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Using the Mercy Method for Weight Estimation in Indian Children

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Abstract

This study was designed to compare the performance of a new weight estimation strategy (Mercy Method) with 12 existing weight estimation methods (APLS, Best Guess, Broselow, Leffler, Luscombe-Owens, Nelson, Shann, Theron, Traub-Johnson, Traub-Kichen) in children from India. Otherwise healthy children, 2 months to 16 years, were enrolled and weight, height, humeral length (HL), and mid-upper arm circumference (MUAC) were obtained by trained raters. Weight estimation was performed as described for each method. Predicted weights were regressed against actual weights and the slope, intercept, and Pearson correlation coefficient estimated. Agreement between estimated weight and actual weight was determined using Bland–Altman plots with log-transformation. Predictive performance of each method was assessed using mean error (ME), mean percentage error (MPE), and root mean square error (RMSE). Three hundred seventy-five children (7.5 ± 4.3 years, 22.1 ± 12.3 kg, 116.2 ± 26.3 cm) participated in this study. The Mercy Method (MM) offered the best correlation between actual and estimated weight when compared with the other methods (r^2 = .967 vs .517-.844). The MM also demonstrated the lowest ME, MPE, and RMSE. Finally, the MM estimated weight within 20% of actual for nearly all children (96%) as opposed to the other methods for which these values ranged from 14% to 63%. The MM performed extremely well in Indian children with performance characteristics comparable to those observed for US children in whom the method was developed. It appears that the MM can be used in Indian children without modification, extending the utility of this weight estimation strategy beyond Western populations.

Keywords

pediatric, weight, Mercy TAPE, Broselow, APLS, Luscombe

Background

Children in remote or resource-constrained settings often fail to enjoy medical advances that are considered routine in other parts of the world. Even relatively basic technologies may be unavailable for the care of these children (eg, weight scales). Accurate patient weights are fundamental to nearly every medical and pharmacologic intervention applied in children, yet there exist many settings where an accurate and reliable scale is simply unavailable.[1-3] Pediatric health care providers circumvent the lack of a scale by using any of a number of strategies for weight estimation. These strategies are typically based on age, although a few rely on length or a combination of age and length to derive an estimated weight. However, all of the existing strategies are met with some limitations; their accuracy drops as children increase in age, they are severely biased in children at the extremes of weight (eg, underweight, obese), and they often perform poorly in children that differ racially or ethnically from the population of children in whom the method was developed.

Notably, only a handful of pediatric weight estimation strategies have been evaluated in Indian children. Varghese et al observed that existing age-based and length-based strategies (eg, APLS, Argall, Nelson, Broselow) tended to overestimate weight in their cohort of children and performed better when the study population was restricted to young children under 15 kg.[4]

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Ramarajan et al corroborated these findings and demonstrated that the extent to which the Broselow tape overestimates weight increases with increasing weight and age prompting the authors to recommend a correction factor of 10% when using this device.[5] Importantly, both studies restricted analyses to children whose height fell within the prespecified range of the tape and neither proposed a solution for weight estimation in children that exceed 143 cm. Thus, the methods reviewed above cannot be broadly applied to the pediatric population as a whole, and clinicians charged with the care of children that exceed the age or length bounds of these methods are left with little guidance on the patients' weight. For this reason the provider's guess remains a common, albeit flawed, method for weight estimation in pediatric emergency settings.[6]

Recently, investigators developed a new 2-variable weight estimation strategy (ie, the Mercy Method) that markedly outperforms the weight estimation strategies discussed above. It demonstrates less bias and greater precision than 12 other methods against which it was evaluated and does not contain the same age- and length-based restrictions found in many of the other methods.[7] However, the Mercy Method (MM), like many weight estimation strategies, was developed using data from Western children. This study was designed to examine the performance of the MM in children from India and compare the performance to other weight estimation methods.

Methods

Subjects and Study Design

Otherwise healthy children, with constitutionally normal growth and development, were eligible for participation in this prospective, single-center study. Children were required to be between the ages of 2 months and 16 years and were excluded from participation for any of the following: (*a*) known or apparent limb deformities, (*b*) unable to be positioned for height/length measurements, and (*c*) an underlying pathological condition or pharmacologic management that would produce abnormal body composition for age. Children were stratified in 1-year age brackets with the goal of enrolling 20 children per bracket. All children were enrolled with informed permission, and assent where applicable, under a protocol that was reviewed and approved by the Ethics Committee of SCB Medical College and the Ethics Committee of the World Health Organization, Geneva.

Data Collection

Anthropometric measurements including weight, height, humeral length (HL), and mid-upper arm circumference (MUAC) were performed by 1 of 2 trained raters. Weight was obtained with children weighed in their underwear or other light-weight clothing using a portable scale that was calibrated daily. Recumbent length in infants was measured using an infantometer. In children that were able to stand unassisted, height was measured using a portable stadiometer with the heels, buttocks, and head in contact with the height rule and the head was aligned in the Frankfort horizontal plane. HL was measured from the upper edge of the posterior border of the acromion process, down the posterior surface of the arm, to the tip of the olecranon process with the arm at the child's side and the elbow bent at 90°. MUAC was measured at the midpoint of the humerus with the arm hanging down at the child's side. Both HL and MUAC were measured to the nearest millimeter using a standard vinyl tape measure.

Rater Qualification

All investigators obtaining measurements were required to undergo training prior to making any measurements in study participants. Raters performed each of the study-related anthropometric measurements in triplicate on 3 adult volunteers to assess inter- and intrarater reliability. Intrarater variance was required to be less than 5% for each anthropometric measure across all volunteers in order to qualify as a study rater.

Data Analysis

Electronic data entry was performed by a single investigator and independently verified by a second study team member against hard copies of the original data collection forms. The MM was applied to the quality assured data as previously described.[7] The MUAC and HL measures for each child were rounded up or down to the nearest 1.0 cm and the corresponding fractional weight for each measurement obtained from the published table. The fractional weights were summed to generate an estimated weight for that participant. Data on age, height, and MUAC were used to estimate weight using 12 other weight estimation methods: Advanced Pediatric Life Support (APLS), Best Guess, Broselow, Leffler, Luscombe-Owens, Nelson, Shann, Theron, Traub-Johnson, and Traub-Kichen.[8-19]

The predicted weights as determined by each method were regressed against actual weights and the slope, the 95% confidence interval (CI) for the slope, the intercept, the 95% CI for the intercept, and the Pearson correlation coefficient were estimated. The percent agreement between estimated weight and actual weight was determined visually using Bland–Altman plots with log-transformation. Mean error (ME) was calculated by taking the difference of the predicted and actual weights. Mean percentage error (MPE) was calculated by dividing the actual weight into the ME and multiplying by 100. Root mean square error (RMSE) was calculated by taking the square root of the average squared error. The intraclass correlation coefficient (ICC) was determined using a 2-way random effects model and an absolute agreement definition to evaluate reliability between raters. All mathematical and statistical analyses were performed with Microsoft Excel 2003 and SPSS v12.

Results

A total of 375 children (7.5 ± 4.3 years) were enrolled in this study with participants evenly split between males and females (50.1% vs 49.9%). The anthropometric constitution of the study population is detailed in Table 1. The population distribution for height was positively skewed and the distribution for weight negatively skewed, resulting in an average body mass index (BMI) that favored children who were underweight or normal as classified by the Centers for Disease Control (Figure 1). The MM proved to be the least restrictive of the methods evaluated, predicting weight in all but one child whose MUAC fell below the lower bound for the method. By contrast, prediction rates for other published weight estimation methods ranged from 66% to 93% (Table 2).

Predictive performance of the MM and the comparator methods are depicted visually in Figures 2 and 3, respectively. The regression parameters generated by the comparison of actual and predicted weights are detailed in Table 2. The MM offered the best correlation (r^2 = .967 vs .517-.844) and came closest to achieving the desired characteristics of fit (ie, slope approaching one, intercept approaching zero) when compared with the other methods. When examined for bias and precision, the MM outperformed the other weight estimation strategies, demonstrating a lower ME, MPE, and RMSE (Table 2). Finally, the MM estimated weight within 10% of actual for the majority of children (70%) and predicted weight within 20% of actual for nearly all children (96%) as opposed to the other methods for which these values ranged from 6% to 29% and from 14% to 63%, respectively (Table 2).

Given that most of the published weight estimation methods tend to perform poorly at the extremes of weight, the data were segregated by BMI percentile and performance of the Mercy method examined independently for infants and children who were underweight, normal, overweight, and obese. As illustrated in Figure 4, the MM appeared to perform with comparable predictive power irrespective of BMI classification; however, weight for the majority of infants was overestimated by this method. Although the ICC was high (0.98) there were modest differences in performance of the MM observed between study raters (eg, MPE: 1.1% vs 2.2%; agreement within 20%: 98% vs 91%).

Table 1. Demographic and Anthropometric Characteristics of the Children Enrolled in the Study[a].

Enrollment, n	375
Weight (kg)	22.1 ± 12.3
Height (cm)	116.2 ± 26.3
Humerus (cm)	23.7 ± 5.9
MUAC (cm)	16.9 ± 3.7
BMI (kg/m^2)	15.1 ± 2.9
BMI percentile	22.9 ± 30.7
Infant (%)	12.0
Underweight (%)	39.5
Normal (%)	40.0
Overweight (%)	2.9
Obese (%)	5.6

Abbreviations: MUAC, mid-upper arm circumference; BMI, body mass index.

[a] All data are provided as mean ± standard deviation unless otherwise indicated.

Discussion

Weight estimation strategies address a critical medical need in settings where there is neither the time nor the opportunity to directly weigh patients. To date, no single previous method has provided accurate estimates of weight across a broad range of ages, weights, and lengths. The MM is the first method to address some of the limitations inherent in the existing weight estimation strategies. By using surrogates for length and girth, the MM expands the age range of children to which a single weight estimation method can be applied and removes some of the restrictions observed in other commonly used methods.

The MM performed extremely well in this Indian cohort, demonstrating goodness-of-fit criteria comparable to those observed for the method when applied to children in the United States.[7] The average absolute error in this study was −0.12 kg, which represented a percentage error of −1.5%, suggesting a slight underestimation of weight by the MM. There was little loss in predictive performance of the MM across BMI in children over 2 years of age; however, the method appears to overestimate the weight of infants in this population. Importantly, the MM predicted weight within 10% of actual weight for 70% of the enrolled children and

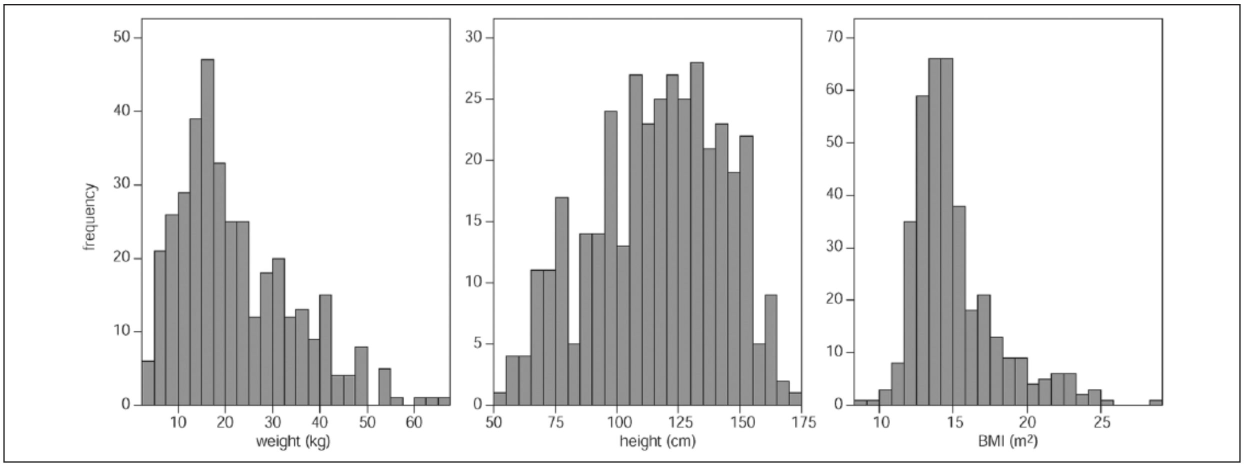

Figure 1. Distribution of pediatric study participants by weight, height, and body mass index (BMI).

Table 2. Regression Parameters and Predictive Performance of the Mercy Method and 12 Other Weight Estimation Methods[a].

	n	Slope	Intercept	r^2	ME (kg)	MPE (%)	RMSE (kg)	% Agreement within 10%	% Agreement within 20%	% Agreement within 30%
Mercy	374	0.93 [0.91-0.95]	1.5 [1.0-1.9]	0.967	−0.12 (2.29)	1.5 (9.9)	1.64	70	96	99.2
APLS	249	0.50 [0.44-0.55]	10.3 [9.1-11.4]	0.531	1.13 (5.63)	13.9 (24.8)	4.12	17	30	45
ARC	350	0.78 [0.72-0.84]	8.0 [6.4-9.5]	0.646	2.82 (7.36)	18.1 (27.3)	5.82	23	41	59
Argall	249	0.74 [0.65-0.83]	9.4 [7.7-11.1]	0.531	4.74 (6.10)	31.5 (31.0)	6.29	10	23	31
Best Guess	347	0.97 [0.90-1.04]	8.0 [6.3-9.7]	0.669	7.30 (7.78)	41.3 (33.2)	8.55	10	24	35
Broselow	321	0.64 [0.57-0.70]	7.4 [6.0-8.9]	0.517	1.22 (3.83)	10.8 (16.3)	2.95	28	60	79
Leffler	247	0.59 [0.53-0.66]	9.4 [8.3-10.6]	0.576	3.00 (5.06)	27.8 (28.5)	4.70	11	23	34
Luscombe-Owens	249	0.74 [0.65-0.83]	10.4 [8.7-12.1]	0.531	5.74 (6.10)	38.0 (31.5)	7.02	6	14	27
Nelson	329	0.89 [0.82-0.96]	6.9 [5.2-8.5]	0.643	4.63 (7.36)	28.2 (31.6)	6.52	18	31	45
Shann	350	0.64 [0.59-0.69]	10.4 [9.1-11.7]	0.652	2.13 (7.04)	18.4 (27.1)	5.56	22	42	55
Theron	249	1.14 [1.0-1.27]	6.5 [3.8-9.2]	0.518	8.97 (9.05)	51.4 (42.6)	9.70	7	14	23
Traub-Johnson	350	0.87 [0.83-0.91]	4.8 [3.8-5.8]	0.844	1.73 (4.71)	11.1 (16.0)	3.74	29	62	85
Traub-Kichen	344	0.79 [0.75-0.82]	6.2 [5.2-7.1]	0.840	1.17 (4.79)	10.0 (16.4)	3.68	28	63	84

Abbreviations: ME, mean error; MPE, mean percentage error; RMSE, root mean square error.

[a] Data are presented as mean ± standard deviation or [95% confidence interval] unless otherwise indicated.

within 20% of actual for more than 95% of the children that were studied.

Conclusions

This study was one of the first prospective evaluations of the MM in non-US children. The data presented herein suggest that the MM does not need to be modified for application to children in India, thus extending the utility of this weight estimation strategy beyond Western populations. The results of additional studies in geographically distinct children will further delineate the role of the MM in the care of children for whom there is no opportunity to obtain an accurate weight. However, integration of the MM into pediatric practice will require training materials that clearly detail how the measurements should be performed so as to generate reliable estimates in the field.

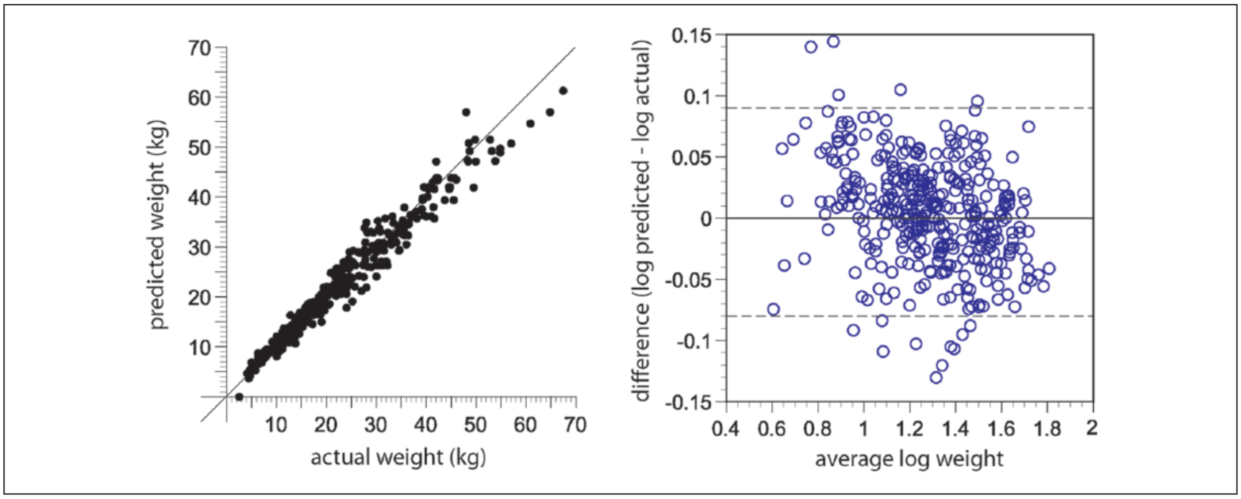

Figure 2. (Left) Actual versus MM-predicted weight. The solid line represents the line of unity. The value on the *x*-axis represents the singular child for whom a weight could not be estimated by the MM. (Right) modified Bland–Altman plot depicting the log-transformed difference between predicted weight and actual weight versus average log weight. Dashed lines depict the 95% limits of agreements.

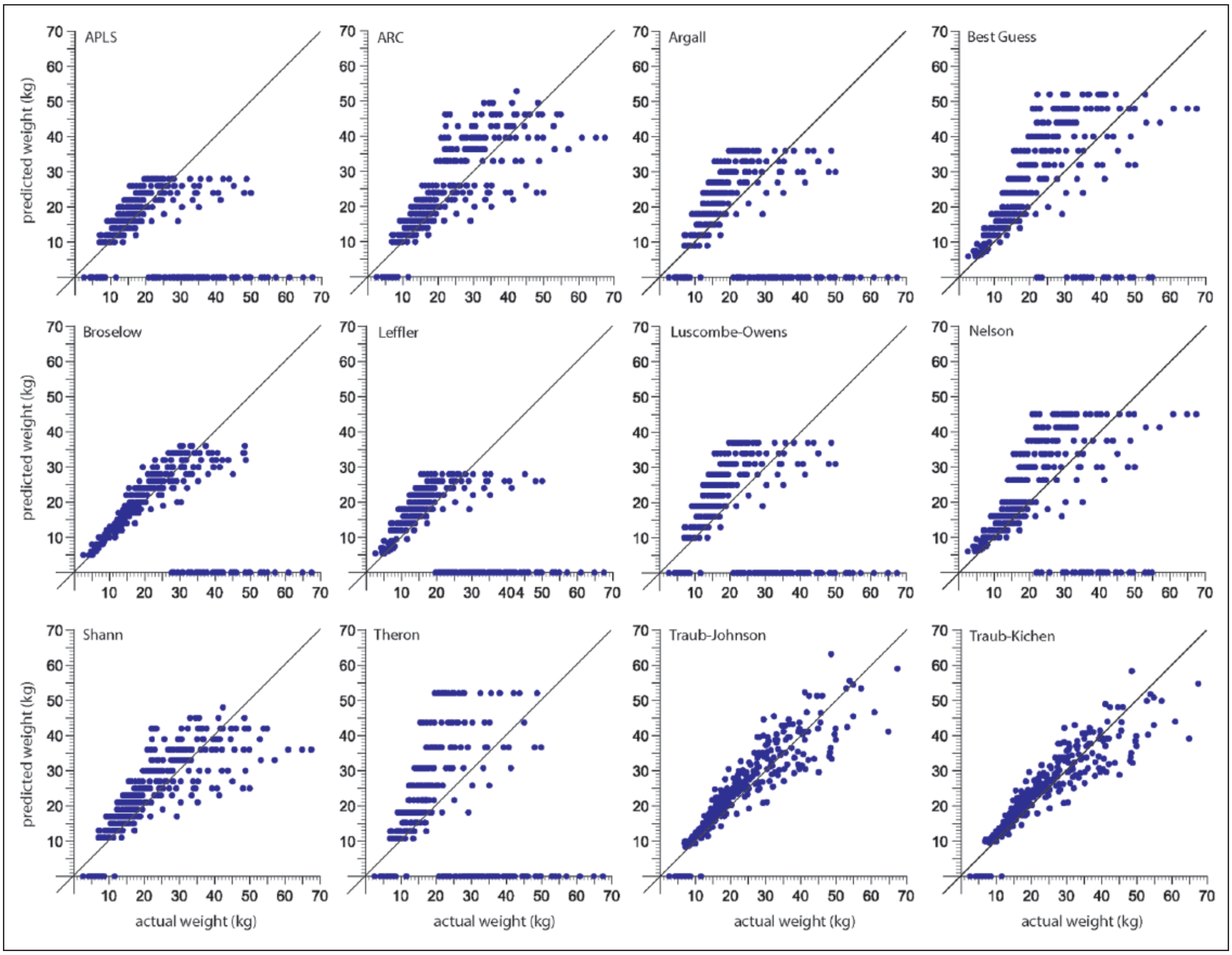

Figure 3. Actual versus predicted weight for 12 other weight estimation strategies. The solid lines represent the lines of unity. Values on the *x*-axis represent children for whom weight could not be estimated by the various methods.

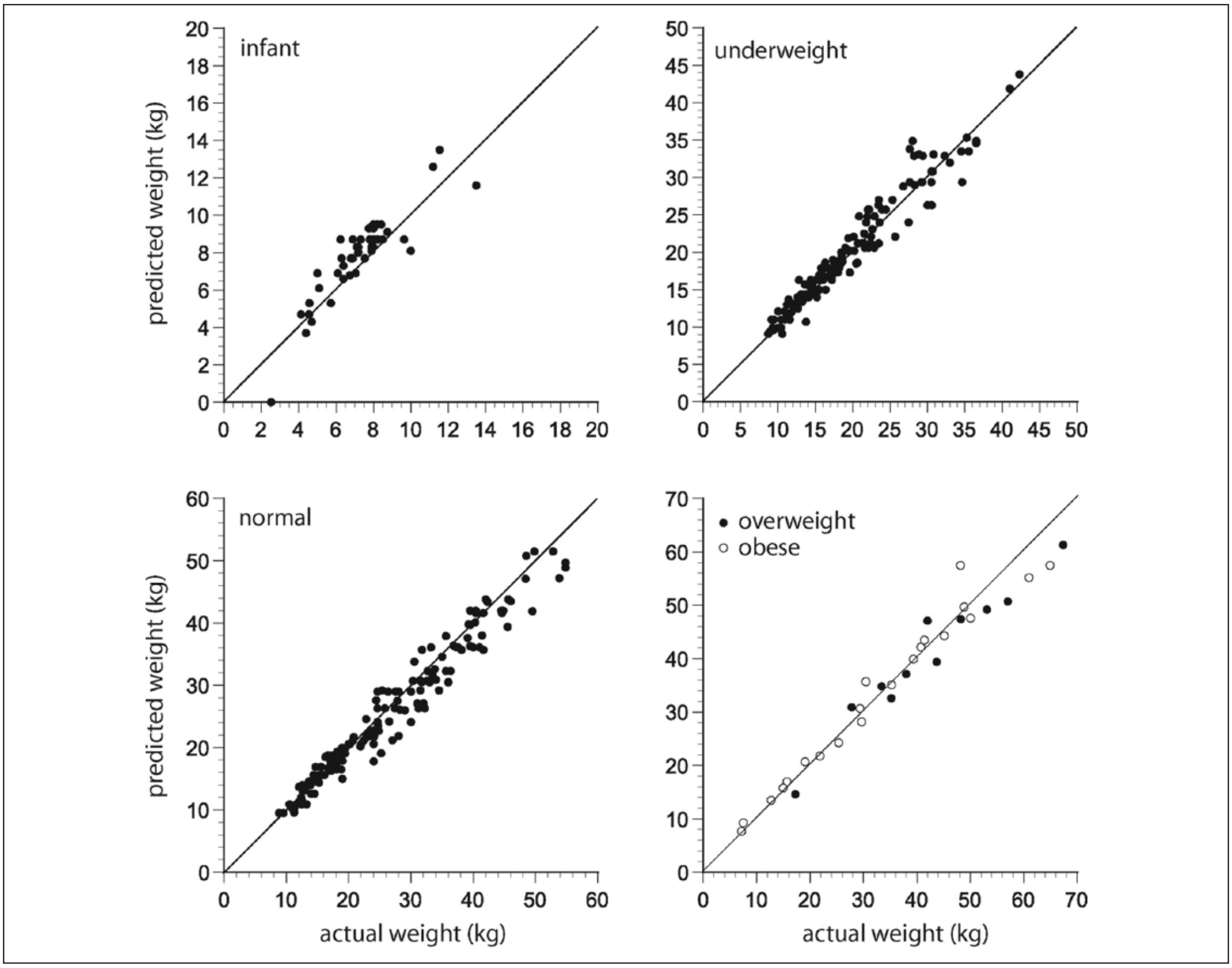

Figure 4. Actual versus MM-predicted weight displayed by BMI percentile classification. The solid line represents the line of unity. The value on the *x*-axis represents the singular infant for whom a weight could not be estimated by the MM.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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