Differences in growth of Canadian children compared to the WHO 2006 Child Growth Standards

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Introduction

Background: To evaluate if there are departures from the WHO Child Growth Standards (WHO-CGS) in postnatal growth of healthy ‘Canadian’ children in Ontario up to age 2 years, including by infant feeding and ethnicity.

Methods: We included data on 9964 healthy, singleton children born in Ontario, Canada. Smoothed weight, length and body mass index (BMI) percentile curves were generated using quantile regression for the Canadian cohort from birth to age 2 years. Differences in percentile values were calculated comparing Canadian children vs. the WHO-CGS.

Results: Canadian children under age 2 years were longer than the WHO-CGS at the 10th (0.8 cm), 50th (1.3 cm) and 90th (1.9 cm) percentiles. Canadian children incrementally surpassed the WHO-CGS in weight after age 6 months, and in BMI after 9 months. By age 2 years, the 50th percentile weight of Canadian males was 823 g (95% confidence interval (CI) 680, 965) higher than the WHO-CGS 50th percentile. Weight differences were seen regardless of feeding practice, and were greatest among children of mothers born in Canada and Europe/Western nations, and least for those of East Asian/Pacific or South Asian heritage. Among Canadian breastfed males, 18% (95% CI 16, 19) of newborns and 26% (95% CI 20, 33) toddlers aged 2 years were classified by WHO-CGS as weighing >90th percentile – much higher than the expected rate of 10%. Similarities were seen for differences in BMI.

Conclusions: Healthy Canadian infants/toddlers are longer and heavier than the WHO-CGS norms. Explanations for these discrepancies require further elucidation.

Keywords: infant and child growth, growth chart, growth standard, WHO, growth standards, length, weight, percentiles.

An important aspect of routine care for young children is serial measurement of weight and length.1 Monitoring early growth helps practitioners assess the health of children, including feeding adequacy.2,3

In 2006, the World Health Organization (WHO) released universal child growth standards (CGS), intended to describe the optimal growth of children.4 The WHO Multicentre Growth Reference Study (MGRS) took place between 1997 and 2003, and included children from Brazil, Ghana, India, Norway, Oman and the US, who were deemed to be free of health or environmental constraints on growth. They used a longitudinal design between birth and 24 months, and a cross-sectional design between 18 and 71 months. Of the 1743 infants enrolled at birth, 882 (50%) complied with the criteria for the longitudinal group, including exclusive or predominant breast feeding until at least 4 months.4

Canadian authorities endorsed using the WHO-CGS to monitor infant growth from 0 to 2 years,5 replacing the Centres for Disease Control and Prevention 2002 growth charts that had predominantly included formula-fed infants, who are prone to excessive growth.6 Although the WHO-CGS are thought to describe optimal growth, regardless of ethnicity, a number of international studies have found marked departures from the WHO-CGS, not entirely explained by feeding practice.7–11 Despite widespread
adoption of the WHO-CGS in Canada, it is unclear if the WHO-CGS reflects the growth of healthy Canadian infants and toddlers. Comparisons between the growth of Canadian children and those of the WHO-CGS have been restricted to single-centre hospital-based cohorts, which may limit their generalisability. One exception was a prospective study of only 73 infants, which sought to match the inclusion criteria of the WHO-CGS. In addition, no study has specifically evaluated performance of the WHO-CGS in Canadian children born to parents from some of Canada’s major immigrant source countries, such as China, the Philippines and Pakistan, none of whom were included in the MGRS. This is potentially relevant, as we previously showed that World region-specific birthweight curves more accurately predict adverse neonatal and obstetric outcomes than a single birthweight curve based on infants of Canadian-born women.

Herein, we compared the WHO-CGS to the postnatal growth of 9964 healthy Ontarian children up to age 2 years, including variations by infant feeding practices and maternal world region of origin. As Ontario comprises over a third of the births and half of immigrants in Canada, and universal health coverage and healthcare practices (i.e. primary care, obstetrics and paediatrics) are largely the same across the provinces, we henceforth refer to our Ontario cohort as ‘Canadian’.

Methods

Study design and participants

We completed a retrospective population-based cohort study using administrative health care data for the province of Ontario, Canada. Analyses took place at the Institute for Clinical Evaluative Sciences (ICES), using datasets linked by unique encoded identifiers. We identified the linked inpatient records of delivering Ontarian mothers and their newborns from the ICES MOMBABY dataset, which uses data from the Canadian Institute for Health Information’s Discharge Abstract Database (DAD). Included were singleton live births in an Ontario hospital at 37 7/7 to 41 6/7 weeks’ gestation, between April 1, 2002 and March 31, 2013, who had at least one well-baby/child visit before 750 days of age, with a measured weight or length in the Electronic Medical Record Administrative data Linked Database (EMRALD). In Canada, it is recommended that children have a well-baby/child visit within the 1st week of life, and at months 1, 2, 4, 6, 12–13, 18 (in Ontario) and at 2–3 years, with weight and length recorded at each visit. We excluded those with a diagnosed congenital or chromosomal anomaly, identified from hospital records at birth and up to 750 days of age, using the diagnostic codes Q00-Q99 in the International Statistical Classification of Diseases, 10th Revision. We also excluded implausible weight, length or body mass index (BMI) values above +5 SD, or below –5 SD, of the sample median for that age group. To enable comparison with the WHO-CGS, we used their inclusion criteria, as follows: single term births without a significant morbidity, no known health or environmental constraints to growth, including maternal smoking, who were exclusively or predominantly breastfed for at least 4 months, with introduction of complementary foods by age 6 months, along with partial breast feeding to at least age 12 months.

Eligible newborn records were linked by their encrypted health care number to the EMRALD, which at the time of this study, comprised electronic medical records (EMRs) from 321 family physicians in 42 geographically distinct primary care practices across Ontario. For each eligible infant in EMRALD, we extracted data for their postnatal visits including date of the visit, age, current weight and length, and feeding practice. For each infant, we also examined each entry in their EMR chart up to age 750 days for any mention of present or past breast or formula feeding, using an algorithm that we developed to search structured and free text fields. Canadian family physicians commonly use the structured Rourke Baby Record system (http://www.rourkebabyrecord.ca) for routine child health surveillance – including growth and feeding – from birth to 5 years of age. For EMRs without a Rourke Baby Record, chart abstractors manually extracted information about the type and duration of infant feeding from free text fields. Each infant’s predominant feeding type in the first 6 months of life was classified as: (i) exclusively breastfed, (ii) mixed breastfed and formula-fed, (iii) exclusively formula-fed, or (iv) unknown.

Maternal world region of origin was used as a practical proxy for ethnicity, categorised as follows: (i) Canada, (ii) Europe and Western nations, (iii) Middle East and North Africa, (iv) Sub-Saharan Africa and the Caribbean, (v) Latin America, (vi) East Asia and the
Pacific, (vii) South Asia, and (viii) Other. Maternal records were linked to the Ontario portion of the federal Immigration, Refugees and Citizenship Canada (IRCC) Permanent Resident Database (PRD), also housed at ICES. This database contains information about original country of citizenship, for immigrants to Canada from 1985 onward. Women not linked to the PRD were classified as non-immigrant women. Over 90% of the latter comprise Canadian-born women, and henceforth, are referred to as ‘Canadian-born’, but their ethnic background is not documented within our administrative datasets.

Residential postal code at the time of birth was used to determine the neighbourhood income quintile and rural residence, derived from Statistics Canada census data.

**Statistical analyses**

We used nonparametric quantile regression methods to generate smoothed weight-for-age (WFA), length-for-age (LFA), and BMI-for-age (BMI-FA) percentile curves for all children in our final cohort. Quantile regression produces virtually similar results to the Lambda-Mu-Sigma (LMS) method when the distribution of the response variable is roughly normal. Curves were fit employing a cubic spline and the use of a smoothing algorithm, with knot locations determined by backward stepwise regression. Separate curves were generated for males and females, and also by type of infant feeding and by maternal world region of origin. BMI – the ratio of weight (in kg) to recumbent length (in m²) – was calculated for a subset of infants who had both a weight and a length recorded at the same visit. BMI is highly correlated with weight-for-length from 0 to 2 years of age.

Percentiles were based on growth measurements at birth (weight only), and subsequent primary care visits centered around key time points of 7 days (range 1–11), 28 days (range 17–34), 2 months (range 50–69 days), 4 months (range 100–129 days), 6 months (range 160–189 days), 9 months (range 250–279 days), 12 months (range 350–379 days), 15 months (range 350–379 days), 18 months (range 500–559 days) and 24 months (range 680–749 days). If a child had more than one weight (or length) measurement within the aforementioned age groups, then we selected that closest to the target age. Age groups were chosen to correspond with those defined in the WHO-CGS methodology.

We calculated differences and 95% confidence intervals (CI) in the 10th, 50th and 90th percentile WFA and LFA; and in the 3rd, 50th and 97th percentile BMI-FA, between Canadian children and those of the WHO-CGS. Estimated 95% CIs were calculated using the sex- and age-specific sample-based errors from our cohort and the coefficients of variation from the WHO-CGS. Differences were calculated by sex and infant feeding type, as well as maternal world region of origin.

Next, we estimated the proportion of exclusively breastfed Canadian children that would be considered an unhealthy size according to the WHO-CGS thresholds. For weight and length, we determined the proportion (95% CI) in each age group who were <10th percentile or >90th percentile according to the WHO-CGS. For BMI, we calculated the proportion in each age group who would be classified as wasted (<3rd percentile) or overweight (>97th percentile) using the WHO-CGS. All weights, lengths and BMI values were converted to WHO-CGS percentiles. CIs for binomial proportions are exact Clopper-Pearson 95% confidence limits.

Statistical analyses were performed using SAS for Linux, Version 9.4 (SAS Institute, Cary, NC) and R for Linux, Version 3.1.2 (R Foundation for Statistical Computing, Vienna, Austria). The study was approved by the institutional review board at Sunnybrook Health Sciences Centre, Toronto, Ontario.

**Results**

Formation of the final cohort of 9964 healthy, singleton term-born infants in EMRALD is shown in Data S1. There were 48 556 WFA measurements, 32 681 LFA measurements, and 31 037 BMI-FA measurements. The average child had 5 weight and 4 length measurements (data not shown). Compared to all hospital births in Ontario, those that linked to the EMRALD database were somewhat more likely to have a Canadian-born mother and reside in a rural area, but were otherwise comparable (Data S2). We were unable to determine infant feeding practices for 2188 (22%) infants.

**Weight-for-age**

At birth, the 50th percentile weight of Canadian males (3530 g vs. 3346 g) and females (3380 g vs. 3232 g) was higher than that of the WHO-CGS (Data S3). By 6 months of age, there was consistent departure in
weight differences at the 10th, 50th and 90th percentile (Figure 1). For example, by age 2 years, the difference at the 50th percentile was 823 g (95% CI 680, 965) among males, and 776 g (95% CI 635, 917) among females (Data S3). These differences were even seen for exclusively breastfed infants (Figure 1).

The 50th percentile weight difference between the Canadian cohort and the WHO-CGS varied significantly at birth by maternal world region of origin, mostly among infants of mothers born in Canada, Europe and Western nations (Data S4a and b). Thereafter, differences were not appreciable up to age 6 months, but were once again evident after 9 months of age.

**Length-for-age**

From birth to age 2 years, compared to their WHO-CGS counterparts, Canadian children were on average 0.8 cm longer at the 10th percentile, 1.3 cm longer at the 50th percentile, and 1.9 cm longer at the 90th percentile (Figure 2). The 50th percentile length was higher among Canadian children than the WHO-CGS estimate, except for breastfed and mixed-fed females at 24 months of age (Data S5).

**BMI-for-age**

The 50th percentile BMI was significantly lower in Canadian children than the WHO-CGS up to 6 months for males and 9 months for females; after age 12 months, the 50th percentile BMI was significantly higher in the Canadian cohort vs. the WHO-CGS, regardless of infant feeding (Data S6). The threshold for infant wasting was generally higher in the WHO-CGS than among Canadian males up to 12 months and females up to age 9 months (Figure 3). Thereafter, there was little difference in 3rd percentile BMI among males, and females, until age 18 months, when positive differences emerged (Figure 3). The pattern of <3rd percentile BMI differences varied slightly for breastfed males and breastfed females.

The threshold for an infant classified as overweight was generally higher in the WHO-CGS than that among Canadian infants up to 4 months of age.

**Figure 1.** Difference in weight-for-age between Canadian minus WHO-CGS males (top panel) and females (bottom panel), at the 10th (red circles), 50th (black squares) and 90th (blue triangles) percentiles. The dashed line at 0 indicates no difference.
The probability of a Canadian male being higher than the expected rate of 10% (Figure 4).

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© WHO-CGS as weighing 18% (95% CI 16, 19) of newborns, and 26% (95% CI 20, 33) of toddlers aged 2 years, were classified by WHO-CGS as being >90th percentile – much higher than the expected rate of 10% (Figure 4). The probability of a Canadian male being <10th percentile by WHO-CGS was generally less than expected. Canadian females followed a similar pattern as the males, in terms of being <10th percentile, but less so for weighing >90th percentile by age 2 years (Figure 4). From birth to age 18 months, a much higher than expected proportion of exclusively breastfed Canadian children were >90th percentile LFA on the WHO-CGS – as much as 30% at age 6 months (Figure 5). Correspondingly, the proportion classified <10th percentile LFA on the WHO-CGS was consistently lower than 10% during the same age period (Figure 5).

Proportion of breastfed children classified as <10th or >90th percentile weight or length

Among exclusively breastfed Canadian males, about 18% (95% CI 16, 19) of newborns, and 26% (95% CI 20, 33) of toddlers aged 2 years, were classified by WHO-CGS as weighing >90th percentile – much higher than the expected rate of 10% (Figure 4). The probability of a Canadian male being <10th percentile by WHO-CGS was generally less than expected. Canadian females followed a similar pattern as the males, in terms of being <10th percentile, but less so for weighing >90th percentile by age 2 years (Figure 4). From birth to age 18 months, a much higher than expected proportion of exclusively breastfed Canadian children were >90th percentile LFA on the WHO-CGS – as much as 30% at age 6 months (Figure 5). Correspondingly, the proportion classified <10th percentile LFA on the WHO-CGS was consistently lower than 10% during the same age period (Figure 5).

Proportion of breastfed children classified as wasted (<3rd percentile BMI), or as overweight (>97th percentile BMI)

Before 12 months of age, exclusively breastfed Canadian males were more likely to be classified by WHO-CGS as wasted, with a prevalence of 11% (95% CI 9, 13) at birth and 7% (95% CI 5, 9) at 9 months; whereas, from age 12 months onward, they were increasingly likely to be classified as overweight, with a prevalence of 13% (95% CI 7, 22) by age 24 months (Data S7). A similar pattern was observed for females, though less pronounced (Data S7).
by the WHO-MGRS Group. No important variations method used herein vs. that by the LMS method used dian cohort, as generated by the quantile regression and 90th percentile weights and lengths for the Cana–

Figure 3. Difference in BMI-for-age between Canadian minus WHO-CGS males (top panel) and females (bottom panel), at the 3rd (orange circles), 50th (black squares) and 97th (green squares) percentiles. The dashed line at 0 indicates no difference.

In a post hoc analysis, we compared the 10th, 50th and 90th percentile weights and lengths for the Canadian cohort, as generated by the quantile regression method used herein vs. that by the LMS method used by the WHO-MGRS Group. No important variations were observed (Data S8a and b). The same was seen comparing the methods for the 3rd, 50th and 97th percentiles (Data S8c).

Comment

Main findings

Healthy Canadian children aged 0–24 months displayed greater length than the WHO-CGS currently adopted across Canada. Differences in weight, however, varied by age, such that Canadian infants weighed more than their WHO-CGS counterparts both at birth, and from age 6 months onward. Correspondingly, Canadian children displayed comparatively lower BMI before 9 months and higher BMI thereafter. Similar patterns were observed with all types of infant feeding. That said, WFA differences were most pronounced among children of mothers born in Canada, or Europe and Western nations, Middle East and North Africa, and Sub-Saharan Africa and the Caribbean. Infants of mothers from East Asia and the Pacific, South Asia, and Latin America appeared to grow more similar to WHO-CGS. By age 2 years, there was a 10% excess in the proportion of male infants classified as overweight.

Strengths and limitations

This study comprised a sample of nearly 10 000 Canadian children who contributed two or more weight measures between birth and age 750 days, and used over 48 000 weight and 30 000 length measures. Our inclusion criteria were similar those used in the WHO study and our use of quantile regression generated comparable results to the LMS method used by the WHO-MGRS Group. As EMERALD has a higher proportion of children with Canadian-born mothers, our sample may have differed slightly from all Ontarians, even though we performed a stratified analysis by maternal world

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Paediatric and Perinatal Epidemiology, 2017, ••, ••–••
region of origin (Data S4a and b). Otherwise, the newborns in EMRALD were similar to all those in Ontario. The ethnic ancestry of Canadian-born women was not available; nonetheless, the majority were born 25–35 years earlier to parents of British and European ancestry. EMRALD had EMR data from 321 physicians across Ontario, and anthropometric data routinely collected at well-baby/child visits. Child weight and length were not obtained using the strict measurement criteria applied in the WHO MGRS. However, the potentially greater variability in growth measurements in EMRALD, particularly for length, which is more prone to measurement error in young children, would not account the consistently greater lengths in Canadian children compared to the WHO-CGS.

In WHO MGRS, 1743 infants were enrolled at birth, but only 882 (50%) complied with the criteria for longitudinal follow-up to age 2 years, including exclusive or predominant breast feeding for at least 4 months of life. We attempted to follow the WHO-CGS criteria, and presented separate analyses by feeding practice. Even then, we could not determine feeding for 22% of infants. We also lacked data on maternal smoking, but the rate in Ontario is under 10%.

Implications

We found important differences in percentiles of weight, length and BMI of young Canadian children compared to the WHO-CGS, regardless of infant...
feeding practice. Since the WHO-CGS is currently used across Canada, these differences could have a substantial impact on how we interpret the ‘normal’ growth of Canadian children.

Our healthy Canadian cohort was markedly longer than the WHO-CGS before 18 months, regardless of feeding practice. In a prior Canadian study of a selected cohort of 73 infants who were breastfed according to the WHO guidelines, median newborn length was markedly greater at birth, but approximated the WHO thereafter. This pattern was also seen in UK infants. In Norway and Belgium, greater child length in the first 2 years of life was reported, including among exclusively breastfed Norwegian children.

Differences in maternal stature are hypothesised to play a role in birth length. Among the countries contributing to the WHO MGRS, the tallest average maternal height was among Norwegians, and the shortest was among Indian mothers, as were the corresponding birth lengths of their infants. While only about 20% of size at birth is determined by additive genetic variation, genetics come to explain nearly 80% of variation in weight, and 40% of variation in height, from 4 months onward. Thus, it is plausible that postnatal growth, especially after 6 months of age, may be partly expressed by parental ethnicity, which may explain why certain groups of healthy children deviate from the standards expressed in the WHO-CGS.

In contrast to length, the direction and magnitude of difference in weight and BMI percentiles between Canadian children and the WHO-CGS depended on age. Compared to their WHO-CGS counterparts,
Canadian children had a higher 50th percentile weight at birth, and again, after 6 months, while the 50th percentile BMI was lower before 12 months and higher thereafter. Correspondingly, a higher than expected proportion of Canadian breastfed children were wasted in the first 9 months and overweight the second year of life, according to the WHO-CGS. Age-related differences in weight percentiles have been observed in a number of international studies comparing national growth references to the WHO-CGS. Rolland-Cachera et al. compared national weight references from the US, UK, Netherlands, Belgium and France to the WHO-CGS, and revealed a strikingly similar pattern of lower median weights after birth and up to 6 months of life, with typically higher weights thereafter.

Although the trough between birth and 6 months observed herein, and in other Canadian studies was less pronounced, the consistency of this pattern of divergence from the WHO-CGS across different populations, and independent of feeding practice, raises questions about using the WHO-CGS to monitor the growth of Canadian children, particularly before 6 months of age.

Some have suggested that the unexpectedly higher weights of WHO-CGS children aged 0–6 months may be from selective dropout of smaller infants. Around 50% of infants enrolled in the WHO MGRS were non-compliant with breast feeding, and their growth measures were excluded. When an infant is smaller than expected, exclusive breast feeding is more likely to be replaced with mixed for formula feeding. In Malawi, among exclusively breastfed infants under age 6 months, more infants fell below the threshold <3rd percentile WFA on the WHO-CGS than on another growth chart. These children were at higher risk of unnecessary referral to a specialist, with interruption of exclusive breast feeding, even when there was no evidence of faltering growth. Hence, while largely adopted for use in many settings, there is some uncertainty around the use of the WHO-CGS as a guide to healthy child growth in the first 2 years of life. Certainly, a similar assessment among Canadian infants and toddlers is required, including by parental ethnicity.

We calculated BMI measures for Canadian infants and toddlers in the first 2 years of life, offering another useful indicator of early childhood growth. The BMI cut-points for classifying a Canadian breast-fed infant as wasted, or a toddler as overweight, were discrepant when using the WHO-CGS. Whether such departures are due to obesogenic feeding practices or normal healthy growth, needs to be determined.

**Conclusion**

Our findings suggest that many healthy Canadian infants and toddlers weigh more and are longer than the norms laid out in the WHO-CGS. Specifically, the degree to which these differences matter for short-term and long-term health trajectories requires longitudinal examination before reconsideration of current use of the WHO-CGS in Canada can be recommended.

**Acknowledgements**

The authors thank Dr. Daniel Roth of The Hospital for Sick Children for his constructive comments over the course of this project. This work was supported by a Healthcare Renewal Policy Analysis grant from the Canadian Institutes of Health Research (CIHR). JGR holds a Canadian Institutes for Health Research Chair in Reproductive and Child Health Services and Policy Research, co-funded by the SickKids Foundation and CIHR. MU holds a CIHR New Investigator Award. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. This study was supported by the Institute for Clinical Evaluative Sciences (ICES), which is funded by an annual grant from the Ontario Ministry of Health and Long-Term Care (MOHLTC). The opinions, results and conclusions reported in this paper are those of the authors and are independent from the funding sources. No endorsement by ICES or the Ontario MOHLTC is intended or should be inferred. Parts of this material are based on data and information compiled and provided by the Canadian Institute for Health Information (CIHI). However, the analyses, conclusions, opinions and statements expressed herein are those of the author, and not necessarily those of CIHI. Conflict of Interest: The authors report no conflict of interest.

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**Appendix 1**

**Members of the Canadian Curves Consortium**


**Supporting Information**

Additional Supporting Information may be found in the online version of this article at the publisher’s website:

**Data S1.** Flow chart of formation of the cross-sectional cohorts with measurements of weight (Cohort 1), length (Cohort 2), or both weight and length concurrently (Cohort 3), between birth and age 750 days.

**Data S2.** Characteristics of the 9964 singleton term livebirths comprising the current study cohort from the EMRALD database, compared to all singleton term hospital livebirths in Ontario between April 1, 2002 and March 31, 2013. Standardised differences were used to compare differences in means or proportions.

**Data S3.** Difference (95% CI) in the 50th percentile weight-for-age between Canadian minus WHO-CGS males (top panel) and females (bottom panel). The left axis shows the 50th percentile weight (kg) in Canada (green circles) and WHO (blue triangles). The right axis shows the difference (95% CI) in 50th percentile weight (g) (black squares). The dashed line at 0 indicates no difference.

**Data S4.** Difference (95% CI) in 50th percentile weight-for-age between Canadian minus WHO-CGS (a) males (b) females, by maternal world region of origin. The dashed line at 0 indicates no difference.

**Data S5.** Difference (95% CI) in the 50th percentile length-for-age between Canadian minus WHO-CGS males (top panel) and females (bottom panel). The left axis shows the 50th percentile length (cm) in Canada (green circles) and WHO (blue triangles). The right axis shows the difference (95% CI) in 50th percentile length (cm) (black squares). The dashed line at 0 indicates no difference.

**Data S6.** Difference (95% CI) in the 50th percentile BMI-for-age between Canadian minus WHO-CGS males (top panel) and females (bottom panel). The left axis shows the 50th percentile BMI (kg/m²) in Canada (green circles) and WHO (blue triangles). The right axis shows the difference (95% CI) in 50th percentile BMI (black squares). The dashed line at 0 indicates no difference.

**Data S7.** Proportion of exclusively breastfed Canadian male (top) and female (bottom) children that would be classified as wasted <3rd percentile BMI-for-age (orange circles) or overweight >97th percentile BMI-for-age (green squares) according to the WHO-CGS. The dashed line indicates the expected proportion of 3%.

**Data S8.** (a) Difference in 10th, 50th and 90th percentile weights of Canadian children, comparing Quantile Regression (QR) vs. Lambda-Mu-Sigma (LMS) methods. (b) Difference in 10th, 50th and 90th percentile lengths of Canadian children, comparing Quantile Regression (QR) vs. Lambda-Mu-Sigma (LMS) methods. (c) Difference in 3rd, 50th and 97th percentile body mass index (BMI) of Canadian children, comparing Quantile Regression (QR) vs. Lambda-Mu-Sigma (LMS) methods.