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ORIGINAL ARTICLE

Cesarean section and the risk of overweight in grade 6 children

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Abstract We examined the relationship between cesarean section (C-section) and the risk of overweight and obesity in children in grade 6 (mean age, 11.92 years; standard deviation= 0.34). Data from phase I through phase III of the National Institute of Child Health and Human Development Study of Early Child Care and Youth Development were used. Children with complete data from 1991 through 2004 were included in this study (n=917). Multiple logistic regression analyses were used to adjust for potential confounding and to evaluate the association of C-section and childhood overweight and obesity. Compared to children delivered vaginally, children delivered by C-section had approximately twice the likelihood of being overweight (odds ratio (OR)=1.86, 95 % confidence interval (CI)=1.27–2.73) or obese (OR=1.87, 95 % CI=1.19–2.95). However, when examined according to sex, males delivered by C-section had an increased risk for being overweight (OR= 1.78, 95 % CI=1.01–3.12) and obese (OR=2.58, 95 % CI= 1.36–4.88), while females had an increased risk only for being overweight (OR=1.99, 95 % CI=1.17–3.39). Conclusion: C-section was associated with an increased risk of overweight and obesity in children in grade 6, but the relationship differed according to gender. Further longitudinal studies are warranted to examine the long-term effect of delivery mode on the risk of childhood overweight.

Keywords Cesarean section · Childhood overweight · Obesity

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Abbreviations

CATCH	Child and Adolescent Trial for Cardiovascular Health
CDC	Centers for Disease Control and Prevention
CI	Confidence interval
C section	Cesarean section
NICHD	National Institute of Child Health and Human Development
OR	Odds ratio
SAPAC	Self-Administered Physical Activity Checklist
SECCYD	Study of Early Child Care and Youth Development

Introduction

The prevalence of childhood overweight tripled from 1980 to 2000 in the USA [30]. Although surveillance data suggest that these rates may be slowing or leveling off [9, 29], childhood obesity remains an important public health concern due to the immediate and long-term health effects. Childhood obesity is associated with an increased risk for high cholesterol and high blood pressure [11], prediabetes [6, 23], sleep apnea [39], and psychosocial problems [7]. Childhood obesity also increases the likelihood that the child will be obese as an adult [10, 37] with an increased risk for heart disease, type 2 diabetes, stroke [28], and numerous cancers [22].

Effective strategies are needed to confront the global obesity epidemic. One possible strategy is to identify modifiable risk factors that occur during the perinatal stage [12]. Over the past two decades, there has been a marked increase in the rates of cesarean sections (C-sections) worldwide [4]. In many middle- and upper-income countries, C-sections are increasing and may eventually surpass vaginal births as the primary delivery mode. For example, in the USA, Huh and colleagues reported that C-sections increased by 11.3 %

between 1996 and 2007 [16] and accounted for approximately one in three births [15, 19], whereas in other countries, this rate has increased to half of all births [25]. Studies have associated the increase in cesarean deliveries to the mothers' preference because they fear of having an adverse experience with vaginal birth, such as vaginal tearing or an emergency C-section [16, 25]. These procedures are also often needed to reduce or eliminate the potential for medical complications during vaginal births. Yet, there is mounting evidence that the increasing C-section rates may have adverse effects on offspring that persist into adulthood [5, 8, 42]. To our knowledge, few studies have investigated the relationship between delivery mode and the risk of childhood overweight and obesity. Among those studies that do exist, findings have been inconsistent [1, 2, 16]. The purpose of this study is to examine the association of C-section and the risk of childhood overweight and obesity among students in grade 6.

Methods

Data source and participants

Data were obtained from phase I to phase III of the National Institute of Child Health and Human Development (NICHD) Study of Early Child Care and Youth Development (SECCYD), one of the most comprehensive studies of children, and the contexts of their development were conducted in the USA. During phase I (1991–1994), a cohort of 1,364 children and their families were recruited at 1 month of age and studied intensively through age 3. During phase II (1995–1999), 1,226 of the enrolled children and their families were followed through first grade. During phase III (2000–2004), 1,061 of the enrolled children and their families continued to have follow-up through sixth grade. More information can be found at http://www.nichd.nih.gov/research/supported/Pages/seccyd.aspx or elsewhere [26]. Only subjects followed from birth to grade 6 (with complete data on weight status, C-section, and covariates) from phase I through phase III for the years 1991 to 2004 were included in this study (n=917). The average age of these included children in grade 6 was 11.92 years (standard deviation=0.34). The study was approved by the Institutional Review Boards of all participating institutions.

Variables

Childhood overweight and obesity

Overweight and obesity measures were defined according to the Centers for Disease Control and Prevention (CDC) growth charts [21] for body mass index (BMI), with overweight (including obesity) defined as ≥85th percentile and obesity as ≥95th percentile. Both overweight and obesity were expressed as dichotomized variables. Standardized procedures were used to measure height and weight during the interviews by NICHD SECCYD staff. Height was measured with children without shoes who were standing, feet together, and their backs against a calibrated 7-ft measuring stick. Weight was measured using a physician's two-beam scale. Scales were calibrated monthly using certified calibration weights. Weight was measured with children in minimal clothing and recorded twice, each time to the nearest 0.25 lb (0.1 kg). This study followed the same children from birth through grade 6. We used data on BMI values from when the children were in grade 6 as outcome variables.

C-section

Home visit interviews were conducted with the mothers when the child was 1 month old. Delivery modes were determined by asking mothers the question, "What type of delivery did you have?" Response options included vaginal delivery, planned C-section, and emergency C-section. In our study, delivery mode was dichotomized as C-section and vaginal delivery due to small sample size.

Covariates

Maternal factors were collected during a maternal interview conducted when the child was 1 month old. These covariates included maternal age in years, education (bachelor's degree or above, less than a bachelor's degree), poverty (above poverty line, at or below poverty line), living status (living single, not living single), depression (depressed, not depressed), breastfeeding status (breastfeeding, not breastfeeding), and smoking during pregnancy (smoked, not smoked). The poverty threshold for a household was determined by the year the income was earned, the total number of members in the household, and the number of full-time children living in the home. The income-to-needs ratios were based on the total family income and calculated as an indicator of socioeconomic status. If the ratio of income to needs was less than 1, households were considered below poverty level, while households with 1 and above were considered at or above poverty level. Maternal depressive symptoms were measured using the Center for Epidemiologic Studies Depression Scale (CES-D). The CES-D provides an index of depressive symptoms and has a high internal reliability (Cronbach's alpha=0.878). The scores can range from 0 to 60 with higher scores representing higher levels of depressive symptoms. In our study, mothers who scored 16 or higher on the CES-D scale were considered to have clinically significant depressive

symptoms [35]. Breastfeeding status was determined by asking mother whether they were currently breastfeeding at the visit when the child was 1 month of age. Child factors determined included sex, ethnicity, birth weight, and behavioral characteristics such as physical activity in hours, index of healthy eating habits, and total daily television (TV) viewing time in hours. The child's sex, ethnicity, and birth weight were reported by the mother during interviews either at the first hospital visit at the time of the child's birth or at the first study home visit when the child was 1 month old. The sample sizes for individual ethnic minority groups were not large enough to allow separate subgroup analyses; thus, ethnicity was dichotomized into White and non-White. The total number of minutes of physical activity ranged from 0 to 515 min (equal to 8.58 h) and was computed on the most recent day of school from the Self-Administered Physical Activity Checklist (SAPAC) that was developed for use in the Child and Adolescent Trial for Cardiovascular Health (CATCH) multisite school-based health promotion study [34]. During the sixth grade, children were asked to complete a questionnaire designed to assess dietary choices. The items on eating habits were slightly modified from the Youth Risk Behavior Survey. Index of healthy eating habits was computed as sum of the responses to four items including: "# times drink fruit juice," "# times eat raw vegetables," "# times eat cooked vegetables," and "# times eat fruit;" the index ranged from 0 to 12 with higher scores indicating more healthy eating habits (Cronbach's alpha=0.56). Total daily TV time ranged from 0 to 510 min (equal to 8.5 h) and was computed as the sum of before and after school minutes of TV/video watching from SAPAC.

Statistical analysis

Chi-squared (χ^2) or *t* tests were used to compare the characteristics of participants in the analytic sample (n=917) with the characteristics of subjects in the excluded sample (n=447). χ^2 tests were also used to determine significance for categorical variables (expressed in frequencies with percentage values), and *t* tests were used to determine the significance for continuous variables (expressed as mean ± standard deviation). Univariate analyses were conducted to examine the relationship between maternal/child factors and childhood overweight/obesity. Factors whose *p* values were less than 0.20 were considered as potential confounders. Multiple logistic regression analyses were used to adjust for potential

Table 1 Comparison of participants characteristics in the analytic sample versus excluded sample, NICHD SECCYD, 1991–2004 (N=1,364)

Characteristics	Analytic sample n=917	Excluded sample n=447	p value[a]
Delivery mode			0.427
Cesarean delivery	186 (20.3)	99 (22.2)	
Vaginal delivery	731 (79.7)	348 (77.9)	
Maternal factors			
Education			0.001
Below bachelor	564 (61.5)	317 (71.1)	
Bachelor or above	353 (38.5)	129 (28.9)	
Poverty			<0.0001
Below poverty line	152 (17.7)	121 (29.3)	
At or above poverty line	708 (82.3)	292 (70.7)	
Family structure			0.012
Living single	118 (12.9)	80 (18.0)	
Not living single	798 (87.1)	365 (82.0)	
Smoking during pregnancy			0.002
Yes	147 (16.7)	77 (24.8)	
No	732 (83.3)	233 (75.2)	
Child factors			
Birth weight (g), mean ± SD	3,495.6±511.7	3,477.0±496.2	0.524
Sex			0.006
Female	467 (50.9)	192 (43.0)	
Male	450 (49.1)	255 (57.1)	
Race			0.424
White	174 (19.0)	93 (20.8)	
Non-White	743 (81.0)	354 (79.2)	

Totals may not equal 100 % because of rounding

SD standard deviation, *NICHD SECCYD* National Institute of Child Health and Human Development Study of Early Child Care and Youth Development

[a] *p* value was from a chi-squared (χ^2) test or *t* test. χ^2 tests were used to determine significance for categorical variables (expressed in frequencies with percentage values), and *t* tests were used to determine the significance for continuous variables (expressed as mean ± SD)

confounding and to evaluate the association of C-section and overweight and obesity for children in grade 6. We also examined the association separately for male and female children. Results included 95 % confidence intervals, and p values less than 0.05 were considered statistically significant. All analyses were performed using SAS, version 9.2 (SAS, Inc., Cary, NC).

Results

Table 1 shows the characteristics of participants in the analytic sample, and these are compared to those of subjects that were excluded due to incomplete. Excluded mothers were more likely to have less than a bachelor's degree (p=0.001), live below the poverty line (p<0.0001), live single (p=0.012), and smoke during pregnancy (p=0.002). There was no significant difference for C-section between the analytic sample and excluded subjects. With respect to child characteristics, there were no significant differences between the analytic and excluded samples, except for sex (50.9 vs. 43.0 % female, respectively, p=0.006).

Univariate analyses of the associations of delivery mode and maternal and child factors for both childhood overweight and obesity are shown in Table 2. A total of 186 children (20.3 %) were delivered by C-section. Children delivered by C-section, compared to vaginal delivery, were significantly more likely to be overweight (41.4 vs. 32.2 %) and obese (24.7 vs. 17.0 %) (both p<0.05). Children of mothers who were younger, had less than a bachelor's degree, lived single, were depressed, not breastfeeding, and smoked during pregnancy or children who were non-White and had higher birth weight were at an increased risk for being overweight (all p<0.05) and obese (all p<0.05, except for those who smoked during pregnancy). In addition, children who had more

Table 2 Childhood overweight and obesity according to maternal and child characteristics, NICHD SECCYD, 1991–2004 (n=917)

	Childhood overweight (n=312)			Childhood obesity (n=170)		
	n (%) or median (range)	OR (95 % CI)	p value[a]	n (%) or median (range)	OR (95 % CI)	p value[a]
Delivery mode						
Cesarean section	77 (41.4)	1.49 (1.07–2.08)	0.018	46 (24.7)	1.61 (1.09, 2.36)	0.016
Vaginal delivery	235 (32.2)	Referent		124 (17.0)	Referent	
Maternal factors						
Age (years)	28.0 (18.0–46.0)	0.95 (0.93, 0.98)	0.0002	28.0 (18.0–43.0)	0.95 (0.92, 0.98)	0.001
Less than a bachelor's degree	222 (39.4)	1.90 (1.42, 2.54)	<0.0001	128 (22.7)	2.17 (1.49, 3.17)	<0.0001
At or below poverty line	59 (38.8)	1.36 (0.95, 1.96)	0.095	33 (21.7)	1.35 (0.87, 2.07)	0.179
Living single	51 (43.2)	1.57 (1.06, 2.32)	0.025	30 (25.4)	1.60 (1.02, 2.52)	0.041
Depressed	91 (40.1)	1.42 (1.04, 1.94)	0.027	54 (23.8)	1.55 (1.07, 2.23)	0.020
Breastfeeding	167 (29.4)	0.58 (0.44, 0.77)	0.0001	86 (15.1)	0.56 (0.40, 0.78)	0.001
Smoking during pregnancy	63 (42.9)	1.61 (1.12, 2.31)	0.010	34 (23.1)	1.45 (0.94, 2.22)	0.091
Child factors						
Male	160 (35.6)	1.14 (0.87, 1.50)	0.337	94 (20.9)	1.36 (0.97, 1.90)	0.073
Non-White	77 (44.3)	1.72 (1.23, 2.40)	0.002	43 (24.7)	1.59 (1.07, 2.36)	0.021
Birth weight (kg)	3.5 (2.0–5.4)	1.47 (1.12, 1.92)	0.005	3.6 (2.0–5.4)	1.79 (1.29, 2.48)	0.001
Physical activity daily (h)[b]	1.3 (0–8.6)	1.04 (0.94, 1.16)	0.465	1.3 (0–8.6)	1.04 (0.91, 1.18)	0.575
Index of healthy eating habits[c]	3.0 (0–11.0)	1.01 (0.96, 1.07)	0.710	3.0 (0–11.0)	1.03 (0.96, 1.11)	0.354
Total TV time daily (h)[d]	1.0 (0–8.5)	1.15 (1.03, 1.29)	0.015	1.3 (0–8.5)	1.13 (0.99, 1.29)	0.072

OR odds ratio, *CI* confidence interval, *BMI* body mass index, *NICHD SECCYD* National Institute of Child Health and Human Development Study of Early Child Care and Youth Development

[a] p value was from a chi-squared (χ^2) or t test. χ^2 tests were used to determine significance for categorical variables (expressed in frequencies with percentage values), and t tests were used to determine the significance for continuous variables (expressed as mean ± SD)

[b] The total number of minutes of physical activity ranged from 0 to 515 min daily (equal to 8.58 h) and was computed from the SAPAC that was developed for use in the CATCH multisite school-based health promotion study [34]

[c] Index of healthy eating habits was computed as sum of the responses to four items including no. time eat/drink fruit juice, no. times eat/drink raw vegetables, no. times eat/drink cook vegetables, and no. times eat/drink fruit; the index ranged from 0 to 12 with higher scores indicating more healthy eating habits

[d] Total TV time ranged from 0 to 510 min daily (equal to 8.5 h) and was computed as the sum of before and after school minutes of TV/video watching from the SAPAC

total TV watching time in hours daily were more likely to become overweight.

Multiple logistic regression analyses of the association between C-section and the risk of childhood overweight and obesity in grade 6 are presented in Table 3. Compared to children delivered vaginally, children delivered by C-section had approximately twice the likelihood of being overweight (odds ratio (OR)=1.86, 95 % confidence interval (CI) 1.27–2.73) and obese (OR=1.87, 95 % CI 1.19–2.95). However, after examining the association separately by child sex, males delivered by C-section had an increased risk for being overweight (OR=1.78, 95 % CI=1.01–3.12) and obese (OR=2.58, 95 % CI=1.36–4.88), while females delivered by C-section had an increased risk only for being overweight (OR=1.99, 95 % CI=1.17–3.39).

Discussion

In this population-based cohort study of 917 mother–child dyads, delivery mode was found to be associated with the risk of both childhood overweight and obesity. However, the relationship between C-section and the risk of childhood overweight status varied by child sex. The observed relationship between C-section and childhood overweight and obesity may be due to adverse outcomes associated with delivery by C-section compared to vaginal delivery. C-section is correlated with increased susceptibility to certain pediatric comorbidities. For example, children delivered by C-section are more likely to develop respiratory (allergies and asthma), autoimmune (type 1 diabetes and celiac disease) [5, 8, 42], and endocrine disorders [16]. The presence of contact at birth with maternal vaginal microbes may compromise the offspring's immune system, leading to greater susceptibility to disease [27]. Infants born by C-section also exhibit a different intestinal microbiota composition in their digestive tracts that may persist into adulthood when compared to vaginally born infants [14, 40]. These obesogenic microbes may influence weight and contribute to higher rates of obesity [18, 24, 38]. For example, C-section-born children have lower counts of *Bifidobacteria* and higher counts of *Clostridium difficile* (a potential obesogenic microbiota) than vaginally delivered children [17, 33, 40].

The relationship between delivery mode and obesity has not been explored in depth. Among the few studies that do exist, the findings are inconsistent. Similar to our findings, a few studies have reported an increased prevalence of obesity among young adults and adolescents delivered by C-section

Table 3 Cesarean delivery and risk of childhood overweight and obesity in grade 6, NICHD SECCYD, 1991–2004 (n=917)

	Overall children		Males		Females	
	Overweight[a] OR (95 % CI)	Obesity[a] OR (95 % CI)	Overweight[a] OR (95 % CI)	Obesity[a] OR (95 % CI)	Overweight[a] OR (95 % CI)	Obesity[a] OR (95 % CI)
Delivery mode						
Cesarean section	1.86 (1.27–2.73)	1.87 (1.19–2.95)	1.78 (1.01–3.12)	2.58 (1.36–4.88)	1.99 (1.17–3.39)	1.41(0.72–2.76)
Vaginal delivery	Referent	Referent	Referent	Referent	Referent	Referent
Maternal factors						
Age (years)	0.97 (0.93–1.00)	0.96 (0.92–1.00)	0.96 (0.91–1.01)	0.96 (0.90–1.02)	0.97 (0.92–1.02)	0.96 (0.90–1.02)
Less than a bachelor's degree	1.51 (1.04–2.19)	1.85(1.14–2.99)	1.52 (0.88–2.63)	1.56 (0.80–3.06)	1.44 (0.85–2.42)	2.15 (1.06–4.35)
At or below poverty line	0.98 (0.59–1.64)	0.97 (0.52–1.80)	0.86 (0.42–1.78)	0.91 (0.39–2.15)	1.15 (0.54–2.48)	1.01 (0.40–2.55)
Living single	0.68 (0.34–1.34)	0.76 (0.34–1.69)	0.54 (0.22–1.35)	0.70 (0.24–2.00)	0.83 (0.29–2.38)	0.72 (0.20–2.56)
Depressed	0.98 (0.66–1.43)	1.02 (0.64–1.61)	1.09 (0.64–1.86)	1.27 (0.68–2.36)	0.86 (0.48–1.54)	0.82(0.39–1.71)
Breastfeeding	0.71 (0.50–1.00)	0.70 (0.46–1.06)	1.03 (0.62–1.70)	0.68 (0.37–1.23)	0.50 (0.31–0.81)	0.70 (0.38–1.28)
Smoking during pregnancy	1.13 (0.73–1.74)	0.91 (0.53–1.56)	0.80 (0.43–1.48)	1.02 (0.48–2.15)	0.92 (0.49–1.73)	1.24 (0.55–2.80)
Child factors						
Male	1.12 (0.81–1.55)	1.29 (0.87–1.91)	NA	NA	NA	NA
Non-White	1.56 (0.98–2.46)	1.23 (0.71–2.13)	1.85 (0.98–3.52)	1.35 (0.63–2.87)	1.28 (0.64–2.57)	1.10 (0.46–2.63)
Birth weight (kg)	1.64 (1.19–2.27)	1.94 (1.31–2.88)	1.83 (1.16–2.89)	2.84 (1.63–4.94)	1.49 (0.93–2.37)	1.30 (0.73–2.33)
Total TV time (h)[b]	1.12 (0.99–1.27)	1.12 (0.96–1.31)	1.08 (0.89–1.31)	1.11 (0.88–1.39)	1.16 (0.98–1.38)	1.11 (0.90–1.37)

OR odds ratio, *CI* confidence interval, *NA* not available, *NICHD SECCYD* National Institute of Child Health and Human Development Study of Early Child Care and Youth Development

[a] Adjusted for maternal factors (age, education, poverty, living status, depression, breastfeeding, and smoking during pregnancy) and child factors (sex, ethnicity, birth weight, and total TV time)

[b] Total TV time ranged from 0 to 510 min daily (equal to 8.5 h) and was computed as the sum of before and after school minutes of TV/video watching from the SAPAC

as compared to vaginal deliveries [3, 13, 16, 46]. In a recent prospective study, Huh and colleagues found that delivery by C-section doubled the odds of obesity at age 3 when compared to vaginally delivered children after controlling for maternal weight at the time of conception, gestational weight gain, and infant birth weight [16]. These findings are also similar to a longitudinal study of Brazilian children that reported higher odds of obesity among younger children delivered by C-section, although this increased risk did not persist into adolescence [3]. Other longitudinal studies [2, 3] found that delivery mode was not associated with overweight or obesity at any age among females but was found to predict overweight among male cohorts.

This study has several strengths. First, child's height and weight were measured with standardized procedures for calculating objective child's BMI. Second, the NICHD SECCYD had a relatively large sample size which increased the power of our study. Also, this national dataset included information on a broad range of social and health-related variables in a diverse population group which allowed adjustment for many potential confounders. The findings of our study contribute to the sparse evidence on the relationship between C-section and the risk of later childhood overweight and obesity.

As expected, our study had some limitations. It is important to note that our findings may have been influenced by childhood-associated birth cohort trends in obesity. In particular, our study found a considerably higher proportion of overweight and obese children. This finding may be due, in part, to the fact that for the older age groups, the BMI references in the CDC 2000 charts were derived from national surveys of US children as measured from 1963 to 1994 and not to measurements done in the year 2000 as was the case for the youngest age groups. Therefore, the findings may reflect secular trends in changes in BMI among older children when compared to younger cohorts. Despite this concern, the CDC 2000 growth charts provide one of the best reference data available for adiposity [20]. There is the possibility of selection bias due to incomplete data or loss to follow-up. One concern is that the participants in the analytic sample might have higher socioeconomic status and may be at a decreased risk of being overweight or obese [43]. However, no significant difference for delivery mode was found in the analytic and excluded samples. It is widely acknowledged that maternal birth weight and the subsequent alteration of the intrauterine environment are perinatal predictors of fetal growth, offspring BMI, and later obesity [31, 32, 36, 44, 45]. Higher maternal pregravid weight and excessive gestational weight gain have been linked to the delivery of large-for-gestational-age infants and an increased risk for childhood obesity [32, 41]. However, lack of information about these perinatal variables may result in residual confounding, which may explain part of the observed relationship. In addition, breastfeeding status could not be determined as exclusive breastfeeding or mixed breastfeeding due to lack of such information. Finally, the index used for the child's healthy eating habits had only a modest internal reliability indicating some misclassification of this variable.

Conclusions

Children delivered by C-section compared to those delivered vaginally were at an increased risk of being overweight or obese in grade 6. Males delivered by C-section were at an increased risk for being overweight and obese, while females delivered by C-section were at an increased risk for being overweight. Longitudinal studies are needed to examine the long-term effect of delivery mode on the risk of childhood overweight and obesity.

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Conflict of interest The authors have no disclosures of competing interests.

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