Reply—Body Fat% is Also a Potentially Poor Individual Measure for Health in Children

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Dear Editor,

We appreciate the comments made by Dr. Hudson and fully agree with the interpretation that there is need for “longitudinal data linking health outcomes to both body fat% and BMI in childhood” [1]. However, it was not the aim of the current study to provide such a longitudinal linking. Our aim was to compare the validity of BMI-SDS (not BMI) to assess nutritional status of single individuals. While nutritional status can be assessed in different ways – like using blood biochemistry, metabolic markers, simple anthropometric parameters and their ratios, questionnaires – measurement of body composition (e.g. by DXA) allows direct quantification of body fat stores. Total body fat reflects the long-term balance of energy intake and consumption and hence is directly linked to nutritional status. There should be little doubt about the fact that an individual who has 35% of its body mass stored as fat is in a different nutritional condition when compared to someone with only 7% of body fat. Moreover, in our study we specifically applied the problem of BMI-SDS validity to sick children. One measure to assess disease activity, effectiveness of a therapeutic regime or quality of care might be the ability to keep an individual patient in an appropriate energy balance or to normalize nutritional status. This is somewhat tricky and challenging in chronic pediatric patients who still have growth potential. Measurements that incorporate information about body composition are more appropriate than taking weight trajectories alone.

BMI and its derivative BMI-SDS are simple anthropometric ratios that relate to body composition and nutritional status due to the fact that accumulation of fat mass does not lead to longitudinal growth. Its association to body composition is rather calculative than based on physiology. BMI found widespread use mostly because it is easy to obtain in daily practice, but not necessarily because of its validity. BMI has certain drawbacks, namely that it does not take into account genetic constitution for body stature. Also a gain in muscle mass will lead to an identical increase in BMI which, however, is not associated with the same risk for adult metabolic or cardiovascular diseases compared to one caused by an increase in fat mass.

Despite its wide use also in pediatrics BMI has not been extensively validated, especially not in sick children. We have done this in our study by applying both BMI-SDS and DXA body fat measurements in the same subjects. Different from Dr. Hudson’s understanding we have not used the 10th and 90th percentiles in our study to classify nutritional status as “healthy” or “unhealthy” or whether it is appropriate for a child’s individual needs – and we agree with Dr. Hudson that this can be done only on the basis of a longitudinal study. We have used the 10th and 90th percentiles as a statistical cut-off to perform a methodological comparison about the degree of agreement between both approaches. We considerately choose the 10th and 90th percentile in line with previous publications about BMI-SDS and for comparison reasons applied these percentiles to the DXA measurement. Obviously, the range outside the 10th and 90th percentiles contains those subjects who have the lowest and highest 10% of the investigated (not necessarily the “normal”) population. Lying outside of these percentiles does not necessarily mean presence of pathology, but considerably increases its risk. Conversely, lying within the 10th and 90th percentile does not automatically exclude pathology, but the risk of occurrence is reduced. Let us assume that two methods measure the same quality. Then all subjects who are identified by one method as being below the 10th or above the 90th percentile should be identified by the other method. Cross-contamination or spill-over between groups should not occur. However, in our study we found a relatively poor discriminative power for BMI-SDS. This failure is not dependent on percentile values chosen for cut-offs. In our study we found an equally low precision when applying higher or lower values (data not presented). The explanation is found in Fig. 1 of our original publication; the considerable inter-individual variation leads to a poor correlation that cannot be overcome by any combination of cut-off values chosen. In this context it is of interest to note that in a previous study we have found similar results when classifying term and preterm newborns according to their fetal growth pattern [2].

We agree with Dr. Hudson’s thoughts about finding out what is a healthy nutritional status, but we believe that we will be only successful if we apply proper methods. It is not our aim to
replace BMI by DXA, but rather create an understanding for the
limitations and imprecisions of this parameter. With the data pre-
sented BMI-SDS seems to be a poor parameter for assessment
of individual subjects with the risk of potentially harmful mis-
classifications when used in clinical routine for decision making.
As stated by Dr. Hudson and also by the early work of A. Keys
et al. these findings do not necessarily limit the use of BMI
in longitudinal follow-up studies, population-based research or
field studies [1,3].

Finally, we would like to conclude our reply by reiterating that
our paper provides the first review and meta-analysis summa-
rizing all currently published DXA body fat data for healthy
children

Thank you for giving us the opportunity to address this important
issue.

1. Hudson LD: Body fat% is also a potentially poor individual measure
2. Schmelze HJ, Quang DN, Fusch G, Fusch C: Birth weight cate-
gorization according to gestational age does not reflect percentage
   body fat in term and preterm newborns. Eur J Pediatr 166:161–167,
   2007.
   43, 1972.

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Dear Editor,

Whilst it is important to validate such a widespread and conventional measure of nutritional status such as body mass index (BMI) against potentially more robust measures, it is important to also contextualize the validity of the ostensive “better” measure – in this case body fat. Although DEXA is the established “gold-standard” for measuring body fat composition, in their paper, Fusch et al fail to highlight the variability in healthy body fat% requirement between individual children thus limiting it as a reliable marker of health in children for comparison [1]. The authors also chose below the 10th centile of body fat% as a pragmatic definition of underweight. They do not highlight that by definition this will include 10% of a normal population (constituting many millions of normal children worldwide). The World Health Organization has suggested using -2 SDS and -3SDS as cut-offs for thinness and severe thinness, and similar thinness scores have been developed using international groups of children by Cole et al. [2], however the authors do not examine the relationship between%body fat and this more extreme group, and this would have been of interest.

The aim of categorizing an individual child as underweight, healthy weight or overweight is to better understand an individual child’s risk associated with that weight status and to consider intervention and minimize harm. However in contrast to adults [3], there is a paucity of longitudinal data linking health outcomes to both body fat% and BMI in childhood. Clinically much variety is seen between children at the same “low” BMI and “low” body fat% in terms of growth, pubertal development and bone mineral density because what constitutes as “low” will be different for each child [4]; and it is likely that there will be variety in associated cardio-metabolic risk for different children at different greater extremes of the BMI, and fat% centile chart [5]. Indeed, when Ansel Keys and colleagues first published on the use of BMI for overweight in the 1970s, it was suggested that its usage be contained to population-based research rather than for individuals [6]. We should be careful that BMI it is not replaced with yet another measure such as%body fat, based on cross-sectional analysis alone, without linkage to outcomes. Furthermore, whilst access to DEXA (which incidentally includes exposure to radiation) remains limited, particularly in lower income countries, more multi-domain clinical approaches, including the BMI, will continue to be necessary.

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Nutritional Status in Sick Children and Adolescents Is Not Accurately Reflected by BMI-SDS

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Nutritional Status in Sick Children and Adolescents Is Not Accurately Reflected by BMI-SDS

Gerhard Fusch, PhD, Preeya Raja, BSc, MSc, Nguyen Quang Dung, MD, PhD, Nadina Karaolis-Danckert, BA, MSc, Ronald Barr, MBChB, MD, Christoph Fusch, MD, PhD, FRCPC

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Key words: body composition, nutritional status, obesity, BMI-SDS

Objective: Nutritional status provides helpful information of disease severity and treatment effectiveness. Body mass index standard deviation scores (BMI-SDS) provide an approximation of body composition and thus are frequently used to classify nutritional status of sick children and adolescents. However, the accuracy of estimating body composition in this population using BMI-SDS has not been assessed. Thus, this study aims to evaluate the accuracy of nutritional status classification in sick infants and adolescents using BMI-SDS, upon comparison to classification using percentage body fat (%BF) reference charts.

Design: BMI-SDS was calculated from anthropometric measurements and %BF was measured using dual-energy x-ray absorptiometry (DXA) for 393 sick children and adolescents (5 months–18 years). Subjects were classified by nutritional status (underweight, normal weight, overweight, and obese), using 2 methods: (1) BMI-SDS, based on age- and gender-specific percentiles, and (2) %BF reference charts (standard). Linear regression and a correlation analysis were conducted to compare agreement between both methods of nutritional status classification. %BF reference value comparisons were also made between 3 independent sources based on German, Canadian, and American study populations.

Results: Correlation between nutritional status classification by BMI-SDS and %BF agreed moderately ($r^2 = 0.75, 0.76$ in boys and girls, respectively). The misclassification of nutritional status in sick children and adolescents using BMI-SDS was 27% when using German %BF references. Similar rates observed when using Canadian and American %BF references (24% and 23%, respectively).

Conclusions: Using BMI-SDS to determine nutritional status in a sick population is not considered an appropriate clinical tool for identifying individual underweight or overweight children or adolescents. However, BMI-SDS may be appropriate for longitudinal measurements or for screening purposes in large field studies. When accurate nutritional status classification of a sick patient is needed for clinical purposes, nutritional status will be assessed more accurately using methods that accurately measure %BF, such as DXA.

INTRODUCTION

Nutritional status impacts the body composition of an individual. Because acute and chronic diseases often affect the energy reserves of the body, such as fat and muscle tissue stores, clinicians use nutritional status classification to evaluate disease severity and treatment effectiveness. As a result, accurate nutritional classification is an important tool for clinicians in the treatment of sick individuals with body compositions that are outside the normal ranges of percentage fat and lean mass.

Ideally, nutritional status should be evaluated by comparing accurate body composition measurements of individuals to reference values of percentage fat and fat-free mass. Dual-energy x-ray absorptiometry (DXA) is considered a reference method for accurately measuring human body composition and is safe to use on children. The values obtained from DXA correlate well
Nutritional Status Classification by BMI-SDS

with direct chemical carcass analysis [1,2]. Further, fat mass values obtained by DXA were shown to be highly correlated with other methods for measuring body composition in children, adolescents, and adults [3,4].

Percentage body fat (%BF) reference values that are based on DXA measurements have been published for various populations: in healthy German subjects (4–14 years; \(n = 4629\)) in the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study [5], in healthy Australian subjects who had not been diagnosed with a medical disease (4–20 years; \(n = 230\)) [6], and in healthy Canadian subjects (3–18 years; \(n = 179\)) [7]. More recently, a nationally representative U.S. sample (National Health and Nutrition Examination Survey, NHANES IV) of 8269 children and adolescents (5–18 years) was used to derive %BF reference percentile data using skinfold thickness [8].

Despite the accuracy of using %BF to evaluate nutritional status, a more common practice in clinical routine is to estimate nutritional status using body mass index (BMI). BMI is a fast, inexpensive, and convenient tool and can be used to identify patients at risk [1]. Its use as a nutritional status predictor is based on the generally accepted observation that higher BMIs are associated with higher amounts of fat and, therefore, adiposity. In adult populations, patients can be classified by nutritional status using BMI category cutoffs. However, for pediatric populations, body mass index standard deviation score (BMI-SDS) is superior to fixed cutoff values, because it is based on gender and age-based percentiles that take into account body compositional changes that occur during healthy child and adolescent growth [9].

An age- and gender-specific national BMI reference percentile chart based on the BMIs of healthy German children and adolescents aged 0–18 years has been developed to classify children and adolescents who are at risk of poor nutritional status [9]. The German Working Group in Child Adiposity guidelines recommend that the 90th and 97th percentiles on this BMI chart should be used as cutoff values to define overweight and obese children and adolescents in the German population [9]. Because accurate nutritional status classification in this population is required to ensure effective evaluation of disease severity and the effectiveness of treatment, there is a need for an easy-to-use tool to assess patients from such a population.

Although BMI has been shown to correlate with percentage fat in the normal range of percentage fat and lean mass values [10–14], this assumption may not be true for body composition values that are seen in sick populations. Body composition in sick children and adolescents is often outside the normal ranges due to the etiology of the disease and/or because these individuals are likely at a high risk for undernutrition during a hospital stay. A recent study showed that BMI is not an effective indicator of obesity in adolescents and adults, because individuals with healthy levels of body fat were falsely classified as overweight or obese based on BMI categorization [15]. To use BMI-SDS as a clinical tool to identify children and adolescents at risk in a sick population, the accuracy of BMI-SDS in predicting the nutritional status within such a population must be assessed. Thus, it is the aim of the present study to evaluate the efficacy of BMI-SDS in classifying the nutritional status in a population of sick individuals.

MATERIAL AND METHODS

Study Population

To evaluate the accuracy of nutritional classification using BMI-SDS over a wide range of body compositions, we investigated a study population of 393 sick children and adolescents (4 months–18 years of age). The study population was selected upon inclusion of 3 groups of children and adolescents with diseases that affect body composition who had been treated at the Children’s University Hospital in Greifswald over a 5-year period. The 3 groups of patients with a high risk for having abnormal body compositions were (1) patients with acute diseases (\(n = 76\)), (2) patients with chronic diseases (\(n = 203\)), and (3) obese patients (\(n = 114\)). Patients with chronic diseases were distributed as follows: hematology and oncology (\(n = 71\)), Crohn’s and celiac disease (\(n = 45\)), asthma (\(n = 7\)), cystic fibrosis (\(n = 7\)), anorexia nervosa (\(n = 7\)), endocrinology (\(n = 31\)), autoimmunology (\(n = 11\)), and other diseases (\(n = 24\)).

This study was approved by the Ethics Committee of the Children’s Hospital, University of Greifswald and the State Authority for Radiation Exposure and Control.

Nutritional Status Classification by BMI-SDS

BMI was calculated based on body weight and body length measurements, which were taken by 2 trained technicians. For infants under 2 years of age, body weight was measured to the nearest 10 g using a standard beam balance (Seca, Hamburg, Germany) and body length was measured to the nearest 0.5 cm in the supine position using a measuring board (Schaefer, Karlsruhe, Germany). For children over 2 years of age, body weight was measured to the nearest 0.1 kg with a Seca calibrated mechanical scale; standing height was measured to the nearest 0.5 cm with a wall-mounted stadiometer (Längenmesstechnik GmbH, Limbach-Oberfrohna, Germany). BMI was converted to BMI-SDS using the Kromeyer et al. reference BMI percentile charts [9] and the LMS transformation method by Cole et al. [16,17]. These reference BMI-SDS charts are based on BMI-SDS values from 34,422 healthy German children and adolescents aged 0–18 years. All of the children and adolescents included in the present study were classified as underweight, normal weight, overweight, or obese using the 10th and 90th gender-specific and age-adjusted BMI percentiles as cutoff values, in accordance with
the guidelines published by the German Working Group in Child Adiposity [9].

Analysis of Percentage Body Fat by DXA

Percentage body fat data was obtained using a whole-body DXA scanner (QDR 1500; Hologic, Waltham, MA) using software version 5.67 (Hologic). In the acutely ill group, %BF measurements were made during the recovery period shortly before discharge from the hospital. Chronically ill and obese patients had multiple %BF measurements on different occasions, but for this study only the first measurement was used.

Classification of Nutritional Status Using Percentage Body Fat by DXA

 Nutritional status classification by %BF was based on the %BF reference values of 3 independent studies: (1) The DONALD study, which is run by the Research Institute of Child Nutrition, Dortmund, Germany [5]. The DONALD study was used because of its large study population of 4629 healthy German children and adolescents (4–14 years, 49.5% boys). (2) A Canadian study led by Sala et al., which was based on 179 healthy Canadian children and adolescents (3–18 years, 49.2% boys) [7]. (3) An American study based on the NHANES IV population-based sample of 8269 subjects (5–18 years) [8]. The %BF measured using DXA of an Australian cohort of healthy children and adolescents (4–20 years, 51.9% boys) [6] was compared to the %BF measurements in the previously described studies [5,7,8] that were used for %BF reference values in the present study.

The %BF measurements made in the present study using DXA were plotted on the 3 independent reference %BF charts to classify the nutritional status of the subjects. Due to the absence of an accepted DXA-based definition of malnutrition, the 10th and 90th age- and gender-specific percentiles of %BF from the above-mentioned studies were chosen to classify nutritional status, parallel to the cutoffs used for BMI-SDS classification.

Underweight was defined as the %BF value below the 10th percentile, normal weight as between the 10th and 90th percentiles, and overweight or obese was defined as above the 90th percentile.

For 3 of the studies (DONALD, Lazarus et al., NHANES IV), the %BF percentile data were used as published in each of the respective publications [5,6,8]. The study led by Sala et al. [7] originally only presented data on whole-body bone mineral content, lean body mass, and fat mass as figures and as equations to calculate mean values. In order to calculate %BF percentiles, the original raw data were kindly provided by Dr. Ronald Barr and %BF was recalculated. The %BF raw data were then used to calculate the 10th and 90th percentiles by applying 1.3 SD below and above the median, respectively. For simplicity, hereinafter ±1.3 SD from the median will be referred to as the 10th and 90th percentiles.

Comparison of Nutritional Status Classification by BMI-SDS and %BF

The nutritional status of subjects was classified as underweight, normal weight, or overweight or obese using both BMI-SDS and %BF by DXA and using 3 individual %BF reference percentiles, as previously described. Nutritional status misclassifications of subjects using BMI-SDS and %BF by DXA were compared.

Statistical Analyses

To assess the difference in underweight, normal-weight, and overweight or obese classification of subjects using BMI-SDS and %BF as determined by DXA, the number of subjects classified in each nutritional status category by both methods was compared. To investigate the correlation between BMI-SDS and %BF, linear regression analysis was performed to develop simple linear regression equations for boys, girls, and both sexes.

Data were analyzed using SPSS (Ver. 20.0, SPSS Inc., Chicago, IL). Results are presented as means and SDs. Student’s t tests were also used to compare variables between groups. The level of statistical significance was set at \( p < 0.05 \).

RESULTS

Tables 1 and 2 present age- and gender-specific %BF characteristics from all 5 studies, including the DONALD study (healthy German children and adolescents [5]), Sala’s study (healthy Canadian children and adolescents [7]), NHANES IV study (population-based study of American children and adolescents [8]), Lazarus et al.’s study (healthy Australian children and adolescents [6]), and the study population of the present study (sick German children and adolescents).

Figure 1 shows a significant relationship between %BF and BMI-SDS for both boys and girls (\( p < 0.0005; r^2 = 0.75, 0.76 \)). BMI-SDS values that approximate −1.3 and +1.3, which correspond to the 10th and 90th BMI percentiles, had a larger variation in %BF for both boys and girls. For example, %BF ranged from 28.9% and 46.9% in girls with a BMI-SDS of 1.3 ± 0.05.

Individual %BF values for boys (Fig. 2A) and girls (Fig. 2B) are presented, grouped according to classification of nutritional status using BMI-SDS. Reference 10th and 90th %BF percentiles from 3 independently published studies are also shown, indicating that regardless of the %BF reference source used, there are discrepancies in nutritional status classification when using BMI-SDS vs %BF.

Table 3A–C compares nutritional status classification based on either BMI-SDS or %BF and the misclassification rates...
Table 1. %BF Values in Boys from the Present Study, DONALD Study [5], Sala Study [7], Lazarus Study [6], and NHANES IV Study [8] According to Age and Gender\(^a\)

<table>
<thead>
<tr>
<th>Present Study</th>
<th>DONALD Study</th>
<th>Sala Study</th>
<th>Lazarus Study</th>
<th>NHANES IV Study(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n)</td>
<td>Age(^c) (years)</td>
<td>Median</td>
<td>Mean ± SD</td>
<td>Age(^d) (years)</td>
</tr>
<tr>
<td>21</td>
<td>4.3 (1.3–7.5)</td>
<td>23.2</td>
<td>28.5 ± 14.6</td>
<td>1191</td>
</tr>
<tr>
<td>31</td>
<td>9.3 (7.5–10.5)</td>
<td>38.7</td>
<td>34.4 ± 12.6</td>
<td>645</td>
</tr>
<tr>
<td>58</td>
<td>11.7 (10.5–13.0)</td>
<td>40.8</td>
<td>36.7 ± 13.3</td>
<td>454</td>
</tr>
<tr>
<td>81</td>
<td>15.0 (13.0–17.0)</td>
<td>21.2</td>
<td>26.0 ± 15.7</td>
<td>376</td>
</tr>
</tbody>
</table>

\(\text{DONALD} = \text{Dortmund Nutritional and Anthropometric Longitudinally Designed Study, NHANES IV} = \text{National Health and Nutrition Examination Surveys IV, } \text{%BF} = \text{percentage body fat.}\)
\(^a\text{BF values are presented as median and mean ± SD, as available.}\)
\(^b\text{Population distribution was not provided by age group (total population size } n = 8269).\)
\(^c\text{Mean age, range in parentheses.}\)
\(^d\text{Percentage of body fat measured by dual-energy x-ray absorptiometry.}\)
\(^e\text{Percentage of body fat measured by skinfold method.}\)
<table>
<thead>
<tr>
<th>Age(^c) (years)</th>
<th>Median</th>
<th>Mean ± SD</th>
<th>Median</th>
<th>Mean ± SD</th>
<th>Median</th>
<th>Mean ± SD</th>
<th>Median</th>
<th>Mean ± SD</th>
<th>Median</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>5.4 (0.4–8.0)</td>
<td>25.3</td>
<td>28.2 ± 11.5</td>
<td>904</td>
<td>5.9 (4.5–8.0)</td>
<td>16.5</td>
<td>17.4 ± 5.8</td>
<td>23</td>
<td>5.2 (3.0–&lt;7.5)</td>
<td>23.6</td>
</tr>
<tr>
<td>33</td>
<td>9.4 (8.0–10.5)</td>
<td>35.5</td>
<td>33.6 ± 12.6</td>
<td>904</td>
<td>8.9 (8.0–10.5)</td>
<td>19.8</td>
<td>20.9 ± 8.5</td>
<td>19</td>
<td>8.9 (7.5–&lt;10.5)</td>
<td>23.1</td>
</tr>
<tr>
<td>50</td>
<td>11.8 (10.5–13.0)</td>
<td>33.1</td>
<td>34.4 ± 12.0</td>
<td>904</td>
<td>11.2 (10.5–13.0)</td>
<td>22.3</td>
<td>23.5 ± 9.8</td>
<td>16</td>
<td>11.5 (10.5–&lt;13.0)</td>
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<td>93</td>
<td>15.2 (13.0–18.0)</td>
<td>31.7</td>
<td>33.2 ± 11.3</td>
<td>904</td>
<td>14.3 (13.0–17.0)</td>
<td>25.4</td>
<td>26.3 ± 8.8</td>
<td>33</td>
<td>15.8 (13.0–&lt;19.0)</td>
<td>26.7</td>
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</tbody>
</table>

DONALD = Dortmund Nutritional and Anthropometric Longitudinally Designed Study, NHANES IV = National Health and Nutrition Examination Surveys IV, %BF = percentage body fat.

*BF values are presented as median and mean ± SD, as available.

Population distribution was not provided by age group (total population size n = 8269).

Mean age, range in parentheses.

Percentage of body fat measured by dual-energy x-ray absorptiometry.

Percentage of body fat measured by skinfold method.
Table 3. Nutritional Status Classification Based on BMI and %BF Classification, and Misclassification Rates of Nutritional Status by BMI-SDS. BMI-SDS Classification of Subjects (age 4 months–18 years) as Underweight, Normal Weight, and Overweight or Obese Was Determined Using Cutoffs Calculated from the Kromeyer et al. Reference Data [9]. %BF cutoffs were obtained from data from the (A) DONALD study [5], (B) Canadian study by Sala et al. [7], and (C) American References Based on NHANES IV [8] data.

<table>
<thead>
<tr>
<th></th>
<th>Boys %BF</th>
<th></th>
<th>Girls %BF</th>
</tr>
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<tbody>
<tr>
<td>BMI</td>
<td>Underweight</td>
<td>Normal Weight</td>
<td>Overweight or Obese</td>
</tr>
<tr>
<td>A</td>
<td>Underweight</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Normal weight</td>
<td>27</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Overweight or obese</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>39</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Misclassification rate (%)</td>
<td>69.2</td>
<td>29.4</td>
</tr>
<tr>
<td>B</td>
<td>Underweight</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Normal weight</td>
<td>6</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Overweight or obese</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>9</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Misclassification rate (%)</td>
<td>66.7</td>
<td>25.4</td>
</tr>
<tr>
<td>C</td>
<td>Underweight</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Normal weight</td>
<td>6</td>
<td>58</td>
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<tr>
<td></td>
<td>Overweight or obese</td>
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<td>7</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>8</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>Misclassification rate (%)</td>
<td>75.0</td>
<td>28.4</td>
</tr>
</tbody>
</table>

BMI = body mass index, %BF = percentage body fat, SDS = standard deviation score, DONALD = Dortmund Nutritional and Anthropometric Longitudinally Designed Study, NHANES IV = National Health and Nutrition Examination Surveys IV. Values correctly identified by both methods are bolded.

Observed when using 3 independently published %BF reference values [5,7,8]. Trends of misclassification persist when using either of the 3 %BF references, in that BMI-SDS was not an accurate tool for classifying underweight boys. Misclassification rates for underweight boys ranged from 66.7% to 75% compared to %BF-based classification using the 3 mentioned studies. The majority of underweight boys were misclassified as normal weight. Surprisingly, when using %BF reference.

Fig. 1. Correlation between BMI-SDS and %BF for boys (A) and girls (B). Relationship between BMI-SDS and %BF for boys (A) and girls (B). Different symbols illustrate the groups classified by BMI percentiles: underweight (open squares), normal weight (closed triangles), and overweight and obese (open circles). The lines indicate the regression line and 95% confidence interval for individual measurements. %BF was measured using DXA.
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Fig. 2. Comparison of nutritional status classification by BMI-SDS and %BF in boys (A) and girls (B). Data for the %BF 10th and 90th percentiles were determined from data obtained from the DONALD study [5] (solid line), Sala et al. study [7] (long dashed line), and NHANES IV study [8] (short dashed line). %BF percentiles were age and gender adjusted. Different symbols illustrate the groups classified by BMI percentiles: underweight (closed circles), normal weight (open squares), and overweight and obese (closed triangles). BMI-SDS reference values were obtained from the Kromeyer et al. study [9].

values obtained from the DONALD study [5] and Canadian-based study [7]. 2 overweight or obese girls were classified as underweight. Overall, the trends for BMI-SDS-based nutritional status misclassification were consistently observed regardless of the %BF reference values used for comparison.

DISCUSSION

The present article compared nutritional status classification using BMI-SDS and %BF by DXA in a sick pediatric population. A moderate agreement was seen between %BF and
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BMI-SDS. It was also shown that BMI-SDS is an inappropriate clinical tool for identifying underweight or overweight children or adolescents on an individual basis but could be useful for classifying the nutritional status of sick children and adolescents for screening purposes. When accurate nutritional status classification is required, a method that reflects body composition more accurately, such as DXA, should be used instead of BMI-SDS.

Poor nutritional status at the time of hospital admission can contribute to a prolonged hospital stay [18] and increase overall health care costs [19]. Further, the nutritional status of a subject might determine the nutritional support that the patient receives [20]. Thus, misclassification may negatively affect the treatment plan and progress of the patient, as well as add to unnecessary health care costs. Therefore, it is of importance to identify which clinical tools are able to accurately classify the nutritional status of sick children and adolescents.

BMI has been shown to have limited diagnostic accuracy in diagnosing obesity due to its inability to distinguish between body fat and lean mass [21] and inability to reflect body fat distribution [22]. In many cases, the increase in %BF does not correspond with an increase in BMI [23]. This suggests that using BMI to monitor the body compositional changes of an individual may be misleading. Because the annual increases in BMI during childhood are generally attributed to the lean rather than to the fat component of BMI [22], this is an increasingly important limitation of BMI or BMI-SDS to classify nutritional status. Further, z-scores reflect the average changes in a population that are associated with average growth. Thus, the accuracy of BMI-SDS at high and low extremes of BMI for age, which are often seen in sick populations, may be compromised.

In the present study, in parallel to previous findings [24,25], we showed that there was a significant correlation between BMI-SDS and %BF. However, large interindividual variations in %BF of subjects of similar BMI-SDS were also observed. Subjects who had %BF below the 10th percentile of any of the 3 %BF reference percentiles were shown to have the highest rates of misclassification by BMI-SDS. As the %BF of the subjects increased, the accuracy of BMI-SDS improved, suggesting that BMI-SDS may be useful as a screening tool for identifying overweight and obese children and adolescents of a sick population but should not be used on an individual basis.

The DONALD study [5] was chosen to provide reference %BF values because of its high data density for the assessed age groups. However, in order to ensure that the reference %BF values were reasonable, we also compared BMI-SDS nutritional status classification to classification based on %BF cutoff values obtained from Canadian references [7] and American references [8]. Regardless of the %BF reference used, similar trends of misclassification across the categories of nutritional status were observed.

In order to investigate the differences in the %BF cutoff values obtained from the independent studies in more depth, the %BF values from the DONALD study [5] were compared to those of the Canadian-based [7], American-based [8], and Australian-based studies [6]. The mean %BF of the Canadian and American population was higher than the median, indicating that there were subjects within the overweight and obese category who had very high percentages of body fat and thus contributed to increasing the mean but not the median %BF values. This may partly explain the differences in classification between %BF reference values from the Canadian and American studies and DONALD values. The lower 10th %BF percentile values from the Canadian and American data resulted in a lower number of false classifications of normal weight subjects as underweight than the number of false classifications using the German-based reference. This discrepancy may be due to a higher percentage of adolescent boys with lower %BF values in the Canadian and American study populations in comparison to the German population of the DONALD study. In contrast, the Canadian and American adolescent girls used to develop the %BF percentiles tended to have a higher %BF than the German adolescent girls in the DONALD study. These variations are likely a result of lifestyle differences between the 3 countries.

Similar trends of nutritional status misclassification by BMI have been reported for adult populations. For instance, a recent study on 17- to 30-year-old Malaysian subjects compared nutritional status classification using BMI categories to %BF measurements [15]. BMI was shown to be less accurate in distinguishing between healthy and obese individuals than %BF. These trends were also reported in studies based on a population of young Japanese females [26] and in 18- to 30-year-old subjects with a BMI ≥ 18.5 kg/m² [15]. A significant portion of the females who had a high %BF were classified as normal weight [15,26]. Additionally, a recent study on 34 adolescents and young adults with Down syndrome reported only a moderate correlation (r = 0.496) between %BF and BMI-SDS classification of obesity [27]. Thus, our findings that (1) BMI-SDS and %BF-based nutritional status classification are moderately correlated and (2) subjects in the sick pediatric population with %BF in the extreme ranges are often misclassified using BMI-SDS are well supported by literature.

A limitation of the present study is that the %BF percentile cutoff points in 4- and 14-year-old children from the DONALD study were used to define nutritional status classifications for children less than 4 years old and more than 14 years old, respectively. This may cause a bias because, ideally, each age group should have its own cutoff points to classify the nutritional status. Additional limitations are that our results are sample specific, and underweight girls were underrepresented in the study population.

A strength of the present study was that accurate measurements of %BF by DXA were used as a reference, instead of less reliable methods such as skinfold thickness. Additionally, BMI-SDS was used for nutritional status classification, instead of BMI categories. Additionally, the present study did not
focus on a specific subset of the population (e.g., obese or those diagnosed with Down syndrome). The wide range of body compositions that was used to assess the efficacy of nutritional status classification using BMI-SDS in the present study was thus representative of a population of sick children and adolescents. Because BMI-SDS is often used in clinical routine to assess the nutritional status of sick populations of children and adolescents, some of whom may not be diagnosed with specific disorders or diseases, this approach was a strength of the present study. Further, to our knowledge, this is the first study to assess the accuracy of nutritional status classification by BMI-SDS in a sick children and adolescent study population.

However, the accuracy of BMI-SDS for monitoring body composition changes over time in such a population was not assessed in the present study. Rudolf et al. recently assessed whether BMI-SDS may be used to monitor the progress of weight management treatment plans and found that caution is needed when interpreting changes in BMI in obese children over time [28]. Because the 10th and 90th percentiles that are used as cutoffs for nutritional status classification are dependent on the standard deviation at the age and gender of interest, uneven distributions of ages may impact the accuracy of longitudinal assessments of classification. Thus, further research is needed to assess the accuracy of BMI-SDS as a longitudinal clinical tool to assess body composition changes in a sick children and adolescent population.

CONCLUSION

In summary, BMI-SDS agrees moderately with %BF classification of nutritional status. BMI-SDS may be used as a screening tool for detecting obesity; however, for clinical purposes, BMI-SDS is not a precise method for predicting %BF. Other methods that provide accurate measurements of body composition such as DXA may be more appropriate for individually classifying the nutritional status of sick children and adolescents.

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