothesis that the SHAPECODER-generated BMIs would be highly sensitive and specific for overweight/obesity and obesity by the measured BMI, we first transformed both SHAPECODER-generated BMIs and actual measured BMIs to BMI percentiles based on the US Centers for Disease Control growth charts.(11) We then used these BMI percentiles to categorize children as overweight/obese or obese based on SHAPECODER as well as based on actual anthropometry. We then calculated the sensitivity, specificity, positive predictive value and negative predictive value for the SHAPECODER-generated BMI as a test for overweight/obesity and obesity as determined by the BMI percentile based on US Centers for Disease Control growth charts.(11)

Results

The mean measured BMI was 17.22 (SD 2.67; range 12.68 to 32.01). The mean measured BMI *z*-score, based on the US Centers for Disease Control growth charts,(11) was 0.80 (SD 1.01; range −2.58 to 3.08). A total of 59.5% of children were not overweight (BMI < 85th percentile), 20.25% were overweight (85th percentile < BMI < 95th percentile), and 20.25% were obese (BMI > 95th percentile). The mean SHAPECODER-generated BMI was 16.50 (SD 2.51; range 13.00 to 26.50).

There was support for excellent inter-rater reliability on the 15 videos coded by both raters: intraclass correlation coefficient = 0.98. With regard to the validity of SHAPECODER, the SHAPECODER-generated BMI showed a very strong correlation with the measured

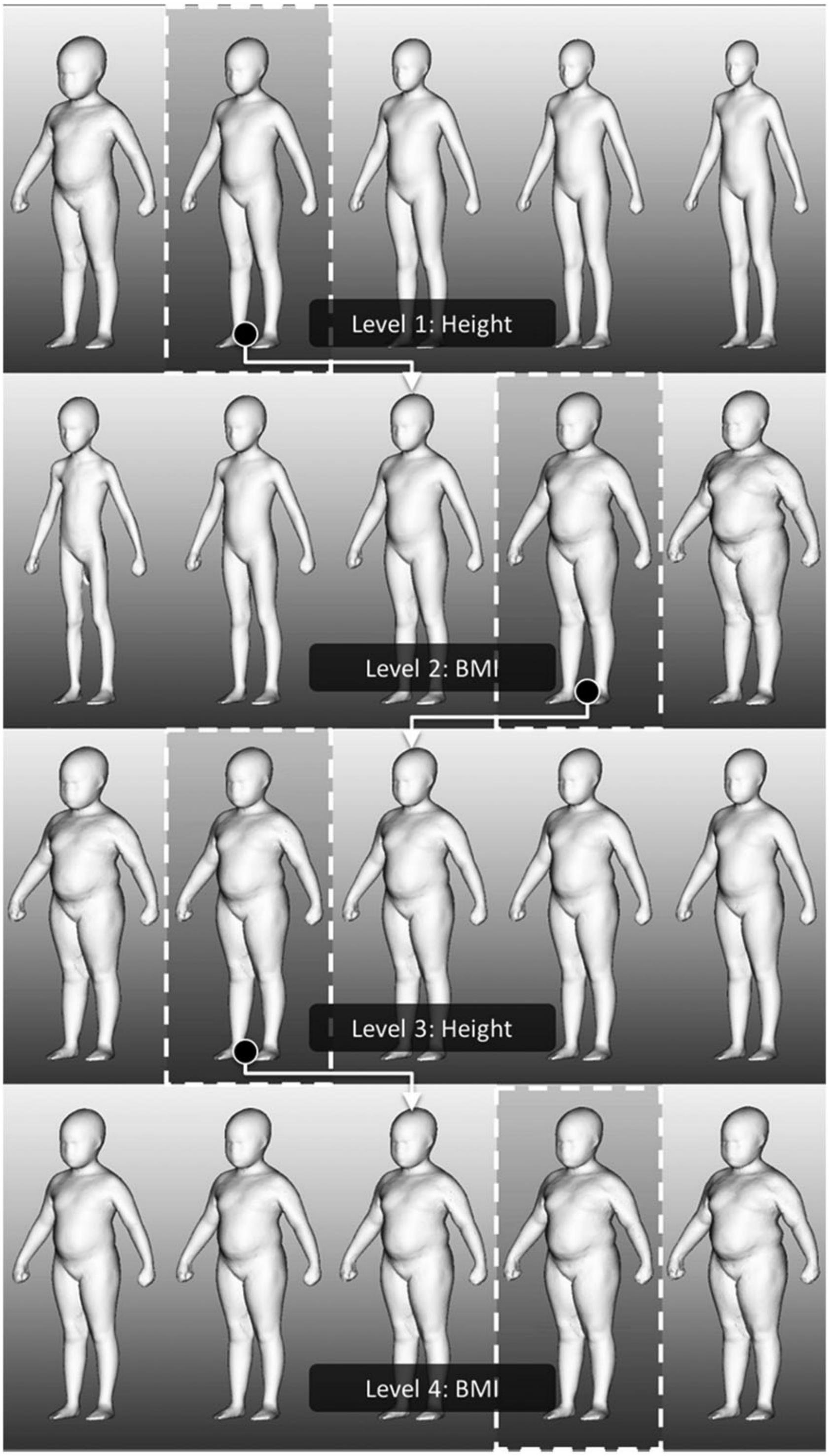

Figure 1 Illustration of four sequential screens from SHAPECODER. At Level 1, the five figures represent body shapes based on evenly spaced heights from 100 to 160 cm. The figure with the dot underneath it represents a hypothetical choice of the rater. At Level 2, the five figures represent a range of body types for the height selected at the first level (e.g. 115 cm) with body mass indexes (BMIs) ranging from 10 to 30 kg/m^2. At Level 3, the five figures represent a narrower range of height (±10 cm) based on the initial selection in Level 1, with the BMI held at the level selected in Level 2. At Level 4, the five figures represent body shapes with BMI varied ±3 kg/m^2 relative to the BMI value selected in Level 2 and the refined height selected in Level 3. The final highlighted choice has a height of 110 cm and 26.5 kg/m^2. Note that each individual image can be rotated on the screen.

BMI ($r = 0.89$, $p < 0.001$). The measured BMI was predicted by the SHAPECODER BMI by the equation: Measured BMI = 1.65 + 0.94 * SHAPECODER BMI (Fig. 2). The R^2 for this regression is 0.79, and the root mean squared error is 1.24 kg/m^2.

The sensitivity and specificity of the SHAPECODER-generated BMI for overweight/obesity by the measured BMI were 62% and 97% respectively. The positive predictive value of the SHAPECODER-generated BMI for overweight/obesity was 94%. The negative predictive value of the SHAPECODER-generated BMI for overweight/obesity was 79%.

The sensitivity and specificity of the SHAPECODER-generated BMI for obesity by the measured BMI were 65% and 99% respectively. The positive predictive value of the SHAPECODER-generated BMI for obesity was 97%. The negative predictive value of the SHAPECODER-generated BMI for obesity was 92%.

Analyses stratified by child sex did not demonstrate meaningful differences.

Discussion

This study provides evidence that a new approach for assessing children's BMI by using a visual rating can be applied with high inter-rater reliability. The correlation of the SHAPECODER-generated BMI with the measured BMI ($r = 0.89$) exceeded correlations reported in prior studies (albeit with child raters), which were all less than 0.60.(4,5) In the single prior study in which sensitivity and specificity for overweight/obesity were reported, SHAPECODER demonstrated somewhat weaker sensitivity (62 vs. 70%(7)) but superior specificity (97 vs. 79%(7)).

SHAPECODER provides fair sensitivity for overweight/obesity and obesity and good specificity. Thus,

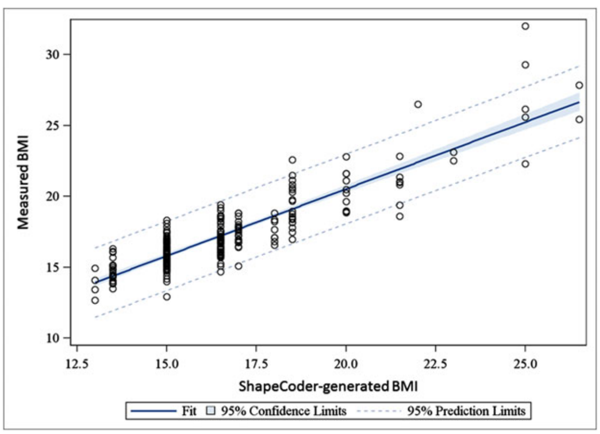

Figure 2 Correlation of SHAPECODER-generated BMI with measured BMI. The regression equation is $y = 0.94x + 1.65$.

although SHAPECODER will only identify about 62% of children who are overweight/obese and 65% of those who are obese, it correctly identifies children as not overweight/obese 97% of the time and correctly identifies children as not obese 99% of the time. When a child is identified as overweight/obese by SHAPECODER, 94% of the time, the child is overweight/obese by anthropometry. When a child is identified as not overweight/obese by SHAPECODER, 79% of the time, the child is indeed not overweight/obese. When the child is identified as obese by SHAPECODER, 97% of the time, the child is obese. When the child is identified as not obese by SHAPECODER, 92% of the time, the child is not obese.

SHAPECODER could be a valuable addition to extant tools that evaluate body type, particularly in large, epidemiologic studies of children that often do not include measured weight and height but sometimes do include videotaped images. SHAPECODER could also be used in research studies examining body image and eating disorders. As in any study, the choice of instrument will depend on whether the costs associated with false positives vs. false negatives are higher or lower in a particular usage context.

There are several limitations to our study. The sample of children used to generate the SBSM in SHAPECODER was relatively small, primarily white, and with a smaller prevalence of overweight and obesity than among the children who were the participants in the current analysis. The SBSM also combines data from boys and girls. The age range of children in the coded sample of videotapes was constricted to 4.0 to 8.1 years, and it is not known if the results apply to children outside of this age range. There were no meaningful differences in our results by child sex, and differences could emerge within a sample of older children. The validity of SHAPECODER among children who have entered puberty is unknown. It is also unknown if the results apply to children of differing sociodemographic characteristics. This study also used 3-D moving images of fully clothed, seated children on videotape by using a stationary camera; reliability and validity of SHAPECODER may have been higher if the children were viewable standing, from all angles, and with less clothing. In addition, although BMI is used in clinical practice to estimate adiposity, it has substantial limitations in accurately identifying overweight/obesity and obesity. Finally, the selection of levels in the software and the separation between adjacent images may have influenced the accuracy and precision of the results. For example, using a narrower range of BMIs in the final level may have improved the results. However, pilot testing suggested that it was not generally feasible to distinguish between figure images separated by less than 1.5 kg/m^2 (Fig. 1).

There are a number of directions for future work. First, confirmatory work in larger populations with varying degrees of adiposity (including larger groups of thinner or underweight children) and diverse race/ethnicity would be beneficial. In addition, sex-specific models for older children would be useful. Future work should also use methods for measuring adiposity that have greater precision than BMI, so that the validation of SHAPECODER-generated categorizations of overweight/obesity and obesity could be carried out against a measure that is a more accurate index of adiposity than BMI. Prior work has described parents' inability to accurately identify their child's own body type,(6,7) but this work has been limited to the use of 2-D figure ratings. If parents can accurately apply SHAPECODER to assess their own child's body shape, then this would suggest that the prior literature concluding that parents cannot accurately recognize their child's body type may be an artefact of the limitations of 2-D rating scales. In summary, SHAPECODER can be used by researchers as a measure of children's BMI or weight status.

Conflict of Interest Statement

The authors have no financial relationships relevant to this article to disclose. The authors have no conflicts of interest to disclose.

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BP created the software, contributed to data analysis and interpretation and helped to write the manuscript. MR created the software, contributed to data analysis and interpretation and helped to write the manuscript. NK contributed to data analysis and interpretation and helped to write the manuscript. ML contributed to coding of body shape, conducted the literature search and helped to write the manuscript. AM contributed to data collection, analysis and interpretation and helped to write the manuscript. DA contributed to data analysis and helped to write the manuscript. JL conceived of the study design, contributed to the data collection and interpretation, helped to conduct the literature search and helped to write the manuscript.

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