# Development of Distinct Body Mass Index Trajectories Among Children Before Age 5 Years: A Population-Based Study

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## Abstract

The prevalence of childhood obesity has increased over the past 3 decades. This study was designed to understand how childhood body mass index (BMI) influences later risk of obesity. We calculated BMIs for children residing in Olmsted County, Minnesota, between January 1, 2005 and December 31, 2012 using medical records data. We defined homogenous BMI trajectory clusters using a nonparametric hill-climbing algorithm. Overall, 16,538 (47%) children had >3 weight assessments at least 1 year apart and were included in the analyses. Within the 8-year follow-up period, children who were younger than 2 years and overweight had a 3- fold increase of obesity (adjusted hazard ratio [HR] = 3.24; 95% confidence interval [CI] = 2.69-3.89) and those aged 5 years and overweight had a 10-fold increased risk of obesity (adjusted HR = 9.97, 95% CI = 8.55-11.62). Three distinct BMI trajectories could be distinguished prior to 5 years of age. The risk of developing obesity in those who are overweight increased dramatically with increasing age. Interventions to prevent obesity need to occur prior to school age to prevent children from entering unhealthy BMI trajectories.

## Keywords

infant, child, preschool, adolescent, overweight, obesity, body mass index, trajectories

## Introduction

The prevalence of obesity among children in the United States between 2 and 19 years of age has increased from 14.5% in 1999-2000 to 17.0% in 2011-2014.[1,2] The number of children who are severely obese has also increased to 5.8% in 2011-2014.[2] Rates of childhood obesity have paralleled increasing rates of childhood hypertension, type II diabetes, nonalcoholic fatty liver disease, and musculoskeletal disorders.[3-6]

A high body mass index (BMI) earlier in life is associated with an increased risk of obesity in adolescence and adulthood.[7,8] Changes in BMI over time contribute to the development of obesity. Individuals who have similar patterns in BMI changes over time, or "trajectories," can be grouped together using statistical models.[9] There is strong evidence in children outside of the United States that BMI trajectory can be determined prior to age 5 years.[10-21]

Studies of young children (<5 years of age) in the United States have identified different patterns of BMI trajectories.

Li et al[22] evaluated BMI trajectory in a nationally representative sample of 1739 US children born between 1984 and 1990 and identified categories of early onset overweight, late onset overweight (age 8 years) and normal weight.[22] O'Brien et al[23] evaluated BMI trajectory in 653 hospitalized patients in different US cities recruited in 1991 between ages 2 and 12 years and observed that children could be categorized into never overweight, overweight at preschool, overweight at elementary school, and overweight at preschool followed by normal weight status. An analysis of 1093 children born between 1992 and 1995 in the Iowa Fluoride Study observed that an increase in BMI trajectory

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in females in the first year of life was associated with elevated BMI in young adulthood, but this was not seen with an increase in the second year of life or in boys.[24] These studies are limited by small samples sizes and the fact that the cohorts are from the 1980s to 1990s.

A retrospective cohort study of 26 234 children in Denver Health outpatient clinics among whom more than 90% lived below the poverty level found that many obese children were already overweight (20%) or obese (36%) by age 3 years.[25] This study utilized a clinic and not a population-based sample.

A need exists to evaluate BMI trajectories in large, US population-based samples in order to advance our understanding of how changes in BMI at different ages influence later risk of obesity. The objective of the study was to examine the associations between baseline BMIs and development of obesity and BMI trajectories in children 0 to 18 years residing in a Midwestern US county between 2005 and 2012.

## Methods

### Study Population

We identified all children and adolescents ages 0 to 18 years residing in Olmsted County, Minnesota, on January 1, 2005 using the Rochester Epidemiology Project (REP) research infrastructure.[26,27] The REP links together medical records from multiple health care providers for the Olmsted County population. We used this resource to identify 96% of the population between 0 and 18 years of age residing in Olmsted County based on US Census county estimates. Overall, we identified 35,210 children as residents of Olmsted County, Minnesota, on January 1, 2005.

### Body Mass Index

Height (length for those younger than 2 years) and weight data were obtained from the electronic medical records from health care providers between January 1, 2005 and December 31, 2012. Data points outside the expected 1st and 99th percentiles were manually reviewed using medical records to exclude errors in data entry. Additionally, we excluded weights of pregnant adolescents <19 years of age from 6 months before to 3 months after the delivery date. To standardize BMI ($kg/m^2$) measures by the child's age and sex, we used the Centers for Disease Control and Prevention growth charts for children 2 to 18 years and the World Health Organization measures for children <2 years of age.[28,29] We defined the baseline BMI as the individual's first measurement between 2005 and 2012. Overall, 16 538 children (47%) had ≥3 BMI measurements separated by at least 1 year, and were included in the analyses. Overweight was defined as or BMI between the 85th and 94th percentile, and

obese was defined as BMI at or above the 95th percentile. Under/normal weight was defined as BMI less than the 85th percentile.

### Statistical Analysis

The number and percent of children in different age groups (0 to <2, 2 to <5, 5 to <13, 13+ years), sex, and race categories are presented overall and by baseline BMI group. We compared the characteristics in each of the groups using $\chi^2$ tests for categorical variables. Proportional hazard regression stratified by age group was used to assess associations between baseline BMI group and becoming obese during follow-up. Per standard survival analysis procedures, individuals who were obese at baseline were excluded from these analyses (not at risk for the outcome). Multivariable models were used to adjust for sex, race, and age (continuous). Results are presented as hazard ratios (HRs) with 95% confidence intervals (CI).

A nonparametric hill-climbing algorithm (KmL) was used to identify distinct, homogeneous clusters of BMI trajectories within each age group. The optimum number of clusters for each age group was determined using the Calinski and Harabatz criterion.[9] Three trajectory clusters were identified as optimum for children aged 2 years or older at baseline, while 2 trajectories were identified as optimum for children 0 to <2 years at baseline. However, to enable comparability, the next best fit (3 trajectories) are also presented for children 0 to <2 years. A plot of the average trajectory for each cluster was used to summarize the overall change over time for each group. We assessed the BMI trajectories separately by age group, race and sex, but because the shapes of the trajectories were similar for both sexes and all races, we present only the trajectories for separate age groups. Analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC) and R version 2.14.0 (The R Foundation for Statistical Computing).

This study was approved by the Mayo Clinic and Olmsted Medical Center Institutional Review Boards, and the requirement for informed consent was waived. However, we only included information from children whose parents had provided authorization for their medical records to be used for research.[30,31]

## Results

Characteristics of the study population are summarized in Table 1. The population was comprised of a comparable proportion of males and females (49% males, 51% females), and a majority of the children were white (81% white). At baseline, 1,824 (11.0%) children were obese. Boys were more frequently obese than girls, and children ≥5 years of age were more frequently obese than younger children. The highest prevalence of obesity was observed among Hispanic

**Table 1.** Characteristics of the Study Population at Baseline and by Weight at Last Follow-up.

| Characteristic | Total Population (n = 16 538), n (%) | Weight Group at Last Follow-up | | | $P^a$ |
| --- | --- | --- | --- | --- | --- |
| | | Under/Normal Weight; BMI < 85th percentile (n = 12 338), n (%) | Overweight; BMI ≥85th and <95th percentile (n = 2376), n (%) | Obese; ≥95th Percentile (n = 1824), n (%) | |
| Sex | | | | | <.0001 |
| Male | 8086 (48.9) | 5879 (72.7) | 1176 (14.5) | 1031 (12.8) | |
| Female | 8452 (51.1) | 6459 (76.4) | 1200 (14.2) | 793 (9.4) | |
| Age (years) at first BMI | | | | | <.0001 |
| 0 to <2 | 2295 (13.9) | 1775 (77.3) | 309 (13.5) | 211 (9.2) | |
| 2 to <5 | 2537 (15.3) | 2002 (78.9) | 319 (12.6) | 216 (8.5) | |
| 5 to <13 | 7243 (43.8) | 5277 (72.9) | 1096 (15.1) | 870 (12.0) | |
| 13 to 18 | 4463 (27.0) | 3284 (73.6) | 652 (14.6) | 527 (11.8) | |
| Race/ethnicity | | | | | <.0001 |
| Black | 912 (5.5) | 653 (71.6) | 134 (14.7) | 125 (13.7) | |
| White | 13,424 (81.2) | 10,099 (75.2) | 1912 (14.2) | 1413 (10.5) | |
| Asian | 622 (3.8) | 476 (76.5) | 85 (13.7) | 61 (9.8) | |
| Hispanic | 537 (3.2) | 332 (61.8) | 95 (17.7) | 110 (20.5) | |
| Other/Unknown | 1043 (6.3) | 778 (74.6) | 150 (14.4) | 115 (11.0) | |
| Follow-up (years), media (IQR) | 6.0 (4.6-7.0) | 6.0 (4.6-7.0) | 6.0 (4.6-7.0) | 6.0 (4.5-7.0) | .29 |

Abbreviations: BMI, body mass index; IQR, interquartile range.
[a] Chi-square *P* value.

children (20.5%), while the lowest was observed among Asian children (9.8%). The median length of follow-up for this population was 6.0 years (interquartile range = 4.6-7.0), and follow-up did not vary by BMI category. A majority of the children who were obese at baseline (61.1%) remained obese at last follow-up, while only 3.6% of the children who were under or normal weight at baseline were obese at last follow-up (Figure 1).

We examined the risk of becoming obese among children who were overweight at baseline compared to children who were under or normal weight. After adjusting for baseline age, sex, and race, children who were overweight at baseline had a greater than 5-fold increased risk of becoming obese during follow-up (adjusted HR = 5.70, 95% CI = 5.20-6.25). We also observed a significant interaction between baseline age and BMI category and the risk of becoming obese during follow-up (interaction *P* < .0001). Children who were overweight at any age had a substantially increased risk of becoming obese during follow-up. This risk increased dramatically with increasing age (Table 2). After adjusting for sex and race, children who were overweight in the 0 to <2 years age group had more than a 2-fold increased risk of becoming obese during follow-up. Children who were overweight by age 5 years or older had nearly a 10-fold increased risk of becoming obese during follow-up compared to children who were normal or underweight.
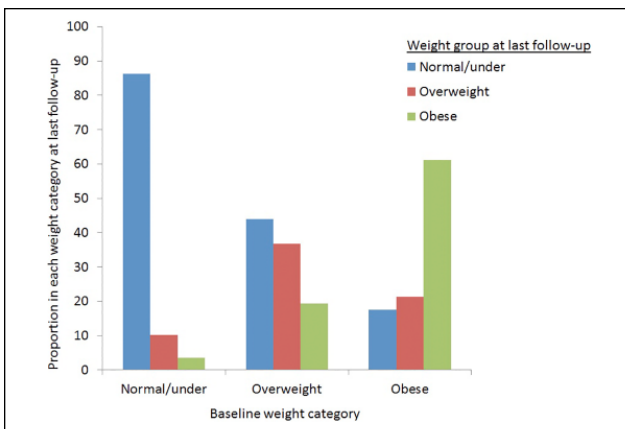


**Figure 1.** Changes from BMI group at baseline to BMI group at last follow-up.

Finally, we assessed BMI trajectories during follow-up by baseline age group. We evaluated trajectories by race and sex and observed the trajectories to be similar, so we combined sexes for all further analyses (data not shown). Overall, children 0 to <2 years had similar BMIs at baseline, but 15.7% clustered into a trajectory of increasing BMIs over time, while the remaining children fit into trajectories where the BMIs remained stable over time (Figure 2, panel A). Children between 2 and <5 years also had similar BMIs at baseline; however, 11.3% of these children clustered into a

**Table 2.** Risk of Becoming Obese (≥95th Percentile for Age) Among Children Who Were Overweight (85th to <95th Percentile for Age) Compared With Children That Were Normal or Underweight at Baseline.[a]

| | Risk of Becoming Obese by | | | |
| | Age at First BMI (Years) | | | |
| Baseline BMI | 0 to <2 Years (n = 2084), HR (95% CI) | 2 to <5 Years (n = 2321), HR (95% CI) | 5 to <13 Years (n = 6373), HR (95% CI) | 13 to 18 Years (n = 3936), HR (95% CI) |
|---|---|---|---|---|
| Unadjusted | | | | |
|   Normal/underweight | Referent | Referent | Referent | Referent |
|   Overweight | 2.40 (19.7-2.92) | 4.40 (3.51-5.52) | 9.71 (8.28-11.39) | 9.57 (7.73-11.84) |
| Adjusted for sex and race | | | | |
|   Normal/underweight | Referent | Referent | Referent | Referent |
|   Overweight | 2.38 (1.95-2.90) | 4.56 (3.63-5.72) | 9.65 (8.23-11.32) | 9.69 (7.82-12.00) |

Abbreviations: BMI, body mass index; HR, hazard ratio.
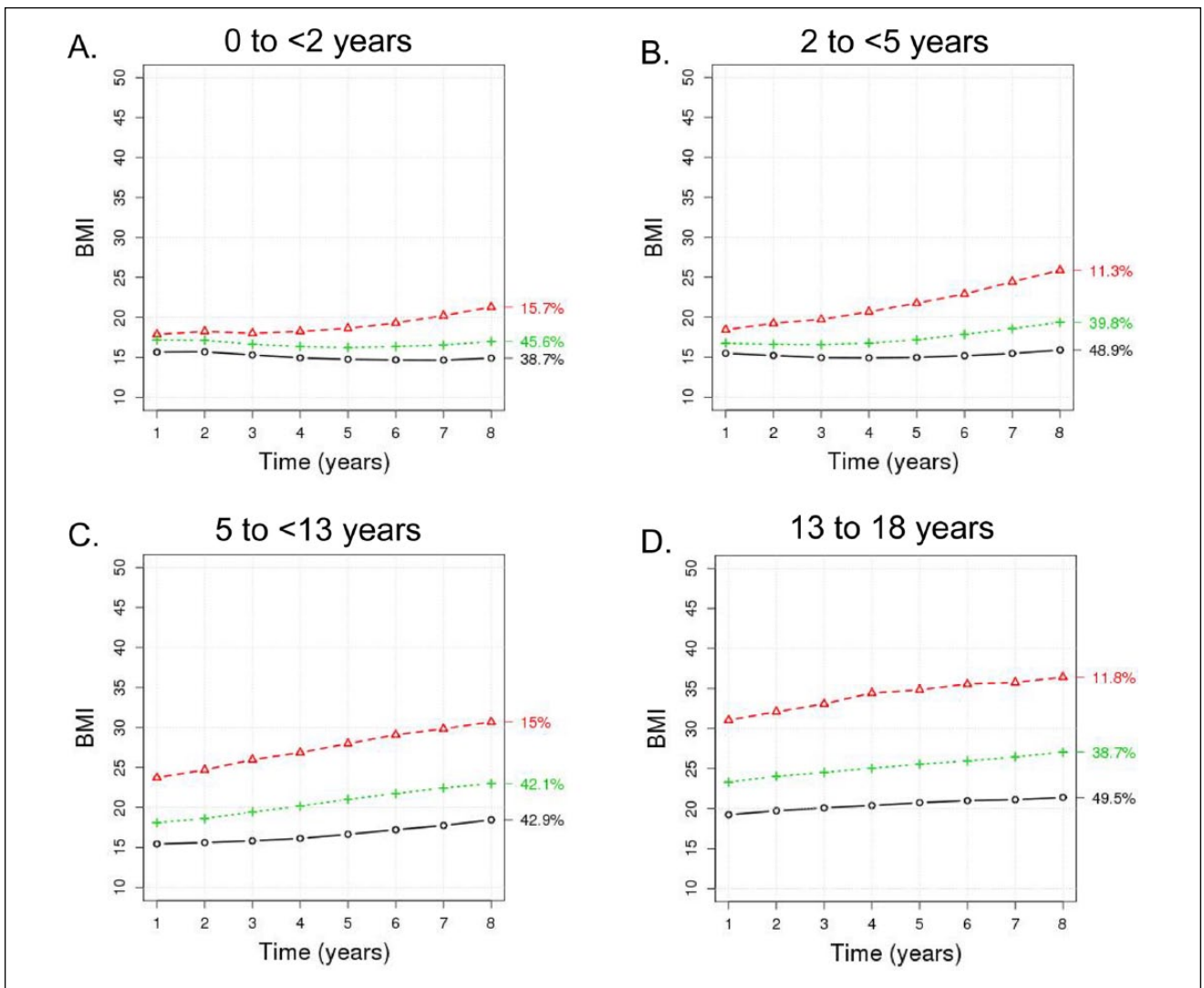[a] Analyses are stratified by baseline age group.



**Figure 2.** Body mass index (BMI) trajectory plots by age group.

trajectory of BMIs that increased during follow-up (Figure 2, panel B). A similar pattern was observed for children ≥5 years of age. Children in these age groups clustered in 3 distinct trajectories. Overall, 15% of the children 5 to <13 years at baseline clustered in a trajectory that increased over time (Figure 2, panel C), while approximately 11.8% of the children between 13 and 18 years stayed in an obese trajectory over time (Figure 2, panel D).

## Discussion

We observed that the risk of future obesity associated with currently being overweight increased dramatically with increasing age. We also observed that children of all ages can be grouped into distinct BMI trajectories. These findings underscore the critical need to offer effective dietary and physical activity interventions to children and adolescents who demonstrate increase in BMI or are overweight in addition to interventions targeting those who are obese.

Overweight children of all ages had a 2- to 10-fold increased risk of becoming obese over 8 years of follow-up compared to children with baseline BMI or weight for length in the normal or underweight categories. These data are consistent with previous studies that have indicated that children who are heavier at any age are at a higher risk of becoming obese during follow-up compared to normal weight children.[7,8,19,32]

Our data also show that the increased risk of obesity among children who are overweight is present at all ages; however, overweight older children are at a significantly higher risk for becoming obese compared to younger children. Children aged 5 years or older who were overweight had an approximately 10-fold increased risk of becoming obese compared with a 3- to nearly 5-fold increased risk in younger children. Furthermore, young children (<5 years) had very similar baseline BMIs, but BMI trajectories diverged during the 8 years of follow-up. In children aged 5 years or older, baseline BMIs differed more substantially across trajectories. Specifically, children ≥5 years who had higher BMIs at baseline tended to remain in a BMI trajectory that continued to increase over time. These data suggest that a child's BMI trajectory may be established prior to age 5 years, which is consistent with what has been found in previous population-based studies outside of the United States.[10,11,15,17,19] Additionally, we observed no significant differences in BMI trajectories between males and females, which is consistent with other studies of BMI trajectory in children.[16,17,19,25]

A prospective cohort study of 9699 children born in 2000-2002 from a national representative sample from the United Kingdom between ages 3 and 11 years found divergence from normal BMI trajectories by age 3 years in the obese group (3.1%) and age 5 years in the overweight (14.4%) group.[17] In addition, data from a longitudinal study of 2120 Canadian children born in 1997-1998 and followed between the ages of 5 months to 8 years indicated that children on a trajectory to obesity (4.5%) can be distinguished from children on a healthy weight trajectory as early as 3.5 years of age.[25] A European birth cohort study with 12050 subjects found that BMI trajectories were defined by 3 years of age and that 1.5% of children were in the rapid growth trajectory.[15] These BMI trajectory ages are similar to our study but the percentage of children categorized in the obesity trajectory varied from the 11% to 16% that we observed in our study. This variance could be due to the different populations studied or the different study time frames utilized. Our data likely reflect the more recent trends toward increasing levels of overweight and obesity, resulting in an increasing number of children in the high BMI trajectories.

When comparing with other BMI trajectory studies in US populations, our cohort is more recent than those recruited by Li et al[22] (1984-1990), O'Brien et al[23] (1991), and Kwon et al[24] (1992-1995) and involves a much larger population size. The findings from our population based cohort consisting of majority white children from the Midwestern United States are similar to those seen in primarily nonwhite, low-income urban population from Denver, Colorado.[25] We noted that the Hispanic children in our population were the most likely to be overweight or obese at baseline. However, we did not observe a significant interaction between race and baseline BMI, and the BMI trajectories of all of the children in our study followed very similar patterns over time. Our study may be limited by small number of racial/ethnic minorities. Further research is encouraged to explore racial and ethnic differences in BMI trajectories throughout childhood and adolescence.

Strengths of our study include the large sample size of children from a community sample with data on weight and height and availability of clinically measured rather than parent-reported weight and height measurements. However, our study has several study limitations. First, we did not have height and weight measurements on approximately 50% of our study population. However, the characteristics of children with and without BMI data were very similar, suggesting that our study sample represents the underlying Olmsted County population. Our study sample characteristics, which are 48.9% male, 29.2% ≤5 years of age, and 81.2% white, are representative of the 2005 US Census estimates for the Olmsted County population with 51.3% male, 26.4% ≤5 years of age, and 75.1% white.[33] Second, weights, heights, and lengths were obtained through standard clinical care; this approach is likely less rigorous than obtaining these measurements through a study protocol. Third, determining the number of BMI trajectories by statistical fit may not correctly estimate the true number of trajectories. However, our trajectories are very similar to those of trajectories observed in a Colorado Medicaid,[25] population and

multiple non-US populations.[13,15,17,19] These similarities suggest that similar BMI trajectories may also be observed in other communities. Fourth, use of BMI as a surrogate for adiposity may result in the misclassification of some children, particularly children of different races or ethnicities, as obese/overweight when they are not.[34] Fifth, we had a limited number of racial and ethnic minority children in our population, potentially limiting the generalizability of our results. Finally, we also did not adjust for socioeconomic variables that are important confounders for development of obesity. Adding socioeconomic status, though, would ideally require multiple measurements, since unlike sex and race, it can change over time.

We showed a 10-fold increased risk of obesity in later life among children who were overweight by age 5 years. Additionally, children at risk for obesity appear to enter a trajectory leading to obesity early in life. Our data therefore suggest that interventions for obesity may need to occur early in life to prevent children from entering unhealthy BMI trajectories. Future studies should evaluate risk factors influencing BMI trajectory in larger populations with more ethnic and racial diversity.

## Authors' Note

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health or the Center for the Science of Health Care Delivery.

## 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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