Association of Adolescent Obesity With Risk of Severe Obesity in Adulthood

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Context Although the prevalence of obesity has increased in recent years, individuals who are obese early in life have not been studied over time to determine whether they develop severe obesity in adulthood, thus limiting effective interventions to reduce severe obesity incidence and its potentially life-threatening associated conditions.

Objective To determine incidence and risk of severe obesity in adulthood by adolescent weight status.

Design, Setting, and Participants A cohort of 8834 individuals aged 12 to 21 years enrolled in 1996 in wave II of the US National Longitudinal Study of Adolescent Health, followed up into adulthood (ages 18-27 years during wave III [2001-2002] and ages 24-33 years during wave IV [2007-2009]). Height and weight were obtained via anthropometry and surveys administered in study participants’ homes using standardized procedures.

Main Outcome Measures New cases of adult-onset severe obesity were calculated by sex, race/ethnicity, and adolescent weight status. Sex-stratified, discrete time hazard models estimated the net effect of adolescent obesity (aged <20 years; body mass index [BMI] ≥95th percentile of the sex-specific BMI-for-age growth chart or BMI ≥30.0) on risk of severe obesity incidence in adulthood (aged ≥20 years; BMI ≥40.0), adjusting for race/ethnicity and age and weighted for national representation.

Results In 1996, 79 (1.0%; 95% confidence interval [CI], 0.7%-1.4%) adolescents were severely obese; 60 (70.5%; 95% CI, 57.2%-83.9%) remained severely obese in adulthood. By 2009, 703 (7.9%; 95% CI, 7.4%-8.5%) non–severely obese adolescents had become severely obese in adulthood, with the highest rates for non-Hispanic black women. Obese adolescents were significantly more likely to develop severe obesity in young adulthood than normal-weight or overweight adolescents (hazard ratio, 16.0; 95% CI, 12.4-20.5).

Conclusion In this cohort, obesity in adolescence was significantly associated with increased risk of incident severe obesity in adulthood, with variations by sex and race/ethnicity.
Given the lack of successful treatment options, risks associated with treatment, and numerous health consequences of severe obesity, primary prevention is critical.

Understanding which individuals are at risk of severe obesity is essential for determining when interventions would need to be implemented to prevent obese individuals from progressing to severe obesity. Although observational studies have reported that the prevalences of overweight, obesity, and severe obesity have increased in recent years,8,13 individuals who are obese early in life have not been studied longitudinally to determine their risk of developing severe obesity in adulthood. To this end, we used a US nationally representative, longitudinal cohort to determine the incidence and risk of severe obesity in adulthood among individuals who were obese during adolescence.

METHODS
National Longitudinal Study of Adolescent Health

The National Longitudinal Study of Adolescent Health (Add Health) is a cohort of adolescents (20,745 individuals aged 11-20 years at baseline; mean age, 15.9 years) drawn from a sample of 80 high schools and 52 middle schools in the United States with unequal probability of selection. Incorporating systematic sampling methods and implicit stratification into the Add Health study design ensured that this sample is representative of US schools in 1994-1995 with respect to region, urbanicity, school size, school type, and ethnicity.

Poststratification sample weights ensure that population estimates at each wave conform to population estimates from individuals eligible for each interview; thus, the respondents are representative of the US school population in grades 7 through 12 in 1994-1995 (wave I) as they are followed into adulthood. Wave II, conducted in 1996 (n=14,738; mean age, 16.5 years) included wave I adolescents still of school age by design (including those currently in high school and high school dropouts). Wave III, conducted in 2001-2002 (n=15,197; mean age, 22.3 years) and wave IV, conducted in 2007-2009 (n=15,701; mean age, 28.9 years) included all wave I respondents, regardless of wave II participation. The most recent data collection (wave IV) includes follow-up interviews from 15,701 wave I respondents drawn from 19,962 of the original 20,745 wave I respondents (exclusions: 96 deceased at wave III and 687 not sampled at wave III), with 80.25% of the eligible respondents (ineligible: 184 who moved out of the country, 87 military stationed out of the country, and 126 deceased at wave IV) consenting to participate in wave IV.

Written informed consent was obtained for all wave I participants. Survey procedures have been described elsewhere and were approved by the institutional review board at the University of North Carolina at Chapel Hill.16

Measures

Weight and height were measured in waves II through IV during in-home surveys using standardized procedures. Wave I used self-reported height and weight data, which were excluded from this analysis because the gain in 1 additional year of follow-up was not an acceptable trade-off for the error that would have been introduced with use of a combination of self-report (wave I) and measured (waves II-IV) height and weight data.

Body mass index (calculated as weight in kilograms divided by height in meters squared) and BMI percentiles from measured height and weight were derived for age and sex using the Centers for Disease Control and Prevention National Center for Health Statistics growth charts.17 Given that adolescent BMI (wave II; 1996) was not linearly associated with incident severe obesity, BMI was categorized using the recommended definitions for comparability across adolescence and adulthood.18 These categories were defined as: (1) normal weight (≥5th to <85th percentile on BMI-for-age growth chart or BMI of ≥18.5 to <25 for individuals aged <20 years; BMI of ≥18.5 to <25 for individuals aged ≥20 years); (2) overweight (≥85th to <95th percentile or BMI of ≥25 to <30 for individuals aged <20 years; BMI of ≥25 to <30 for individuals aged ≥20 years); (3) obesity (≥95th to <120% of 95th percentile or BMI of ≥30 to <40 for individuals aged <20 years; BMI of ≥30 to <40 for individuals aged ≥20 years); and (4) severe obesity (≥120% of 95th percentile for individuals aged <20 years19; BMI of ≥40 for individuals aged ≥20 years). Respondents who exceeded scale capacity (for wave III: 330 lb [148.5 kg] [n=12]; for wave IV: 440 lb [198 kg] [n=2]) were classified as severely obese. Incident severe obesity in adulthood was classified as nonsevere obesity at adolescence (wave II) and severe obesity at adulthood (wave III or IV; 2001-2009).

Age was recorded as the respondent’s age on the date of examination. Age at onset of severe obesity was defined as age at the wave in which the individual was initially classified as severely obese. We observed a nonlinear relationship between age at onset of severe obesity and development of severe obesity in young adulthood; thus, we categorized age at onset of severe obesity as younger than 20 years (reference), 20 to 24.9 years, 25 to 29.9 years, and 30 years or older.

Consistent with previous Add Health research,20,21 race/ethnicity was obtained from a combination of in-home surveys from parents and adolescents and was categorized as non-Hispanic white, non-Hispanic black, Hispanic (Cuban, Puerto Rican, Central/South American, Mexican, or other Hispanic), or Asian American (Chinese, Filipino, or other Asian).

Statistical Analyses

Statistical analyses were conducted using Stata software, version 10.1 (Stata Corp, College Station, Texas). To account for Add Health’s stratified sampling strategy, clustered sampling design, and nonresponse bias,22,23 sample weights and survey analysis techniques were used in all analyses. All results are nationally representative of adolescents who were enrolled in grades.
ADOLESCENT OBESITY AND RISK OF SEVERE ADULT OBESITY

7 through 12 in 1994 and followed up into adulthood.

For descriptive analyses, percentages were calculated for categorical variables, while means were calculated for continuous variables. To compare individuals with incident severe obesity with individuals without severe obesity, a 2-sided t-test and F-statistic were used to test for statistical differences (P < .05). Incidence rates of severe obesity during the transition from adolescence to adulthood were calculated by sex, race/ethnicity, and adolescent weight status (normal, overweight, and obese). A 2-sided F-statistic was used to compare the incidence of severe obesity by these categories, and the Bonferroni correction (P = .0167) was applied for multiple comparisons.

Discrete time hazard models (with a complementary log-log link), a type of a survival analysis model appropriate when the outcome is ascertained at periodic measurements, were used to determine the relationship between adolescent obesity and incidence of severe obesity in adulthood. Given the relatively low incidence of severe obesity in individuals who had normal weight as adolescents, the 3 categories used to obtain absolute incidence rates (normal weight, overweight, and obese) were condensed to 2 categories, obese vs nonobese (ie, collapsing normal weight and overweight into the nonobese category) for the hazard analyses. Given the particular discrete time interval based on the examination dates and obesity data, models were conditioned on time as a unit of analysis, with age at the examination during which severe obesity was first recorded serving as the primary time variable in all models. Age-specific hazard ratios (incidence rate ratios) were calculated for the probability of becoming severely obese during a given age range, conditioned on no severe obesity at the beginning of that interval. Discrete time hazard models assume that once individuals become severely obese, they remain severely obese and, thus, while included in models, they no longer contribute to the analysis.

The hazard models included only race and sex to provide net effects of risk rather than causal modeling of these relationships. Thus, a parsimonious model was used to describe the relationship between adolescent obesity (vs nonobesity) and risk of severe obesity in adulthood. To determine whether the relationship between adolescent obesity and severe obesity risk varied by sex and race/ethnicity, a 3-way interaction was used to examine effect modification using Wald tests (P = .10). Despite borderline significance (P = .14), differences in the associations across race/ethnicity are clinically important given the racial/ethnic disparities in the prevalence of obesity and its comorbidities. Thus, final models were sex-stratified and included interactions between adolescent obesity and race/ethnicity. Additionally, effect measure modification by age at severe obesity onset with adolescent obesity and race/ethnicity. Additionally, effect measure modification by age at severe obesity onset with adolescent obesity and race/ethnicity was tested, but neither showed effect modification.

RESULTS

Data from the initial 14 738 participants measured at wave II (Figure) were included in the analytic sample frame, with a total of 29 476 observations spanning 1996 (wave II) to 2009 (wave IV), excluding participants of Native American race/ethnicity (n = 45); individu-

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Figure. Flow of Current Analytical Sample in the National Longitudinal Study of Adolescent Health

<table>
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<tr>
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<tr>
<td>20 745 US adolescents in grades 7-12 in a nationally representative sample (ages 11-20 y; mean, 15.9 y)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14 738 Wave I respondents still of school age, including school dropouts (ages 12-21 y; mean, 16.5 y)</td>
<td>15 197 Wave I respondents regardless of wave I participation (ages 18-27 y; mean, 22.3 y)</td>
<td>15 701 Wave I respondents regardless of wave II or III participation (ages 23-32 y; mean, 28.9 y)</td>
</tr>
<tr>
<td>5904 Excluded: Excluded at wave II</td>
<td>5468 Excluded at wave II</td>
<td>3699 Missing sampling weights&lt;sup&gt;b&lt;/sup&gt;</td>
<td>45 Native Americans</td>
</tr>
<tr>
<td>699 Missing height/weight measurements</td>
<td>46 Missing height/weight measurements</td>
<td>74 Missing race/ethnicity</td>
<td>1381 Underweight at wave II</td>
</tr>
<tr>
<td>144 Pregnant girls/women at wave II</td>
<td>436 Excluded at wave III or IV (missing height/weight measurements at wave III or IV)</td>
<td>79 Severely obese at wave II</td>
<td></td>
</tr>
<tr>
<td>8834 Included in final analytic sample (all respondents with height and weight measured at least twice [at wave II and at wave III and/or IV])</td>
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<sup>a</sup> Wave I participants not included in the current analysis because it used self-reported height and weight data.

<sup>b</sup> Cases added in the field, selected as part of a paired subsample, or without a sample flag.
als missing sampling weights (needed to correct for nonresponse bias and sample design) (n = 3699), height and weight data at wave II (n = 46) or wave III or 4 (n = 436), or race/ethnicity (n = 74); individuals who were underweight (because the amount of weight gain necessary to shift from underweight to severe obesity in the 13-year time frame of the study could indicate a different phenotype or surrogate for other metabolic conditions) (n = 1381); and girls/women who were pregnant at baseline (n = 144). Given interest in incident severe obesity, individuals who were already severely obese at baseline (n = 79 [1.0%; 95% confidence interval [CI], 0.7%-1.4%]) were excluded; these 79 individuals were more likely to be racial/ethnic minorities than participants included in the analytic sample and most (n = 60 [70.5%; 95% CI, 57.2%-83.9%]) remained severely obese in adulthood (result not shown).

The final analytic sample included all available exposure, outcome, and covariate data across waves II, III, and IV, totaling 15 598 observations across 8834 individuals. The analytic sample included significantly more whites, older individuals, and individuals of higher parental education than those excluded. However, inverse probability weighting showed no evidence of selection bias by these factors in final models.

Over the 13-year period between adolescence (1996) and adulthood (2007-2009), a total of 703 incident cases of severe obesity in adulthood were observed, indicating a total incidence rate of 7.9% (95% CI, 7.4%-8.5%) (Table 1). Individuals with incident severe obesity in adulthood had a higher adolescent BMI, were older, and were more likely to be racial/ethnic minorities compared with individuals without severe obesity.

A substantial proportion of obese adolescents became severely obese by their early 30s, with significant variation by sex (Table 2). Among individuals who were obese as adolescents, incident severe obesity was 37.1% (95% CI, 30.6%-43.6%) in men and 51.3% (95% CI, 44.8%-57.8%) in women. Incident severe obesity was highest among black women at 52.4% (95% CI, 40.9%-63.8%). Across all sex and racial/ethnic groups, less than 5% of individuals who were at a normal weight in adolescence became severely obese in adulthood.

In analysis using multivariate, discrete hazard models, obese adolescents were significantly more likely to develop severe obesity than normal-weight or overweight adolescents (hazard ratio, 16.0; 95% CI, 12.4-20.5), with variation across race/ethnicity and sex (Table 3). While the hazard ratio for men was higher than for women, the incidence of severe obesity in adulthood was higher among women (51.3%; 95% CI, 44.8%-57.8%) than men (37.1%; 95% CI, 30.6%-43.6%). Thus, the male-female differences in risk must be interpreted relative to the difference in rates of incidence.

### TABLE 1

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>No Severe Obesity</th>
<th>Incident Severe Obesity</th>
<th>No Severe Obesity</th>
<th>Incident Severe Obesity</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI, mean (SD)</td>
<td>22.7 (2.2)</td>
<td>28.8 (3.8)</td>
<td>22.7 (3.2)</td>
<td>29.1 (3.8)</td>
</tr>
<tr>
<td>Overweight, % (SE)</td>
<td>18.0 (0.6)</td>
<td>25.6 (2.4)</td>
<td>17.6 (0.4)</td>
<td>26.6 (1.7)</td>
</tr>
<tr>
<td>Obese, % (SE)</td>
<td>6.4 (0.4)</td>
<td>57.6 (2.8)</td>
<td>6.3 (0.3)</td>
<td>57.9 (1.9)</td>
</tr>
</tbody>
</table>

**Abbreviation:** BMI = body mass index, calculated as weight in kilograms divided by height in meters squared.

**Sample size:** 8834 individuals with measurements in adolescence (wave II [1996; aged 12-21 years]) and in adulthood (wave III [2001-2002; aged 18-27 years] and wave IV [2007-2009; aged 24-33 years]). Results were weighted for national representation and standard errors were corrected for multiple stages of cluster sample design and unequal probability of selection. Longitudinal severe obesity status is defined for adolescents (<=20 years) as BMI of 25 to 30 (wave II); BMI of 30 and greater (wave III and IV). Results were weighted for national representation and standard errors were corrected for multiple stages of cluster sample design and unequal probability of selection.

**Significant difference (P < .05) between individuals with severe obesity and individuals without severe obesity.

**Adolescent (<=20 years) overweight is defined using the 2000 CDC/NCHS growth chart age- and sex-specific BMI 95th percentile and for adults (>=20 years) as BMI of >=30.

**Adolescent (<=20 years) obesity is defined using the 2000 CDC/NCHS growth chart age- and sex-specific BMI 95th percentile and for adults (>=20 years) as BMI of >=30.

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Table 2. Incidence of Severe Obesity by Adolescent Weight Status, Stratified by Sex and Race/Ethnicity, National Longitudinal Study of Adolescent Health*

<table>
<thead>
<tr>
<th>Adolescent Weight Status</th>
<th>Incidence, % (95% Confidence Interval)</th>
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<tbody>
<tr>
<td></td>
<td>Overall</td>
</tr>
<tr>
<td>Male, %</td>
<td>6.3 (5.2 to 7.4)</td>
</tr>
<tr>
<td>White</td>
<td>6.2 (4.8 to 7.5)</td>
</tr>
<tr>
<td>Black</td>
<td>7.8 (5.5 to 10.1)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>6.7 (3.8 to 9.6)</td>
</tr>
<tr>
<td>Asian*</td>
<td>1.3 (−0.2 to 2.8)</td>
</tr>
<tr>
<td>Female, %</td>
<td>9.5 (8.3 to 10.7)</td>
</tr>
<tr>
<td>White</td>
<td>8.3 (6.9 to 9.7)</td>
</tr>
<tr>
<td>Black</td>
<td>15.3 (12.2 to 18.3)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>8.8 (6.1 to 11.6)</td>
</tr>
<tr>
<td>Asian*</td>
<td>7.8 (5.0 to 16.1)</td>
</tr>
</tbody>
</table>

*Sample consists of 8834 individuals with measurements in adolescence (wave II [1996; 13-21 years]) and in adulthood (wave III [2001-2002; 18-26 years] and wave IV [2007-2009; 24-33 years]). Incident severe obesity defined as individuals who became severely obese in young adulthood (waves III and IV). Results were weighted for national representativeness. Standard errors were corrected for multiple stages of cluster sample design and unequal probability of selection.

†Within adolescent weight status group, male-female differences are statistically significant (P < .05 by F statistic).

‡Data for Asians should be interpreted with caution because of small sample size.

§Within sex and adolescent weight status groups, white-Asian differences are statistically significant (P < .01 by F statistic with Bonferroni correction).

Within sex and adolescent weight status groups, white-black differences are statistically significant (P < .0167 by F statistic with Bonferroni correction).
In summary, data from a nationally representative, ethnically diverse longitudinal sample suggest a high incidence of severe obesity during the transition from adolescence to adulthood. The clinical implications of these observed trends are concerning given the comorbidities and chronic disease associated with severe obesity. Findings highlight the need for interventions prior to adulthood to prevent the progression of obesity to severe obesity, which may reduce severe obesity incidence and its potentially life-threatening consequences.

Author Contributions: Dr Gordon-Larsen had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.


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REFERENCES