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Classification of weight status in infancy and obesity prediction according to weight-for-length and body mass index

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Abstract

Objective

Weight-for-length (WFL) is recommended for assessing weight status in infants under 2 years, although body mass index (BMI) may be an alternative. We compared weight classifications using WFL and BMI and assess their ability to predict later obesity.

Study Design:

This longitudinal study analysed public health data from Calgary, Canada (2000–2018). Growth measures from full-term infants under 2 years and children aged approximately 4.5 years were assessed using World Health Organization growth standards. Classification agreement and predictive performance were examined.

Results

Among 191,956 children, 51% were male. WFL and BMI showed moderate-to-strong agreement. Areas under the receiver operating characteristic curve for predicting later overweight and obesity ranged from 67.7%–79.2% for BMI and 65.7%–80.0% for WFL. Infant overweight/obesity classifications (> 2 z-scores) poorly predicted later status.

Conclusion

BMI and WFL showed comparable classification and predictive performance. Further research should evaluate BMI-based infant growth monitoring.

INTRODUCTION

Weight-for-length (WFL) has been used internationally over the past 40 years as the standard metric to monitor growth of infants 0–2 years of age. Current guidelines by the Center for Disease Control, the American Academy of Pediatrics, and the Canadian Collaborative Group recommend using WFL for the assessment of weight status in infancy, and to transition to body mass index (BMI)-for-age for those aged 2–19 years [1–4]. Nonetheless, there is some evidence that the WFL growth charts, are not the best tool for this purpose [5–7]. Infancy is characterized by a period of very rapid growth and considerable changes in body proportions and composition. During the first six months of life, infants double their birthweight, and their BMI increases from a median of 13 to 17 kg/m^2. From 6 to 12 months, infants double their weight again, but their BMI decreases from the peak of 17 at 6 months to 15 kg/m^2 by 24 months [8]. However, WFL growth chart percentiles do not consider the age of infants.

More recent findings suggested that BMI may be a better indicator for overweight and obesity status in infants below two years of age and possible advantages of using BMI in this age group have been identified [5–7]. BMI percentiles incorporate measures of weight and length plotted according to age, which may avoid misclassifications of growth. In addition, BMI-for-age may be particularly sensitive to changes in body composition in early years, which might improve assessment of underweight and obesity risk in clinical settings [5–7]. Studies which examined agreement between BMI and WFL in characterizing risk of overweight and obesity at one and six months found that BMI had a higher positive predictive value (PPV) across infancy and childhood [5–7]. Having a higher BMI at 2 months was highly predictive of obesity risk at 2 years of life, unlike having a higher WFL (47% vs. 29%) [6]. Already at 1 month of age, compared to WFL, BMI was more predictive of body composition outcomes in healthy term infants ($P < 0.05$) [7]. One study found that BMI trajectories for normal weight children and those who developed severe obesity at 6 years began to differ by 4–6 months of age, and a BMI of ≥ 85th percentile in infancy at 6, 12 and 17 months doubled the risk of severe obesity by age 6 years [5].

The World Health Organization (WHO) first released BMI growth charts for children aged 0–5 years in 2006 [3]. Since then, BMI charts for infants have been poorly adopted in clinical practice [9], possibly owing to the lack of research on the utility of BMI as metric in this age group. Identification of appropriate anthropometric measurements that better correlate with body composition and are more predictive of unhealthy weight status are key to improve early detection of obesity risk, allowing for timely interventions. This study aims to assess differences and similarities in weight classifications according to BMI and WFL in infants < 2 years of age and to examine the predictive performance of WFL and BMI for predicting children's weight status at pre-school age.

Materials/Subjects and METHODS

Data

Using the PHANTIM database that includes public health visits by children under 5 years of age in Alberta, we selected all visits in Calgary Zone between 2000-2018 [10], and obtained data on growth from birth through pre-school age (~4.5 years). Birth data including the child's sex, birth weight and gestational age, as well as maternal age, were obtained from the Notice of Birth (NOB), which was completed at the hospital and submitted to Calgary Zone Public Health Clinical Support Systems. The information was entered into PHANTIM by a team of business support specialists. Gestational age was confirmed through the obstetrical care record from the pregnancy and included in the PHANTIM database. Growth data for infants including weight (kg) and length/height (cm) were measured during well child immunization clinic visits at 2, 4, 6, 12, and 18 months. At approximately 4.5 years, weights and heights were measured during the preschool clinic visit. These data were recorded into PHANTIM by Calgary Zone Public Health nurses. Data on feeding type (only breastmilk, only formula, mixed feeding) were obtained during clinic or home visits or from the NOB forms. The data recorded into PHANTIM by a

Calgary Zone Public Health nurse. These data were commonly collected at <1 month, and then at 2, 4, 6, 12, and 18-month visits.

The primary analysis included children who had their growth measures and sex recorded during at least one point in infancy and at ~4.5 years. Preterm children (birth <37 weeks of gestation) and post-term (>42 weeks of gestation), those missing gestational age data, and nothing-by-mouth feeding group were excluded. In terms of growth measures, implausible values (>4 or <-4 z-scores) were removed by recoding them to missing.

Measures and definitions

Age- and sex-specific standardized body size scores (z-scores) of weight and length/height were calculated for each infant according to the WHO 2006 growth standards, using the Zscore06 package in Stata [11]. Children's weight status was defined according to the WHO 2006 growth standards for children below 5 years [3,12]. The at-risk of overweight category was defined as WFL or BMI z-scores >1, overweight >2 and obese >3 z-scores. Wasting was defined as a WFL or BMI z-score <-2 and severely wasted as a z-score <-3. At each time point during infancy, children's weights were classified according to WFL and BMI. At approximately 4.5 years of age, children's weight status was defined based on BMI following the same cut-offs [12]. Accordingly, these categorizations provided binary variables indicating the child's weight classifications at each time point.

For the prediction of overweight and obesity at ~4.5 years, overweight/obese status was defined based on BMI z-scores and dichotomized according to WHO cut-off points (>2 z-scores were coded as 1 and all other weight groups were coded as 0).

Analysis

Ethical approval was obtained through the Conjoint Health Research Ethics Board at the University of Calgary (ID: REB20-0702). Statistical differences in the sample characteristics among infants were compared using the Student's test for continuous variables and Fisher's exact test for categorical variables. The statistical analysis comprised two steps. The first analysis focused on comparing weight classifications during infancy (2 through 18 months) based on WFL and BMI using the McNemar test of proportions. The statistical agreement between WFL and BMI classifications was examined using kappa statistic [13].

The second analysis compared the predictive performance of WFL and BMI in predicting overweight/obesity at ~4.5 years. Area under receiver operator characteristic (AUROC) curves were used to assess the predictive performance based on the overall ROC area, sensitivity, specificity, and predictive values of BMI and WFL z-scores for predicting overweight/obesity (BMI z-score > 2) at ~4.5 years. Additionally, being classified as overweight/obese in infancy (at each age point from 2 to 18

months, separately) was examined as a predictor for overweight/obesity (BMI z-score >2) at ~4.5 years. The risk threshold was set to 10% in the prediction model, consistent with previous studies [14]. The statistical analysis was conducted using Stata15 [15].

RESULTS

The participants characteristics are summarized in Table 1 (eTable 1). The PHANTIM database included demographic, growth and feeding data on 256,883 children between 2000–2018. The inclusion flowchart is presented in eFigure 1. Of the included sample (N = 190,261 distinct children), 51% were male, and the mean and standard deviation (sd) of maternal age was 30.8 ± 5 years. At 6 months of age, 3% of children were exclusively breastfed and 64.8% of children were in the mixed breast-feeding group. At ~ 4.5 years, weights and heights were available for 82,795 children. Mean BMI z-score at the 4.5 years visit was 0.3 ± 1.0.

Table 1
Subject characteristics (PHANTIM database 2000–2018, N = 190,261)

		Females		**Males**		**Total**	
		N	***%***	***N***	***%***	***N***	***%***
Gestational age group	Early Term (37^{+0} – 38^{+6} weeks)	27,948	30.0	30,349	31.2	58,297	30.6
	Full term (39^{+0}- 40^{+6} weeks)	53,089	57.1	54,319	55.9	107,408	56.5
	Late term (41^{+0}- 41^{+6} weeks)	11,997	12.9	12,559	12.9	24,556	12.9
Feeding status at 6 months	Breast fed	2,933	3.2	2,699	2.8	5,632	3.0
	Formula fed	2,289	2.5	2,338	2.4	4,627	2.4
	Mixed feeding	60,344	64.9	62,971	64.8	123,315	64.8
	No observation recorded at 6 months	27,468	29.5	29,219	30.0	56,687	29.8
		mean	*sd*	*mean*	*sd*	*mean*	*sd*
Birth weight (g)		3282	458	3406	481	3345	474
BMI z-score	2 months	0.0	0.9	0.1	1.0	0.1	1.0
	4 months	-0.1	1.0	0.0	1.1	0.0	1.0
	6 months	0.0	1.0	0.1	1.1	0.1	1.0
	12 months	0.4	1.0	0.4	1.0	0.4	1.0
	18 months	0.4	0.9	0.5	1.0	0.5	1.0
	4.5 years	0.2	1.0	0.3	1.0	0.3	1.0
WFL z-score	2 months	0.1	1.0	0.3	1.1	0.2	1.1
	4 months	0.0	1.0	0.0	1.1	0.0	1.0
	6 months	0.2	1.0	0.2	1.1	0.2	1.0
	12 months	0.4	1.0	0.4	1.0	0.4	1.0
	18 months	0.4	0.9	0.5	1.0	0.4	1.0
Maternal age, years		30.8	5.0	30.8	5.0	30.8	5.0

Abbreviations: sd, standard deviation, BMI, body mass index, WFL, weight-for-length

Weight status classifications in Infancy: WFL vs. BMI

The proportion of infants in each weight classifications (severely wasted, wasted, at risk of overweight, overweight, and obese) according to WFL versus BMI differed significantly across almost all age groups (Table 2). Regarding low weight groups, up until 4 months of age, 0.2% of children were classified as severely wasted by WFL and BMI. However, as children aged (6–18 months), more were classified as severely wasted according to BMI. Regarding higher weight groups, more children were flagged as being at risk of becoming overweight based on WFL in their first six months of age (an additional 3.1% at 2 months, 1.4% at 4 months and 2% at 6 months) compared to BMI. However, this difference was not observed at 12 months ($P = 0.254$), and it reversed beyond 12 months of age as an additional 0.7% at 18 months were classified to be at risk of overweight based on BMI. At 18 months, relatively higher portions of children were classified as “at-risk of overweight” according to BMI. Small differences were observed in classifying overweight, more children were classified as “overweight” based on WFL, as compared to BMI, during their first year of life (3.9% versus 2.6% at 2 months, and 3.4% versus 3% at 6 months), whereas BMI classified more children as “overweight” at 18 months (5% versus 4.8%). Overall, for the obese category, small differences were found with more children being classified as “obese” according to WFL, 0.4% versus. 0.3% at 2 months, 0.3% for both metrics at 4 months, 0.4% at 6 months, 0.6% for both metrics at 12 months, and 0.6% for both metrics at 18 months.

Table 2
Weight classifications by weight-for-length and body mass index across infancy (PHANTIM database 2000–2018)

Severely wasted, n (%)	**2 months**	**4 months**	**6 months**	**12 months**	**18 months**
WFL	354 (0.2)	327 (0.2)	155 (0.1)	74 (0.1)	57 (0.0)
BMI	264 (0.2)	282 (0.2)	190 (0.1)	97 (0.1)	63 (0.1)
Difference	p < 0.0001	p = 0.0001	p < 0.0001	p < 0.0001	p = 0.043
Wasted, n (%)					
WFL	2,791 (1.8)	3,136 (2.1)	2,064 (1.5)	1,003 (0.7)	696 (0.6)
BMI	2,299 (1.5)	3,275 (2.2)	2,655 (1.9)	997 (0.7)	707 (0.6)
Difference	p < 0.0001	p < 0.0001	p < 0.0001	p = 0.809	p = 0.569
Normal, n (%)					
WFL	120,366 (76.1)	119,266 (80.7)	110,064 (78.5)	100,410 (73.2)	91,540 (72.0)
BMI	128,449 (81.1)	121,675 (82.3)	112,880 (80.5)	100,485 (73.3)	90,393 (71.1)
Difference	p < 0.0001	p < 0.0001	p < 0.0001	p = 0.382	p < 0.0001
Risk of overweight, n(%)					
WFL	27,869 (17.6)	20,571 (13.9)	22,685 (16.2)	28,345 (20.7)	28,048 (22.1)
BMI	22,889 (14.5)	18,413 (12.5)	19,880 (14.2)	28,451 (20.8)	28,933 (22.8)
Difference	p < 0.0001	p < 0.0001	p < 0.0001	p = 0.254	p < 0.0001
Overweight, n (%)					
WFL	6,231 (3.9)	4,087 (2.8)	4,742 (3.4)	6,451 (4.7)	6,099 (4.8)
BMI	4,074 (2.6)	3,737 (2.5)	4,145 (3.0)	6,313 (4.6)	6,366 (5.0)
Difference	p < 0.0001	p < 0.0001	p < 0.0001	p = 0.005	p < 0.0001
Obese, n (%)					
WFL	646 (0.4)	460 (0.3)	563 (0.4)	818 (0.6)	748 (0.6)

Abbreviations: WFL, weight-for-length, BMI, body mass index

Severely wasted, n (%)	2 months	4 months	6 months	12 months	18 months
BMI	392 (0.3)	478 (0.3)	537 (0.4)	765 (0.6)	734 (0.6)
Difference	p < 0.0001	p = 0.549	p < 0.0001	p = 0.0002	p = 0.116
Abbreviations: WFL, weight-for-length, BMI, body mass index					

Agreement between WFL and BMI classifications in infancy

The agreement between WFL and BMI classifications in infancy was moderate at 2 months (kappa: 0.61, agreement 86.1%), which improved with age; reaching strong agreement (kappa between 0.83–0.90, agreement ranging from 93.3% to 96.5%) for all other infancy age points (4, 6, 12 and 18 months) (eTable 2).

Predicting overweight and obesity (> 2 z-score) at ~ 4.5 years based on WFL and BMI z-scores.

The AUROC for BMI and WFL in predicting overweight and obesity in later childhood based on BMI and WFL z-scores were similar, which ranged from 67.7% to 79.2% for BMI and 65.7% to 80.0% for WFL across infancy. Both tools had higher specificity (ranging from 90.1% to 93.8% for BMI, and from 90.1% to 95.2% for WFL) than sensitivity (ranging from 20.2% to 47.5% for BMI, and from 14.8% to 49.2% for WFL) across infancy. For both metrics, the overall predictive accuracy consistently increased with age (Table 3, Fig. 1). Similarly, the tools had higher negative predictive vales (NPV) than PPVs, with the PPV improving for both tools as age increased (Table 3).

Table 3
The performance of weight-for-length and body mass index continuous z-scores for predicting overweight and obesity at ~ 4.5 years.

		Age groups				
		2m	**4m**	**6m**	**12m**	**18m**
BMI	Sensitivity (%)	20.29	26.21	28.14	41.64	47.59
	Specificity (%)	93.83	92.49	92.55	90.28	90.19
	Positive predicted value (%)	14.26	14.94	15.62	17.58	19.24
	Negative predicted value (%)	95.88	96.14	96.33	96.88	97.23
	ROC area,	0.677	0.704	0.710	0.764	0.792
	95% CI	0.6673–0.6871	0.6942–0.7136	0.7004–0.7203	0.7555–0.7730	0.7835-0.8000
WFL	Sensitivity (%)	14.38	25.16	28.48	43.78	49.27
	Specificity (%)	95.22	92.68	92.44	90.11	90.23
	Positive predicted value (%)	13.18	14.75	15.60	18.03	19.81
	Negative predicted value (%)	95.66	96.09	96.34	96.99	97.32
	ROC area,	0.657	0.698	0.711	0.772	0.800
	95% CI	0.6472–0.6672	0.6885–0.7080	0.7010–0.7209	0.7634–0.7808	0.7922–0.8086
Abbreviations: BMI, body mass index, WFL, weight-for-length, ROC, receiver operator characteristic, CI, confidence interval, m, months						
Overweight and obesity at ~ 4.5 years were based on a BMI z-score > 2.						

Predicting overweight and obesity (> 2 z-score) at ~ 4.5 years based on overweight/obese status (> 2 z-score) in infancy, according to WFL and BMI

Being classified as overweight/obese (> 2 z-score) by BMI or WFL in infancy poorly predicted overweight/obese status in later childhood. The overall AUROC area of the two metrics was highly comparable, which ranged between 53.5% and 63.8% for BMI and between 53.8% to 64.3% for WFL across infancy (Table 4).

Table 4
The performance of being overweight/obese according to weight-for-length and body mass index for predicting overweight and obesity at ~ 4.5 years.

		Age groups				
		2m	**4m**	**6m**	**12m**	**18m**
BMI	Sensitivity (%)	9.31	11.25	13.78	26.03	31.82
	Specificity (%)	97.83	97.99	97.58	95.84	95.87
	Positive predicted value (%)	17.81	21.93	21.84	23.76	27.44
	Negative predicted value (%)	95.52	95.64	95.85	96.30	96.63
	ROC area,	0.535	0.546	0.557	0.609	0.638
	95% CI	0.5299–0.5402	0.5406–0.5520	0.5504–0.5630	0.6009–0.6163	0.6297–0.6458
WFL	Sensitivity (%)	10.88	11.24	14.91	27.58	32.57
	Specificity (%)	96.73	97.81	97.23	95.72	96.09
	Positive predicted value (%)	14.38	20.56	20.89	24.28	29.00
	Negative predicted value (%)	95.56	95.63	95.88	96.38	96.68
	ROC area,	0.5381	0.545	0.560	0.616	0.643
	95% CI	0.5325–0.5437	0.5396–0.5507	0.5539–0.5669	0.6084–0.6240	0.6351–0.6514

Abbreviations: BMI, body mass index, WFL, weight-for-length, ROC, receiver operator characteristic, CI, confidence interval, Overweight/obese status in infancy was defined as a z-score > 2 based on BMI and WFL, overweight and obesity at ~ 4.5 years were based on a BMI z-score > 2

DISCUSSION

The study examined weight distributions of children according to WFL and BMI in infancy and examined the predictive performance of both tools with regards to obesity prediction in a large sample of pre-school aged children. The results showed differences and similarities in weight classifications by WFL versus BMI in children < 2 years. Although the comparison of weight classifications of children in their early months according to WFL and BMI yielded statistically significant differences, the clinical value of

these differences can be questioned considering the small differences in proportions in WFL and BMI classifications, that varied by age and considering the reversal of the trend beyond 6 months of age. Moreover, the moderate to strong agreement in WFL and BMI classifications and similar predictive performance indicate that BMI can be equally useful for the purpose of infants' weight assessment, as the recommended tool, WFL. While current guidance recommends WFL for assessing children's weight status during infancy [4,16,17], this study does not support that WFL offers a more accurate tool for weight assessment in infancy compared to BMI.

The similarity in predictive accuracy of WFL and BMI in infancy are in line with previous results [18,19]. Rifas-Shiman et al. examined the association between ever being overweight in infancy with obesity at 5 years and found that BMI and WFL estimates in infancy provided similar results, both indicating that overweight status in infancy was strongly associated with obesity in later childhood (OR = 6.3 [95% CI, 5.7–7.0] based on WFL, and OR = 6.0 [5.4–6.7]) based on BMI) [19]. Aris et al assessed whether "ever being overweight" in infancy (6–24 months) according to WFL and BMI is a risk factor for cardiometabolic outcomes in early adolescence. The associations between later fatness and ever being overweight as an infant according to WFL (effect size = 1.1, 95% CI = 0.6–1.6) and BMI (effect size = 1.4, 95% CI = 0.9–1.9) provided consistent results[18]. Both studies were powered to examine differences of obesity assessment by WFL and BMI; however, they focused on the predictive ability of these metrics in the overweight group only, excluding other weight groups. Our results examined the distributions of weight classifications by WFL and BMI across all weight groups and at multiple points in infancy.

As the difficulty to manage obesity increases with age [14,20], childhood offers a window of opportunity for effective preventive interventions [20–24]. Misclassifying children who are at risk of becoming overweight can therefore lead to missed opportunities to provide timely support to children and their caregivers. Accordingly, for predicting childhood obesity, the tool's sensitivity is prioritized over its specificity, as it is unlikely that children falsely classified as being at risk will suffer harmful consequences from obesity interventions[14,22], given such interventions are supportive and not stigmatizing [25–29]. Our results showed that both tools had low sensitivity and thus are poor predictors for later risk of overweight and obesity.

The current results support previous findings indicating the advantage of using BMI to assess weight status for infants. Given recommendations in Canada and the United States of America to use BMI for children above the age of two years [4,16,17], using BMI charts in infancy could streamline clinical practice and improve the longitudinal monitoring of growth patterns in children as compared to when a transition between two different metrics (i.e., WFL and BMI) is required at age two years. Some findings suggested that using BMI as an indicator for adiposity can be problematic in groups of varying ethnic backgrounds since body compositions can vary according to population ancestry [30]; however, this limitation also applies to WFL considering the reliance on weight and length without the possibility to consider muscle mass.

Considering the WHO cut-point of defining overweight (> 2 z-score) used in this study, it is expected that about 2.3% of children in a healthy population would be in this category. The expected population weight distribution was better approximated by the BMI estimates of overweight in the study sample, which may indicate the possibility that WFL overidentifies overweight in early infancy. Classifying children to be “at risk of overweight” based on (> 1 z-score) WHO cut-point also warrants caution, given that both WFL and BMI do not differentiate between fat mass and muscle mass and due to the arbitrary statistical basis for these cut-off points. Weight classifications based on WHO cut points are useful at the population level to explore current or changing trends but may not be readily applicable to all individuals, considering their reliance on anthropometrics and not body composition.

To the best of our knowledge, this is the largest study to examine differences and similarities in weight classifications by WFL and BMI in infancy, and to assess the tools’ predictive ability for obesity risk in later childhood. The longitudinal nature of the PHANTIM database allowed an examination of weight assessments across multiple points in infancy. The data were measured by trained professionals, potentially minimizing errors in measurements. The study also has limitations; it was not possible to assess socioeconomic variables, including ethnicity, or morbidities to account for their potential effects on weight distributions in infancy and childhood based on WFL and BMI. Also, administrative data are subject to missingness, which contributed to a lower sample size at ~ 4.5 years. Although no patterns were identified to deem the missingness in this dataset as non-random, missingness could have potentially contributed to selection bias, which needs to be considered when interpreting the study’s results. Overall, the study’s large sample size and design offered insights into the performance of BMI as compared to the recommended tool, WFL, to inform clinical guidance. The benefits from streamlining clinical practice by using WHO BMI charts from birth to 19 years of age may outweigh the possible advantages of using WFL in infancy. Streamlining the weight assessment process may potentially increase the consistency and accuracy of child weight assessments and facilitate the effective communication with caregivers. The current findings indicate a need to revisit the guidelines making WFL charts the predominant standard for weight assessments in infancy.

Declarations

Conflict of Interest: The authors declare no conflict of interest and received no financial support for this manuscript.

Contribution of Authors:

SE and TF conceptualized the study.

SE, NS, DP cleaned and analyzed the data.

TF, AL, SD, MK, NS, and DP provided advice at different stages.

SE, TF, AL, SD, MK, NS, and DP approved the final version of the manuscript.

SE is the guarantor and attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Ethics: Ethical approval was obtained through the Conjoint Health Research Ethics Board at the University of Calgary (ID: REB20-0702).

Data availability: The data are not publicly available due to Alberta Health Services restrictions but may be requested directly from Alberta Health Services, subject to approval.

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Figures

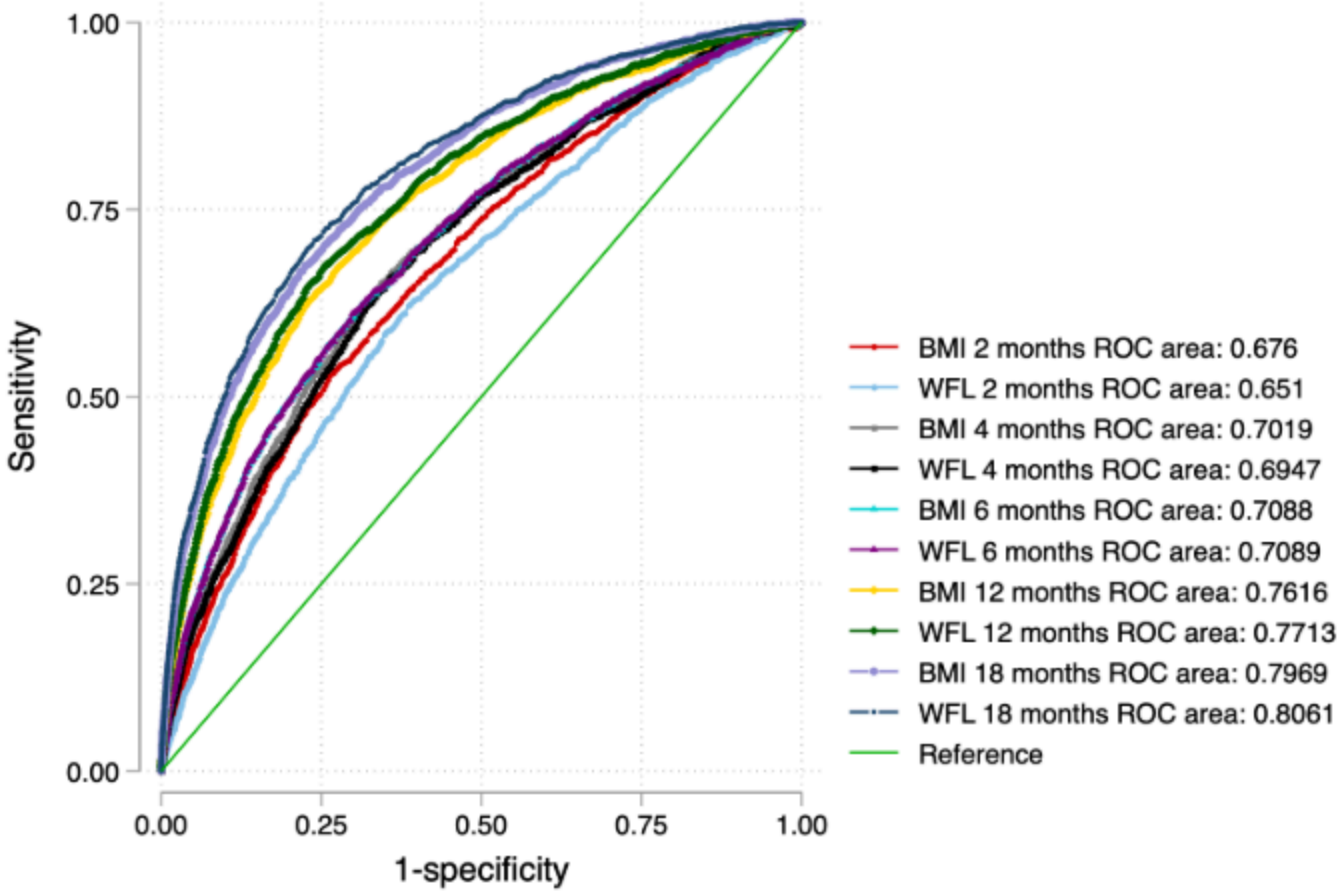


Figure 1

Receiver operator characteristic curves showing performance of body mass index (BMI) and weight-for-length (WFL) z-scores for predicting overweight/obesity (>2 z-score) at ~4.5 years of age.

Supplementary Files

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