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Circannual Growth in Wisconsin Children and Adolescents: Identifying Optimal Periods of Obesity Prevention

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Abstract

Background: Recent studies suggest kids tend to gain the most weight in summer, but schools are chastised for supporting obesogenic environments. Conclusions on circannual weight gain are hampered by infrequent body mass index (BMI) measurements, and guidance is limited on the optimal timeframe for pediatric weight interventions.

Objectives: This study characterized circannual trends in BMI in Wisconsin children and adolescents, and identified sociodemographic differences in excess weight gain.

Methods: An observational study was used to pool data from 2010-2015 to examine circannual BMI z-score trends for Marshfield Clinic patients age 3-17 years. Daily 0.20, 0.50, and 0.80 quantiles of BMI z-score were estimated, stratified by gender, race, and age.

Results: BMI z-scores increased July-September, followed by a decrease in October-December, and another increase-decrease cycle beginning in February. For adolescents, the summer increase in BMI was greater among those in the upper BMI z-score quantile relative to those in the lower quantile (+0.15 units vs. +0.04 units). This pattern was opposite in children.

Conclusions: BMI increased most rapidly in late summer. This growth persisted through autumn in adolescents who were larger, suggesting weight management support may be beneficial for kids who are overweight at the start of the school year.

Keywords

Body Mass Index; Circannual; Children; Adolescents

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Conflicts of Interest Statement

The authors have no conflicting financial or other interests to report.

Introduction

According to the National Health and Nutrition Examination Survey, 17% of children in the U.S. are affected by obesity,¹ a prevalence three times greater than what was observed 30 years ago. Childhood obesity is among the strongest predictors of adult obesity,² making this a major public health concern. Adult obesity is among the leading drivers of type 2 diabetes, high blood pressure, hyperlipidemia, and cancer, as well as increased social stigma and reduced academic achievement.³ In response to this dramatic increase in overweight and obesity, U.S. healthcare organizations, concerned scientists, and local communities have initiated multiple programs in an effort to prevent excess body weight gain in children.⁴ Due to their centralized location and ability to reach a large volume of kids, many of these programs have focused on weight gain prevention in school settings. Yet schools have received considerable ire regarding the obesity epidemic, based largely on a mix of evidence and a perception that school environments promote convenient access to high calorie foods and sugar-sweetened beverages, along with decreasing opportunities for physical activity.⁵

Some researchers have questioned the supposition that there is a large negative impact of schools on childhood obesity. During the span of the developing years, children who are overweight tend to develop into adolescents who are affected by overweight or obesity,⁶ but it is unclear if their generally accelerated body weight gain is distinguishable within a given circannual timeframe, such as during the school year. Recent short-term observational cohort studies have found that body mass index (BMI) actually increased at a higher rate during the short summer months as compared to the school months.⁷⁻⁹ Similar patterns have also been noted in intervention studies. Economos and colleagues^{10, 11} found decreased BMI z-scores in children within school districts undergoing an obesity intervention as compared to controls, but BMI z-scores increased at similar rates for both school districts during the out-of-school summer months. Similarly, improved fitness and body fat levels eroded during summer break in children who completed a school-based program.¹² Conclusions from two recent systematic reviews have suggested that, in a given year, the largest increases in body fat actually occur at some point during the summer months when children are away from school.^{13, 14} Perhaps more concerning, summertime weight gain appears to be accelerated, or start at an earlier age, among those affected by obesity at the start of the school year and possibly in certain disadvantaged groups.^{13, 14}

Collective findings from these previous studies suggest that the net progress in weight gain normalization achieved during the school year may be undone sometime over the summer. Conclusions on circannual body weight gain are hampered, however, by methodological shortcomings in prior studies. In particular, previous studies have typically used infrequent BMI measurements, often limited to two per year. Thus the precise pattern of weight change in proportion to height is poorly understood beyond the beginning and end of the school year. Only one prior study was conducted in a rural setting,¹² and only one study used serial medical records to estimate circannual weight gain patterns in kids.¹⁵ There is limited guidance on the optimal time period when pediatric weight gain prevention interventions should occur. The purpose of this study was to characterize circannual trends in BMI among north-central Wisconsin children and adolescents, as well as to identify sociodemographic differences in excess weight. Our study aimed to replicate some elements, as well as extend

findings from, the recent paper by Bhutani and colleagues.¹⁵ We also used serial medical records, but we applied our analyses in a larger rural population and modeled BMI quantile patterns by day.

Methods

Design and setting

A retrospective observational study was used to examine BMI trends for pediatric patients who were medically-homed (i.e. receive their primary care from) at the Marshfield Clinic Health System (MCHS) during the years 2010–2015. Data was pooled across all years to create a common circannual dataset. Data was extracted from the MCHS research data repository, which stores medical/administrative information from system electronic health records (EHR). MCHS serves a predominantly rural patient base with clinics throughout small communities in north-central Wisconsin.

Sample

As of December 31st for each study year, eligibility criteria for individuals in the analytical sample were: (1) age 3–17 years, and (2) medically-homed to MCHS. Per standard methods for healthcare quality reporting,¹⁶ ‘homed’ individuals had ≥2 ambulatory visits over the previous three years plus ≥1 visit in the previous two years, or had an assigned primary care provider from MCHS. Given the retrospective, data-only nature of the study design, human subjects approval was granted with a waiver of written/verbal informed consent and HIPAA authorization from the MCHS Institutional Review Board.

Measures

The study endpoint was BMI z-score. BMI was calculated by dividing weight (kg) by height (m) squared. Both heights and weights were extracted from the EHR, and were originally collected by clinic staff using standardized procedures as part of routine outpatient visits. BMI z-score for a given individual was calculated by subtracting the U.S. Center for Disease Control and Prevention’s (CDC) population average BMI (for age) from the individual’s BMI, then dividing by the population BMI standard deviation.^{8, 17} An individual’s BMI z-score essentially reflects deviation from the population mean BMI. As recommended by others,^{18, 19} BMI z-score was selected as the outcome because it obviates the influence of age, while simultaneously accounting for height, on body weight values in this rapidly growing population. Several covariates were also extracted from the EHR, including age, gender, and race/ethnicity.

Analytical dataset

Source data was at the level of calendar day on which BMI was collected during patient encounters. To help mitigate frequent healthcare users from disproportionate representation, an extraction algorithm was applied to ensure each individual’s visits were separated by at least 30 days. Also, only concurrently measured values for weight and height were used to calculate BMI z-scores, with the following exception. For records that had an available height or weight value, but a missing corresponding weight or height value (i.e., missing one of the two elements needed to calculate BMI) on that same encounter date, the missing

height or weight value recorded on the date closest to the index encounter date was used as a reasonable stand-in value. Said stand-in height or weight values, however, had to have been collected within 7 days of the index encounter date. To reduce the influence of data entry errors and body weight extremes, implausible BMI z-scores were excluded based on a CDC algorithm,²⁰ which eliminated 946 (0.03%) available BMI records. To establish the feasibility of combining data across multiple school years during the study period, radially smoothed curves²¹ for mean BMI z-score were first fit for each individual school year (2010–11 through 2014–15). Time was modeled in daily increments over each year, beginning in September and ending in August to approximate the typical academic calendar in Wisconsin, where school usually starts in early September and ends by early June. When processing a given year, the source dataset included one additional month of data at the beginning and end of the year to ensure the estimated BMI z-score curves had the appropriate trajectory in September and August. These preliminary analyses indicated that reasonably similar BMI z-score patterns occurred across all study years, thus study data was pooled into a single circannual dataset comprised of the concatenated yearly datasets used in the radial smoothing analyses.

Statistical analyses

The primary statistical analyses entailed fitting quantile regression²² models with BMI z-score as the outcome. A specific quantile regression formulation was used to account for the contribution of more than one clinical encounter by some individuals.²³ In contrast to linear regression, which estimates the conditional mean given specified covariates, quantile regression estimates conditional quantiles. For this study, we estimated the 20th, 50th (median), and 80th percentiles (i.e., 0.20, 0.50, and .80 quantiles) of BMI z-score. These percentiles were used to draw contrasts between general markers of kids who were lighter, average, and heavier; not a stratified analysis of kids in baseline World Health Organization or CDC-defined BMI risk categories (e.g., <5th percentile as underweight, 95th percentile as obese).²⁴ Natural cubic splines²⁵ were used to characterize the day-of-school-year exposure as a smooth continuous function. The analyses examined patterns in cross-sectional BMI z-score observations by day, as opposed to longitudinal patterns within individual patients. First, a model containing only the spline for the day-of-school-year effect was fit and estimated BMI z-score curves with corresponding 95% pointwise confidence intervals were generated. The remaining models contained the day-of-school-year spline and a categorical demographic factor, plus their interaction. Demographic factors assessed were gender, race/ethnicity (Non-Hispanic White vs. Hispanic or non-White), and age (3–7, 8–12, and 13–17 years). In addition to generating estimated BMI z-score curves with 95% pointwise confidence intervals for each demographic factor, pairwise comparisons (e.g., female vs. male) of estimated BMI z-score values were performed for each day of the school year. The analysis of age was adjusted for multiple comparisons since more than two age groups were compared for a given day of the school year.²⁶ Analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC).

Results

There were 78,722 unique children/adolescents in the final analytical dataset, with 320,899 qualifying BMI observations during the complete 2010–2015 study timeframe (23% of patients had 6 visits with a qualifying BMI observation during this time). The initial dataset contained 576,975 total patient-encounters (records), with the majority of record exclusions (37%) due to a missing height or weight value that exceeded the allowable limit of 7 days between one another. Remaining record exclusions were mainly due to encounters that occurred within 30 days of one another, and a minimal number of record exclusions (~1%) were due to biologically implausible values or duplicate records. Across all BMI observations, the patient age distribution was 3–5 years (21%), 6–8 years (20%), 9–11 years (20%), 12–14 years (20%), and 15–17 years (18%). The sample was 47% female, and 86% were Non-Hispanic White. The median BMI z-score across all encounters was 0.58, indicating most individuals were above the established population-normalized BMI for their age.

As outlined in the Figure 1 estimate of median BMI z-scores, the general pattern had four phases over a given year. The largest gain (0.10 units) occurred during the months July through September, followed by a commensurate decrease in BMI z-score over the ensuing three months. Beginning again in February, another period of BMI z-score gain occurred, followed by a decrease of similar magnitude in May and June. This latter cycle, however, was more muted at 31% (17%) less increase (and decline) relative to the former pattern observed during late June through January.

Most circannual differences were rather subtle between compared subgroups. In the upper BMI z-score quantile (i.e., kids who were heavier), males were significantly larger than females, but both genders had similar seasonal patterns of BMI z-score increase and decline. In contrast, females were larger than males in the lower BMI z-score quantile (i.e., kids who were lighter) and they also experienced more pronounced increases during the late summer through early autumn period (Figure 2). Children/adolescents who were Non-White or Hispanic were significantly larger than their White, non-Hispanic counterparts at all BMI z-score quantiles, particularly in the upper quantile (Figure 3). Seasonal patterns were fairly similar though across all BMI z-score quantiles by race/ethnicity. Age was perhaps the most variable exposure studied. Adolescents age 13–17 had significantly larger BMI-z-scores than children age 3–7 across all BMI z-score quantiles (Figure 4). Also in adolescents age 13–17, the summer-autumn changes in BMI z-score among adolescents in the upper BMI z-score quantile (+0.15 units) was far greater than that observed in adolescents in the lower quantile (+0.04 units), along with a greater decrease in April-June for adolescents too. This pattern was opposite in children age 3–7, where those in the lower BMI z-score quantile saw larger BMI z-score change (+0.16 units) than those in the upper BMI z-score quantile (+0.11 units).

Discussion

North-central Wisconsin children and adolescents did not show major BMI increases throughout the school months. Seasonal patterns in our study generally mimicked

observations from kids in the northern hemisphere over the previous century in that most body weight is gained in approximately early autumn.²⁷ The trajectory and (presumed) velocity of BMI z-score change was not constant though, as it included two general periods of increase, followed by subsequent decline, over a circannual timeframe. Specifically, July through September had the sharpest BMI increase, followed by a more modest growth phase in late winter through early spring. This pattern was not readily apparent in prior studies where few BMI measures were available.^{13, 14} It differed somewhat from recent studies in southern Wisconsin and Denmark, where BMI increases appeared flatter¹⁵ or nearer to linear²⁸ during the school months. We also observed an unexpected mid-winter nadir in BMI z-scores. School breaks, inclement weather, and nearby holidays would seem to both limit physical activity and increase caloric consumption at that time. Both prior studies^{15, 28} were conducted in more densely populated areas though, which could reflect different BMI z-score trajectories in urban vs. rural samples.

Consistent with prior studies,^{14, 15, 29} kids who were non-White or Hispanic were clearly larger for their age relative to kids who were non-Hispanic White. And by adolescence, BMI z-scores were markedly larger throughout the year for all kids, which is consistent with the higher rates of overweight and obesity observed in older (childhood) age groups across the U.S.²⁹ Among the kids in our study who were larger (80th percentile of BMI z-score), older age groups seemed to have a somewhat faster increase in their BMI z-score during the late summer and early autumn as compared to young kids age 3–7 who were larger. The typical early winter decline in BMI z-score that follows this period of growth also seemed more diminished in adolescents. This adds detail to the known year-over-year growth trends of adolescents who are affected by overweight or obesity, most of whom were also overweight during their childhood.⁶ We did not examine actual conversion to obesity in this multiple cross-sectional study, but the circannual pattern of body weight change in children who are larger seems to be more volatile in adolescence (i.e., more pronounced BMI increases in summer-autumn and decreases in spring seasons). Whether or how such circannual changes could influence later health outcomes is unclear, but could be explored in future cohort studies.

Assuming the circannual patterns of BMI z-score change in our study is broadly representative, it could have important implications for the design of school-based obesity prevention initiatives in the U.S. Year-round health education is important for all kids, but there may be more ideal time periods for certain emphases. For example, the end of the school year occurs nearest to the nadir of all children and adolescents' circannual bodily growth. For those who are at higher risk of obesity, more aggressive nutrition and physical activity skill-building efforts, focused on the home environment, might be effective at this time, just before said kids leave for the summer and will soon begin their most rapid phase of BMI increase. Adolescents who are already affected by obesity could benefit from such efforts too, but may also need school-based weight management support at the start of the school year, when BMI z-score tends to increase persistently until spring. It is important to point out, however, that such seasonal guidance operates under the assumption that the observed fluctuations in BMI z-score are a known function of volitional choices in diet and physical activity habits. Lifestyle data was unavailable in our study, thus it would be an important area of future research to examine concomitant changes in lifestyle, which may

further interact with seasonal changes in endogenous mechanisms related to sunlight exposure (e.g., vitamin D, melatonin).³⁰⁻³²

From a methodological perspective, our study findings also call into question how school-based obesity programs are best interpreted. Such evaluations often employ a paradigm where BMI is measured once at the beginning and once at the end of the school year. This method obscures the BMI z-score increase at summer's end, followed by the drop in late autumn and more modest, but similar, cycle in the remaining school months. And without a parallel control school/group, it could lead to spurious conclusions on intervention effectiveness. It is insufficient for evaluating obesity prevention interventions in childhood, where regular BMI assessments are needed throughout the school year to test whether changes in body weight during academic months are excessive, unidirectional, or parallel expected seasonal variation. As a growth endpoint, program evaluators should also be mindful that BMI is a composite measure. We did not disaggregate relative contributions of weight and height separately, which could be informative since, historically, height tends to increase more in spring/summer and weight increases are typically more pronounced in early autumn in kids.³³ Examining seasonal covariance in height and weight could also facilitate historical comparisons.

This study was strengthened by the large number of BMI observations in a defined population, as well as the daily BMI z-score values used in conjunction with statistical smoothing to improve interpretability. The major limitation was that this was not a cohort design with daily repeated measures of the same kids. Rather, we extracted several hundred thousand daily BMI observations from medical records over six pooled calendar years. Thus an underlying assumption was that said daily cross-sectional BMI z-score observations, when smoothed, reasonably represented a true circannual BMI change over time among unique patients in our target population. If a large fraction of atypical patients tended to visit MCHS clinics disproportionately during certain periods of the year, it could be a source of selection bias. For example, illness visits were not distinguishable from preventive care visits, and a differentially high volume of such visits that coincide with immune function cycles³⁴ during certain times of the year could also influence growth changes. Also, children's growth patterns have been shown to vary according to birth month,^{35, 36} which might be another influential factor worth exploring in future cohort analyses. Another limitation was that height and weight measures were collected in multiple MCHS centers by staff with varying levels of training, which could increase error in BMI measures. Finally, the source population was largely rural and racially homogenous, which limited generalizability and precluded more detailed examination of race/ethnicity groups, among other sociodemographic factors that may be influential such as comparing urban vs. rural kids.

Because BMI in childhood and adulthood are closely linked, mitigating excess body weight gain in childhood may reduce the ensuing risk factors for chronic diseases (e.g., dyslipidemia, hyperglycemia) faced by adults who are affected by obesity. Viewed from a population-level, where excess weight gain can accumulate year-over-year, even small accelerations in the typical velocity of body weight gain during developing years can influence the prevalence of obesity in adults. The informatics methods used in this EHR-

based epidemiologic study of seasonal BMI z-score patterns could be adopted by other healthcare quality consortiums to inform the design of regional pediatric obesity prevention initiatives, and could also complement evaluations of school-based programs which typically have limited BMI measures. More robust childhood BMI surveillance may eventually direct weight gain prevention efforts toward the children, places, and time periods where they are most beneficial.

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JJV and DAS conceived the methodological study design, interpreted the findings, and drafted the initial manuscript. BAK and LPH created the data collection approach and executed statistical analyses, interpreted study findings, and made significant contributions to the final manuscript draft. JJP and AM conducted literature searches, and also contributed to writing and revising manuscript drafts. All authors gave final approval of the submitted manuscript.

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Figure 1.
Circannual median body mass index (BMI) z-score among children and adolescents in north-central Wisconsin.

Figure 2.

Gender-stratified differences in circannual body mass index (BMI) z-score quantiles among north-central Wisconsin kids.

Figure 3. Race/ethnicity-stratified differences in circannual body mass index (BMI) z-score quantiles among north-central Wisconsin kids.

Figure 4.

Age-stratified differences in circannual body mass index (BMI) z-score quantiles among north-central Wisconsin kids.