ORIGINAL ARTICLE

Body shape and size in 6-year old children: assessment by three-dimensional photonic scanning

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BACKGROUND: Body shape and size are typically described using measures such as body mass index (BMI) and waist circumference, which predict disease risks in adults. However, this approach may underestimate the true variability in childhood body shape and size.

OBJECTIVE: To use a comprehensive three-dimensional photonic scan approach to describe variation in childhood body shape and size.

SUBJECTS/METHODS: At age 6 years, 3350 children from the population-based 2004 Pelotas birth cohort study were assessed by three-dimensional photonic scanner, traditional anthropometry and dual X-ray absorptiometry. Principal component analysis (PCA) was performed on height and 24 photonic scan variables (circumferences, lengths/widths, volumes and surface areas).

RESULTS: PCA identified four independent components of children’s body shape and size, which we termed: Corpulence, Central: peripheral ratio, Height and arm lengths, and Shoulder diameters. Corpulence showed strong correlations with traditional anthropometric and body composition measures (r > 0.90 with weight, BMI, waist circumference and fat mass; r > 0.70 with height, lean mass and bone mass); in contrast, the other three components showed weak or moderate correlations with those measures (all r < 0.45). There was no sex difference in Corpulence, but boys had higher Central:peripheral ratio, Height and arm lengths and Shoulder diameters values than girls. Furthermore, children with low birth weight had lower Corpulence and Height and arm lengths but higher Central:peripheral ratio and Shoulder diameters than other children. Children from high socio-economic position (SEP) families had higher Corpulence and Height and arm lengths than other children. Finally, white children had higher Corpulence and Central:peripheral ratio than mixed or black children.

CONCLUSIONS: Comprehensive assessment by three-dimensional photonic scanning identified components of childhood body shape and size not captured by traditional anthropometry or body composition measures. Differences in these novel components by sex, birth weight, SEP and skin colour may indicate their potential relevance to disease risks.

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INTRODUCTION

Body shape is frequently assessed in epidemiological studies in adults to predict risks of mortality and other adverse health outcomes.1,3 In addition to overall body weight-for-height (body mass index (BMI)), those studies often also assess measures of central body shape (for example, waist and hip circumferences, waist–hip ratio and regional fat mass distribution), which reflect the characteristic sexual dimorphism in body shape and body fat distribution.3–5 Men have relatively more central fat (‘android’ distribution) while women have relatively more peripheral fat (‘gynoid’), a difference which is explained by sex hormone actions.6

In contrast to convincing evidence in adults that waist circumference and BMI combine synergistically to predict later disease risks,1,7 the added value of estimating central body shape in children is less clear. Four studies have assessed the contribution of waist circumference to cardiovascular disease risk factors in children; only one (a study of 154 overweight or obese girls aged 5–16 years) reported a positive association between waist circumference and fasting insulin resistance that was independent of BMI.8 The other three studies were population based (sample sizes were 436, 5235 and 7589 children aged 7–12 years) and reported no additional contribution of waist circumference beyond BMI alone.9–11 Furthermore, measures of BMI and central body shape (such as waist circumference) show much higher inter-correlation in children than in adults, and therefore regression models that include both parameters are often affected by colinearity.12,13 Finally, restriction of assessment of body shape to disease markers in adults may underestimate the wider variations in childhood body shape and size.

In recent years, three-dimensional (3-D) photonic scanning has been used in several studies to assess body shape and size in adults.14–16 The advantage of this approach is its ability to rapidly capture many diverse measurements (circumferences, widths, lengths) at different sites.17 Nevertheless, only one study has assessed body shape in children using 3-D photonic scanning.18 We used this method to describe variation in body shape and size in children and to assess how well these dimensions are captured by traditional anthropometric and body composition measurements.

METHODS

Subjects

Pelotas is a city located in Southern Brazil, with a population of 330 000 inhabitants according to the 2010 Brazilian Demographic Census.19 The

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Anthropometric, body composition and photonic scan measures at age 6 years

The fifth follow-up of the cohort, at mean age 6.8 years (min. 5.8–max. 7.6 years), occurred between October 2010 and August 2011, required a visit to the study clinic and followed up 3722 children. The examination included traditional anthropometry (weight, height, sitting height and waist circumference), body composition assessment (whole-body dual X-ray absorptiometry (DEXA, GE Lunar Prodigy densitometer, UK) and air-displacement plethysmography, Cosmed, Rome, Italy) and questionnaire assessment of lifestyle and health status.21 The study protocol was approved by the Research Ethics Committee of the Federal University of Pelotas, affiliated with the Brazilian Medical Council, and confidentiality of information was warranted.

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RESULTS

Children’s characteristics are summarized in Table 1. More than 70% were white and almost 40% were overweight or obese. Boys were taller and had higher DXA fat-free mass than girls, while girls had higher hip and thigh circumferences and higher total fat mass and trunk, android and gynoid fat mass. There were no sex differences in weight, BMI or waist circumference.

Analysis of the photonic scan measurements identified four independent components (Table 2). The first component (which we termed ‘Corpulence’) showed positive loadings with the following measures: waist, hip, seat, chest, abdomen, knee, calf and biceps circumferences, sagittal diameter, waist and abdomen width, body volume, and torso volume. The second component (‘Central:peripheral ratio’) showed positive loading with torso surface area (and positive trends with all other measures of central body area) and negative loadings with thigh circumference, inside leg length, arm length, arm volume and leg surface area. The third component (‘Height and arm lengths’) showed positive loadings with height, arm length, torso surface area and arm surface area and negative loading with thigh circumference. Finally, the fourth component (‘Shoulder diameter’) showed positive loadings with upper shoulder diameter and wrist circumference and negative loading with arm volume. After standardization, all components have a mean of 0 and an s.d. of 1.

To assess how well these four components of body shape and size were captured by traditional anthropometric and body composition measurements, we assessed their correlations (Table 3). Corpulence was strongly correlated (Pearson coefficients r > 0.70) with weight, BMI, waist circumference, height and all DXA total and regional body composition measures. In contrast, components 2–4 showed at best only weak positive correlations (all r < 0.45) with traditional anthropometric and DXA parameters. Notably, waist:hip ratio showed modest association with Corpulence (r = 0.39) and weak association with Central:peripheral ratio (r = 0.14). An exploratory analysis of non-traditional measurements showed that Central: peripheral ratio was positively correlated with (photonic scan measured) waist:hip circumference ratio (r = 0.74).

Differences in the four components by sex, birth weight, BMI z-score, SEP and skin colour are shown in Table 4. We observed that the magnitude of differences was higher to Corpulence in almost all independent variables, despite differences seen in other three components. There was no sex difference in Corpulence, but...
boys had higher Central:peripheral ratio, Height and arm lengths and Shoulder diameter than girls. In addition, children with low birth weight had lower z-score of Corpulence (−0.37) and Height and arm lengths (−0.13) but higher values for Central:peripheral ratio (0.13) and Shoulder diameter (0.15) than other children. Furthermore, obese children had substantially higher values for Corpulence and Central:peripheral ratio (presenting a z-score mean of 1.7 and 0.4, respectively), and lower values for Height and arm lengths and Shoulder diameter than other children (z-score mean of −0.3 and −0.1, respectively). Children from higher SEP showed higher z-score mean of Corpulence when compared with children from lowest SEP (0.3 vs −0.3). Furthermore, they also presented higher mean of Height and arm lengths, despite the magnitude of differences have been higher to Corpulence in almost all independent variables, those other traditionally poorly captured components (Central:peripheral ratio, Height and arm lengths and Shoulder diameter) showed significant patterning by sex, birth weight, obesity status, SEP and skin colour, which suggests that they might contribute independently to prediction of disease risks.

Boys presented a more central body shape than girls, indicating that the typical sex-divergent pattern of adult body shape, often assumed to reflect sex hormone actions, are already seen in prepubertal children. Similarly, previous studies have reported sex differences in body shape in prepubertal children. Taylor et al.3 reported that prepubertal boys had more waist fat but less hip fat than girls, and those differences widened in pubertal stages.3 Another study reported that 5–7-year boys had higher waist circumference and waist–hip ratio than girls.29 In our cohort, unadjusted analyses showed that boys and girls had equal average waist circumference, but their mean hip circumference was 1 cm smaller than that of girls. After adjustment for height and total body composition, we observed that boys had higher waist circumference but lower hip and thigh circumferences than girls (data not shown). Hormonal differences explain the sex dimorphism in body shape after puberty7 but could also contribute to differences in prepubertal children. Garnett et al.26 found significant sex differences in the circulating concentrations of estradiol, leptin and testosterone before puberty.

Associations with sociodemographic indicators, BMI and birth-weight tended to be much stronger for the first component than for the other three. Birth weight has been inconsistently associated with body shape and body fat distribution in childhood.27–29 We found that children with low birth weight presented markedly lower values for Corpulence, slightly lower values for Height and arm lengths and slightly higher Central:peripheral ratio. It indicates that in our cohort low birth weight children tend to remain generally smaller at 6 years and present a more central body shape than other children. We also observed significant differences in body shape and size by SEP and skin colour. The higher values for Corpulence in children from high SEP and white skin colour is consistent with previous reports of higher BMI and body fat mass in this cohort and in other studies30–32 and likely reflects differences in nutrition and other childhood factors. Nevertheless, further studies should examine whether differences in components of body shape and size are related to lifestyle factors, such as feeding habits, physical activity, sedentary behaviour and so on in childhood.

Body shape measured by 3-D photonic scanning has been reported in adults,14,33 in whom differences were detected between Thai and British adults15 and by parity in women.34 To our knowledge, this is the first study to use 3-D photonic scanning to assess the variability and potential determinants of body shape in children.

3-D photonic scanning enabled us to assess different dimensions of body shape, beyond traditional anthropometric assessment. Thus we could see that traditional measures capture the same single component of children’s body shape and size. Our findings suggest that some of those other, yet overlooked, components of body shape and size could be estimated by additional simple anthropometric assessment. Use of body shape and size could be estimated by additional simple anthropometric assessments. Further studies should be required to validate that approach and to show predictive value of the other three components.

Strengths of our study are the large sample size and the low rate of attrition owing to loss of contact or refusal (9.8%), which minimizes bias. In addition, comprehensive assessments using traditional anthropometry and DXA allowed comparability of 3-D.

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Table 1. Description of sociodemographic and anthropometric variables of children by sex: the 2004 Pelotas Birth Cohort Study

| SEP quintiles         | Male, N (%) | Female, N (%) | P-valuea |
|----------------------|-------------|---------------|----------|
| First (upper)        | 388 (22.6)  | 372 (22.9)    | 0.427    |
| Second               | 351 (20.4)  | 367 (22.7)    |          |
| Third                | 383 (22.3)  | 362 (22.4)    |          |
| Fourth               | 298 (17.4)  | 253 (15.6)    |          |
| Fifth (lower)        | 297 (17.3)  | 266 (16.4)    |          |

| Skin colour          | Male, N (%) | Female, N (%) | P-valuea |
|----------------------|-------------|---------------|----------|
| White                | 1143 (70.8) | 1092 (72.2)   | 0.526    |
| Brown                | 219 (13.6)  | 185 (12.2)    |          |
| Black                | 252 (15.6)  | 236 (15.6)    |          |

| BMI category         | Male, N (%) | Female, N (%) | P-valuea |
|----------------------|-------------|---------------|----------|
| Normal weight        | 1088 (65.2) | 1005 (63.7)   | 0.409    |
| Overweight           | 289 (17.3)  | 302 (19.1)    |          |
| Obese                | 291 (17.5)  | 272 (17.2)    |          |

| Birth weight, g      | Male, N (%) | Female, N (%) | P-valuea |
|----------------------|-------------|---------------|----------|
| < 2500               | 130 (7.5)   | 156 (9.6)     | 0.036    |
| ≥ 2500               | 1593 (92.5) | 1471 (90.4)   |          |

| Continuous variables | Mean (s.d.) | Mean (s.d.) | P-valuea |
|----------------------|-------------|-------------|----------|
| Weight (kg)          | 25.1 (5.8)  | 24.9 (6.1)  | 0.228    |
| Height (m)           | 1.22 (0.1)  | 1.20 (0.1)  | < 0.001  |
| Body mass index (kg·m⁻²) | 16.9 (2.8) | 17.0 (3.1)  | 0.190    |
| Waist circumference (cm) | 58.4 (7.3) | 58.4 (7.8)  | 0.951    |
| Hip circumference (cm) | 60.0 (7.1) | 60.7 (7.5)  | < 0.001  |
| Thigh circumference (cm) | 38.3 (5.3) | 38.9 (5.7)  | 0.002    |

| DXA variables        | Mean (s.d.) | Mean (s.d.) | P-valuea |
|----------------------|-------------|-------------|----------|
| Fat mass (kg)        | 4.9 (3.9)   | 6.3 (4.2)   | < 0.001  |
| Fat free mass (kg)   | 20.2 (2.5)  | 18.5 (2.4)  | < 0.001  |
| Trunk fat mass (kg)  | 2.1 (1.9)   | 2.7 (2.1)   | < 0.001  |
| Android fat mass (kg) | 0.4 (0.4)  | 0.5 (0.4)   | < 0.001  |
| Gynoid fat mass (kg) | 1.1 (0.7)   | 1.3 (0.7)   | < 0.001  |

Abbreviations: BMI, body mass index; DXA, dual X-ray absorptiometry; SEP, socio-economic position. *Chi-squared. **Analysis of variance. *Measured by photonic scanner.
scanning to other techniques. Limitations include the single age point at 3-D scanning; therefore, future assessments are needed to inform how applicable our findings are to other ages and to assess how body shape changes with age. Moreover, the disease relevance of our new components of body shape is yet unknown and will require future studies. Finally, 3-D photonic scanning has not been validated in Brazilian children. In a validation study in a multi-ethnic sample of children of similar age in the United Kingdom, 3-D photonic scan outcomes were found to over-estimate manual measurements for almost all outcomes, varying from 0.6 cm to calf girth up to 3.7 cm to chest girth.18 However, ranking consistency was very high, and when compiling

### Table 2. Principal components for body shape and size in children aged 6 years: the 2004 Pelotas Birth Cohort Study

| Photonic measurement       | Component 1 ('Corpulence') | Central:peripheral ratio | Height and arm lengths | Shoulder diameter |
|----------------------------|----------------------------|--------------------------|------------------------|------------------|
| Hip circumference          | 0.24                       | 0.11                     | −0.03                  | −0.03            |
| Seat circumference         | 0.24                       | 0.09                     | −0.00                  | −0.04            |
| Chest circumference        | 0.24                       | 0.08                     | −0.00                  | −0.04            |
| Abdomen circumference      | 0.23                       | 0.10                     | −0.05                  | −0.03            |
| Waist width                | 0.23                       | 0.11                     | 0.01                   | 0.02             |
| Abdomen width              | 0.23                       | 0.10                     | −0.01                  | −0.04            |
| Knee circumference         | 0.23                       | −0.04                    | −0.08                  | −0.03            |
| Calf circumference         | 0.23                       | −0.00                    | −0.09                  | −0.04            |
| Biceps circumference       | 0.22                       | 0.03                     | −0.07                  | 0.04             |
| Sagittal diameter          | 0.22                       | 0.10                     | −0.02                  | −0.05            |
| Body volume                | 0.24                       | 0.06                     | 0.03                   | −0.05            |
| Torso volume               | 0.23                       | 0.20                     | 0.10                   | −0.02            |
| Inside leg length          | 0.09                       | −0.62                    | −0.02                  | 0.03             |
| Leg volume                 | 0.21                       | −0.28                    | −0.19                  | −0.03            |
| Leg surface area           | 0.19                       | −0.39                    | −0.19                  | −0.01            |
| Thigh circumference        | 0.20                       | −0.27                    | −0.33                  | −0.03            |
| Torso surface area         | 0.20                       | 0.24                     | 0.24                   | 0.01             |
| Arm length                 | 0.08                       | −0.24                    | 0.66                   | 0.24             |
| Height                     | 0.17                       | −0.21                    | 0.39                   | 0.04             |
| Arm surface area           | 0.20                       | −0.11                    | 0.30                   | −0.04            |
| Upper shoulder diameter    | 0.07                       | 0.11                     | −0.21                  | 0.81             |
| Wrist circumference        | 0.12                       | 0.03                     | −0.07                  | 0.39             |
| Arm volume                 | 0.13                       | 0.05                     | −0.05                  | −0.29            |
| Neck circumference         | 0.18                       | 0.10                     | −0.00                  | 0.09             |
| Variance explained         | 66.7%                      | 8.2%                     | 4.9%                   | 4.1%             |

Values in bold correspond to the loadings considered as representative of each component.

### Table 3. Correlations between 3DPS components in 6-year-old children and traditional anthropometric and body composition measures: the 2004 Pelotas Birth Cohort Study

| Variable                     | Component 1 ('Corpulence') | Component 2 ('Central:peripheral ratio') | Component 3 ('Height and arm lengths') | Component 4 ('Shoulder diameter') |
|------------------------------|----------------------------|------------------------------------------|----------------------------------------|----------------------------------|
| **Traditional anthropometry**|                            |                                          |                                        |                                  |
| Weight                       | 0.99 ( < 0.001)            | 0.04 (0.023)                             | 0.03 (0.116)                           | −0.04 (0.052)                   |
| BMI                          | 0.93 ( < 0.001)            | 0.20 ( < 0.001)                          | −0.18 ( < 0.001)                       | −0.07 ( < 0.001)               |
| Waist circumference          | 0.95 ( < 0.001)            | 0.13 ( < 0.001)                          | −0.06 (0.002)                          | −0.04 (0.022)                   |
| Height                       | 0.70 ( < 0.001)            | −0.30 ( < 0.001)                         | 0.43 ( < 0.001)                        | 0.04 (0.038)                    |
| Waist–Hip ratio              | 0.39 ( < 0.001)            | 0.14 ( < 0.001)                          | −0.09 ( < 0.001)                       | 0.03 (0.185)                    |
| Sitting height               | 0.69 ( < 0.001)            | −0.17 ( < 0.001)                         | 0.29 ( < 0.001)                        | 0.01 (0.546)                    |
| Leg length                   | 0.48 ( < 0.001)            | −0.32 ( < 0.001)                         | 0.44 ( < 0.001)                        | 0.05 (0.004)                    |
| **Non-traditional measures**|                            |                                          |                                        |                                  |
| Waist-thigh ratio            | 0.07 ( < 0.001)            | 0.74 ( < 0.001)                          | 0.46 ( < 0.001)                        | 0.01 (0.471)                    |
| **Body composition (DXA)**   |                            |                                          |                                        |                                  |
| Fat mass                     | 0.93 ( < 0.001)            | 0.12 ( < 0.001)                          | −0.09 ( < 0.001)                       | −0.07 ( < 0.001)               |
| Lean mass                    | 0.78 ( < 0.001)            | −0.08 ( < 0.001)                         | 0.21 ( < 0.001)                        | 0.03 (0.157)                    |
| Bone mass                    | 0.82 ( < 0.001)            | −0.10 ( < 0.001)                         | 0.15 ( < 0.001)                        | −0.02 (0.332)                   |
| Trunk fat mass               | 0.91 ( < 0.001)            | −0.15 ( < 0.001)                         | −0.10 ( < 0.001)                       | −0.06 (0.001)                   |
| Android fat mass             | 0.90 ( < 0.001)            | −0.17 ( < 0.001)                         | −0.11 ( < 0.001)                       | −0.06 (0.001)                   |
| Gynoid fat mass              | 0.93 ( < 0.001)            | −0.10 ( < 0.001)                         | −0.08 ( < 0.001)                       | −0.07 ( < 0.001)               |

Abbreviations: BMI, body mass index; DXA, dual X-ray absorptiometry; 3DPS, three-dimensional photonic scan. Pearson correlation coefficients (p-values) are displayed. Values in bold represent high correlations coefficients according to Pearson’s correlation between the components of children’s body shape and size and anthropometry and body composition variables.
Awards for Latin America on Health Consequences of Population Change in collaboration with Brazilian Public Health Association (ABRASCO). The 2004 birth cohort study was conducted by the Postgraduate Program in Epidemiology at Federal University of Pelotas, in collaboration with Brazilian Public Health Association (ABRASCO). The 2004 birth cohort study is supported by the Wellcome Trust through the scheme called ‘Major Awards for Latin America on Health Consequences of Population Change’. The World Health Organization, Brazilian National research Council (CNPq) and Brazilian Ministry of Health have supported previous phase of the study. LPS is supported by ‘Science without Borders’ Brazilian scheme under protocol number 201801-2014-0.

**AUTHOR CONTRIBUTIONS**

LPS, KKO and AJDB designed and conducted the study. LPS performed the analyses and drafted the manuscript. KKO proposed the idea, supervised the analyses and helped in drafting the manuscript. JCKW helped in interpreting results and reviewing the manuscript. CGV, ISS and AM participated in the design and conduct of the original cohort study as well as in interpreting results and reviewing the manuscript. All authors read and approved the final manuscript.

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In conclusion, one component Corpulence explained almost 70% of the variance in children’s body shape and size, and traditional anthropometry and body composition measures were strongly correlated with Corpulence but not with the other three components identified here. Differences in these three novel components of body shape and size by sex, birth weight, obesity status and skin colour suggest that they might potentially contribute additionally to future disease risks; however, this hypothesis requires testing in future studies.

**KEY MESSAGES**

1. Traditional anthropometric and body composition measurements capture only one single component of children’s body shape and size. Through 3-D photonic scanning, it was possible to identify four distinct components.
2. Different associations between these components and sex, birth weight, SEP and skin colour might indicate their potential relevance to disease risks.
3. Sex differences in Central:peripheral ratio and other dimensions of body shape are seen even in prepubertal children, suggesting the influence of factors other than pubertal and adult sex steroid exposures.

**CONFLICT OF INTEREST**

The authors declare no conflict of interest.

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| Component 1 ('Corpulence') | Component 2 ('Central: peripheral ratio') | Component 3 ('Height and arm lengths') | Component 4 ('Shoulder diameter') |
|---------------------------|-------------------------------------------|----------------------------------------|----------------------------------|
| Gender                    |                                            |                                        |                                  |
| Male                      | 0.29                                       | <0.001                                 | <0.001                           | <0.001                           |
| Female                    | 0.02                                       | 0.07                                   | 0.09                             | 0.08                             |
| Birth weight              |                                            |                                        |                                  |
| <2500 g                   | −0.02                                      | −0.08                                  | −0.10                            | −0.09                            |
| ≥2500 g                   | 0.04                                       | 0.01                                   | 0.01                             | −0.02                            |
| BMI (z-score)             |                                            |                                        |                                  |
| −2 to ≤ +1                | −0.53                                      | −0.08                                  | 0.10                             | 0.03                             |
| >+1 to ≤ +2               | 0.39                                       | −0.07                                  | −0.13                            | 0.01                             |
| >+2                       | 1.66                                       | 0.37                                   | −0.29                            | −0.12                            |
| SEP                       |                                            |                                        |                                  |
| 1 (lowest)                | −0.29                                      | 0.05                                   | −0.09                            | 0.04                             |
| 2                         | −0.10                                      | 0.04                                   | 0.02                             | 0.05                             |
| 3                         | 0.02                                       | 0.02                                   | −0.06                            | 0.02                             |
| 4                         | 0.16                                       | −0.04                                  | 0.07                             | −0.04                            |
| 5 (highest)               | 0.33                                       | −0.10                                  | 0.11                             | −0.09                            |
| Skin colour               |                                            |                                        |                                  |
| White                     | 0.03                                       | 0.04                                   | −0.01                            | 0.01                             |
| Brown                     | −0.09                                      | −0.04                                  | −0.05                            | 0.02                             |
| Black                     | −0.08                                      | −0.19                                  | 0.13                             | −0.01                            |

Abbreviations: BMI, body mass index; SEP, socio-economic position. Mean components scores and P-values are displayed from analysis of variance.
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Supplementary Information accompanies this paper on International Journal of Obesity website (http://www.nature.com/ijo)