Childhood Health and Developmental Outcomes After Cesarean Birth in an Australian Cohort

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abstract

BACKGROUND AND OBJECTIVES: Concerns have been raised about associations between cesarean delivery and childhood obesity and asthma. However, published studies have not examined the long-term neurodevelopmental outcomes or fully addressed confounding influences. We used data from the LSAC (Longitudinal Study of Australian Children) to explore the relationship between cesarean delivery and physical and socio-emotional outcomes from 0 to 7 years, taking into account confounding factors.

METHODS: Data were from 5 waves of LSAC representing 5107 children born in 2003 and 2004. Outcome measures included: global health, asthma, BMI, use of prescribed medication, general development, medical conditions and/or disabilities, special health care needs, and socio-emotional development. Models adjusted for birth factors, social vulnerability, maternal BMI, and breastfeeding.

RESULTS: Children born by cesarean delivery were more likely to have a medical condition at 2 to 3 years (odds ratio: 1.33; $P = .03$), use prescribed medication at 6 to 7 years (odds ratio: 1.26; $P = .04$), and have a higher BMI at 8 to 9 years (coefficient: 0.08; $P = .05$), although this last effect was mediated by maternal obesity. Parent-reported quality of life for children born by cesarean delivery was lower at 8 to 9 years (coefficient: –0.08; $P = .03$) but not at younger ages. Contrasting this finding, cesarean delivery was associated with better parent-reported global health at 2 to 3 years (odds ratio: 1.23; $P = .05$) and prosocial skills at age 6 to 7 years (coefficient: 0.09; $P = .02$).

CONCLUSIONS: Cesarean delivery was associated with a mix of positive and negative outcomes across early childhood, but overall there were few associations, and these were not consistent across the 5 waves. This study does not support a strong association between cesarean delivery and poorer health or neurodevelopmental outcomes in childhood.

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Dr Robson conceptualized the study, was involved in the design of the study and the interpretation of findings, provided content expertise, and was the primary author of the article; Drs Vally and Mohamed were involved in the design of the study, the interpretation of findings, and the drafting and revising of the manuscript; Ms Yu completed the data cleaning and analysis, and contributed to drafting the manuscript; Dr Westrupp led the funding application for the study and the data analysis for the paper, and co-drafted and revised the manuscript with Dr Robson; and all authors approved the final manuscript.

The contents of the published material herein are the sole responsibility of the authors and do not reflect the views of the National Health and Medical Research Council. They should also not be attributed to the Australian Government Department of Social Services, the Australian Institute of Family Studies, or the Australian Bureau of Statistics.

www.pediatrics.org/cgi/doi/10.1542/peds.2015-1400

DOI: 10.1542/peds.2015-1400

Accepted for publication Aug 12, 2015

WHAT'S KNOWN ON THIS SUBJECT: A number of studies have reported an association between birth by cesarean delivery and adverse childhood health outcomes such as obesity, asthma, atopy, and a number of neurodevelopmental abnormalities. However, these studies have had limited capacity to control for confounders.

WHAT THIS STUDY ADDS: Using a prospective cohort while controlling for birth factors, social vulnerability, maternal BMI, and breastfeeding, we found few differences between children delivered by cesarean delivery and those born vaginally. Higher child BMI was explained by maternal BMI.

Cesarean delivery is now 1 of the most common operations in both developed and developing countries,[1,2] and concerns have been raised about possible associations between it and a number of adverse childhood health outcomes.[3–6] For example, studies have reported that children born by cesarean delivery may have increased rates of respiratory illness in their first year of life[5,7,8] and beyond,[9,10] and relationships have also been described with diabetes[11] and child overweight and obesity.[12,13]

Notwithstanding these potential adverse associations, children born by cesarean delivery are usually healthy, and it is important to recognize that many factors influence child health other than mode of birth. Thus, an important limitation of many of the studies published to date is a lack of capacity to examine multiple physical and socio-emotional outcomes simultaneously across childhood, and to account for the large number of potential confounding influences. To address this current gap in the literature, we used 5 waves of data from the infant cohort of the LSAC (Longitudinal Study of Australian Children) to prospectively examine a broad range of children's outcomes from the first year of life until 9 years of age. Our goal was to test whether children born by cesarean delivery were more likely to have poor physical and socio-emotional outcomes compared with children born vaginally. In line with previous research findings,[10,12–14] we hypothesized that children born by cesarean delivery are more likely to experience asthma and allergies in their early years of life and have a higher BMI compared with their vaginally delivered peers.

METHODS

The LSAC is a nationally representative prospective study designed to study childhood growth and development.[15] Participating children were randomly selected in a 2-stage cluster sampling design, with Australian post codes as the primary sampling units and infants enrolled in the Medicare Australia database as the secondary sampling units. The LSAC was initiated by the Australian Federal Government and approved by the Australian Institute of Family Studies Ethics Committee. Further details regarding the study design and sample population can be found elsewhere.[16] Our study used data collected from the infant cohort across 5 waves, comprising 5107 families recruited in 2004. The cohort was broadly representative of Australian infants, although infants with more highly educated parents were overrepresented, whereas single parents, non–English-speaking families, and those living in rental properties were slightly underrepresented.

Data were collected by using face-to-face interviews and paper questionnaires (waves 1–3) or computer-assisted self-interview (waves 4 and 5) completed by the primary parent. Direct assessments of the children were conducted at ages 4 to 5 years (wave 3), 6 to 7 years (wave 4), and 8 to 9 years (wave 5). The cohort was recruited when children were aged 0 to 1 year (wave 1; 85% retention from eligible cohort) and were followed up at aged 2 to 3 years (wave 2; 90%), 4 to 5 years (wave 3; 86%), 6 to 7 years (wave 4; 82%), and 8 to 9 years (wave 5; 80% retention). Families were excluded from the present study if the child was in breech presentation at delivery (n = 67), where the mode of birth was indeterminate (n = 21), and where there was a multiple pregnancy (n = 165). Thus, 4865 children were included in the final study group.

All participating families provided written informed consent. Although the LSAC has overarching ethics approval, this particular study also received prospective approval from the Human Research Ethics Committee of the Australian Capital Territory Health Department.

Measures

Participant characteristics were collected via interview or questionnaire at wave 1 (child age 0–1 year) with information on maternal age, employment, education, and family composition (single-parent household versus other). Socioeconomic position was calculated from parental income, education, and occupational prestige[12]; families with a standardized score at or below the 25th percentile were classified as having a "low" socioeconomic position. Birth factors such as preterm birth, low birth weight, assisted ventilation, or intensive care required after birth, and whether the mothers were breastfeeding at 2 months, were also collected at wave 1. The cutoff point used for measuring breastfeeding was 2 months because some children in the study were aged <3 months at the time of assessment.

For physical outcome measures, children's global health, reported asthma, BMI, and use of prescribed medication were evaluated. Primary caregivers also reported their concerns about their child's general development, sleeping problems, medical conditions and/or disabilities, and whether their child had any special health care needs. Socio-emotional outcomes of children evaluated included temperament, social development, mental health, and quality of life. These measures are described in detail in Table 1.

Data Preparation

Analyses were conducted by using Stata version 13.1 (StataCorp, College Station, TX).[17] Variables were derived and imputed by using the survey methods procedure to weight the analyses for participants' unequal probability selection into the sample, and the multistage, clustered

TABLE 1 Measurement of Child Physical and Outcomes

Construct	Age	Source	Measure(s)
Physical health outcomes			
Special health care needs	0–1, 2–3, 4–5, 6–7, 8–9	P	1-item: whether child has a condition that has lasted or is expected to last at least 12 mo (yes = 1; no = 2).
Low global health	0–1, 2–3, 4–5, 6-7, 8-9	P	1-item: a 5-point Likert scale dichotomized for analysis to excellent/very good or good/fair/poor)[15] in response to the question: "In general, how would you say child's current health is?"
Reported asthma	0–1, 2–3, 4–5, 6–7, 8–9	P	1-item: whether child has ever been diagnosed as having asthma or taken medication for asthma in the last 12 mo (yes = 1; no = 2)
BMI	2–3, 4–5, 6-7, 8–9	D	Direct assessment of height and weight of child at time of interview. BMI was calculated and converted into age- and gender-specific *z* scores[34]
Use of prescribed medication	0–1, 2–3, 4–5, 6–7, 8–9	P	1-item: whether child has ever needed or used prescribed medication (yes = 1; no = 0)
Sleeping problems	0-1, 2–3, 4–5, 6–7, 8–9	P	1-item using a 4-point Likert scale dichotomized to not a problem at all/ small problem/a moderate problem/a large problem[15]; in response to the question "How much is child's sleeping pattern or habits a problem for you?"
Medical conditions/disabilities	0–1, 2–3, 4–5	P	1-item: whether child has any medical conditions or disabilities that have lasted or are likely to last for ≥6 mo (yes = 2; no = 1).
General development	0–1, 2–3, 4–5, 6–7	P	1-item: maternal concern about child's general learning, behavioral, and language development (concerned/little concerned = 1; not concerned = 0)
Socio-emotional outcomes			
Temperament	0-1	P	An abbreviated form of the Short Temperament Scale for Infants was used,[35] measuring 3 of the temperament dimensions: cooperation, irritability, and approach-sociability
Social development	2–3, 4–5, 6-7, 8-9	P	The BITSEA[36] was used when children were aged 2–3 y, with 10 items to assess children's social competence. The SDQ[37] was used when children were aged 4–5, 6–7 and 8–9 y; 5 items assessed prosocial behavior on a 3-point scale (not true = 1; somewhat true = 2; certainly true = 3).
Mental health	0–1, 2–3, 4–5, 6–7, 8–9	P	The BITSEA[36] was used when children were aged 2–3 y, with 8 items to assess children's internalizing problems and 8 items to assess children's externalizing problems. The 20 items of the SDQ were used to assess externalizing (hyperactivity and conduct problems) and internalizing problems (emotional symptoms and peer problems)
Quality of life	2–3, 4–5, 6-7, 8–9	P	19 items on the parent self-report questionnaire assessing children's overall quality of life. The items assessed physical development, emotional functioning, social functioning, and psychosocial health; on a 5 point scale (1 = never; 2 = almost never; 3 = sometimes; 4 = often; 5 = almost always)

BITSEA, Brief Infant-Toddler Social and Emotional Assessment; D, direct child assessments; P, parent-report measures; SDQ, Strengths and Difficulties Questionnaire.

sampling design. Multivariate multiple imputation was performed by using an iterative Markov Chain Monte Carlo method, with fully conditional specification. The augmented-regression option was used to handle perfect prediction, given the large number of categorical variables in our final models. Two imputation models were used to accommodate different sample sizes in the physical health and socio-emotional outcomes. The first model imputed physical health outcome variables, and the second model imputed the socio-emotional outcome variables. Wave 1 sample weights, cluster variables (post codes and strata), and control variables were entered as "regular" nonimputed variables into both imputation equations. Twenty-five imputations for each data set were requested and successfully produced.

Two sets of missing data comparisons were undertaken: (1) comparing participants included in the analytic sample (n = 4247) with excluded participants (n = 618); and (2) within the final analytic sample, participants with complete data (n = 1822) were compared with participants with missing data that required imputation (n = 2425). Excluded participants were 3 to 3.5 times more likely, and participants with imputed data were 2 times more likely, to have a low socioeconomic position. Excluded participants and participants with imputed data were both twice as likely to be a young mother (ie, aged <25 years) and to speak a language other than English, and both were also more likely to have 2 more children in the household and to live in relatively remote locations. Despite these differences in social characteristics, the pattern of results in the final analysis models did not change substantially across imputed and nonimputed data sets.

Statistical Analysis

Logistic and linear regression was used for analyses of categorical and continuous variables, respectively. Logistic regression analyses were conducted to assess the contribution of cesarean delivery to binary childhood physical health outcomes, with results presented as odd ratios with 95% confidence intervals. Linear regression analyses were conducted to investigate the associations of cesarean delivery with continuous outcome variables, including the children's BMI and socio-emotional outcomes, with results presented as standardized regression coefficients with 95% confidence intervals. A series of 4 adjusted models were run to test the contribution of 3 sets of risk factors separately (adjusted models 1–3) and then altogether (adjusted model 4). All tests were 2 tailed, and P values <.05 were regarded as statistically significant.

RESULTS

Participant Characteristics

Overall, 28.2% of the families in the study had children delivered by cesarean delivery, a rate very similar to the national rate of cesarean delivery in Australia (28.5%) during the recruitment period (calendar year 2004). Sample descriptive statistics of families in the cesarean delivery group (N = 1374), compared with vaginal births (N = 3491), are shown in Table 2. Children born by cesarean delivery were more commonly preterm, low birth weight, and were more likely to require intensive care or ventilator support. In terms of social factors, families in the cesarean delivery group were more likely to be in the lowest quartile for socioeconomic position, less likely to speak a language other than English at home, less likely to be a single-parent family, and less likely to have more children in the household. There were no differences between the groups in rates of parents born overseas, remote geographical location, or indigenous status.

Long-term Childhood Health Outcomes

Child physical health outcomes associated with cesarean delivery from birth to 9 years of age are shown in Table 3. There was no effect of cesarean delivery on parent-report of special health care needs up to 4 to 5 years of age. However, our fully adjusted model indicates that children born by cesarean delivery had 33% higher odds of having a medical condition or disability at age 2 to 3 years. This effect was largely consistent across the unadjusted and adjusted models at this age group but was not seen in the 4- to 5-year-old group. Cesarean delivery was also associated with lower parent-rated levels of poor global health when children were aged 2 to 3 years (wave 2); that is, children born via cesarean delivery were perceived by parents as having better health compared with the non–cesarean delivery reference group among 2- to 3-year-olds. However, this effect of cesarean delivery on global health was only present at aged 2 to 3 years and did not persist beyond this age group. Furthermore, this effect was lost when social vulnerability was added to the model for 2- to 3-year-olds, although the fully adjusted model continued to show an effect of cesarean delivery.

Children delivered by cesarean delivery had 26% higher odds of the use of prescribed medication at age 6 to 7 years. The effect for this age group persisted for all of the partially adjusted models and seemed to be a consistent effect size across all of the models. This effect also seemed to continue for children aged 8 to 9 years; however, in the fully adjusted model for this age group, this effect was not found to be statistically significant. There was no effect of cesarean delivery on maternal concerns regarding children's general development, mother-reported asthma, or sleeping problems.

There was an emerging effect evident from child age 6 to 7 years, whereby children born by cesarean delivery had higher BMI scores. The increase

TABLE 2 Sample Characteristics for Children Born via Cesarean Delivery or Non–Cesarean Delivery

Variable	Cesarean Delivery (N = 1374)	Non– Cesarean Delivery (N = 3491)	Relative Risk	P
	Proportion	Proportion		
Birth factors				
Instrumental delivery	1.00	0.11	9.1	NA
Preterm (<37 wk)	0.07	0.05	1.4	.01
Low birth weight (<2500 g)	0.05	0.04	1.2	.04
Child required intensive care after birth	0.22	0.13	1.7	<.001
Child required ventilator after birth	0.07	0.04	1.8	<.001
Social vulnerability factors				
Lowest quartile for socioeconomic position	0.29	0.24	1.2	.004
Language other than English	0.12	0.16	0.75	<.001
Mother aged <25 y	0.09	0.16	0.6	<.001
Single-parent family	0.09	0.11	0.8	.08
≥2 children in household	0.57	0.61	0.9	.005
Primary parent born overseas	0.19	0.20	0.95	.42
Remote/very remote location	0.03	0.04	0.75	.70
Indigenous status	0.03	0.04	0.75	.40

NA, not available.

TABLE 3 Physical Health Outcomes for Children Born via Cesarean Delivery, Across 4 Adjusted Models

Model	Cesarean Delivery Compared With Non–Cesarean Delivery (Reference Group)							
	Model 1		Model 2		Model 3		Model 4	
	Adjusted for Preterm, LBW, Use of Ventilator, Intensive Care After Birth		Adjusted for Social Vulnerability		Adjusted for Maternal BMI and Breastfeeding		Full Adjusted Model	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Special health care needs								
Wave 1 (0–1 y)	0.96 (0.72 to 1.29)	.80	1.08 (0.80 to1.45)	.62	1.02 (0.76 to 1.37)	.89	0.93 (0.69 to 1.25)	.61
Wave 2 (2–3 y)	1.04 (0.84 to 1.27)	.74	1.08 (0.87 to 1.33)	.49	1.03 (0.84 to 1.27)	.78	0.98 (0.79 to 1.21)	.85
Wave 3 (4–5 y)	1.03 (0.85 to 1.26)	.74	1.07 (0.88 to 1.30)	.50	1.01 (0.83 to 1.24)	.91	0.97 (0.79 to 1.18)	.74
Medical conditions/disabilities								
Wave 1 (0–1 y)	1.02 (0.74 to 1.40)	.92	1.20 (0.87 to 1.67)	.27	1.03 (0.75 to 1.41)	.87	1.00 (0.72 to 1.39)	.98
Wave 2 (2–3 y)	1.40 (1.09 to 1.80)	.01	1.52 (1.16 to 1.974	.002	1.39 (1.07 to 1.81)	.01	1.33 (1.02 to 1.74)	.03
Wave 3 (4–5 y)	1.12 (0.88 to 1.42)	.36	1.20 (0.93 to 1.54)	.16	1.14 (0.89 to 1.46)	.30	1.15 (0.89 to 1.48)	.29
Low global health								
Wave 1 (0–1 y)	0.94 (0.75 to 1.19)	.63	1.04 (0.82 to 1.32)	.74	0.92 (0.73 to 1.17)	.51	0.97 (0.76 to 1.24)	.83
Wave 2 (2–3 y)	0.78 (0.64 to 0.96)	.02	0.86 (0.70 to 1.05)	.13	0.80 (0.65 to 0.98)	.03	0.81 (0.66 to 1.00)	.05
Wave 3 (4–5 y)	0.91 (0.73 to 1.13)	.38	1.00 (0.80 to 1.25)	.99	0.91 (0.73 to 1.14)	.40	0.96 (0.77 to 1.20)	.74
Wave 4 (6–7 y)	1.06 (0.85 to 1.32)	.58	1.20 (0.96 to 1.50)	.11	1.04 (0.84 to 1.28)	.74	1.13 (0.90 to 1.42)	.31
Wave 5 (8–9 y)	0.98 (0.79 to 1.23)	.88	1.08 (0.86 to 1.36)	.50	0.92 (0.73. 1.15)	.47	1.00 (0.80 to 1.27)	.97
Prescribed medication								
Wave 1 (0–1 y)	1.19 (0.96 to 1.47)	.11	1.26 (1.02 to 1.57)	.04	1.18 (0.95 to 1.45)	.13	1.16 (0.93 to 1.44)	.19
Wave 2 (2–3 y)	1.06 (0.86 to 1.31)	.61	1.10 (0.89 to 1.37)	.38	1.03 (0.83 to 1.27)	.81	1.00 (0.80 to 1.24)	.98
Wave 3 (4–5 y)	0.92 (0.74 to 1.13)	.42	0.98 (0.79 to 1.22)	.86	0.90 (0.72 to 1.12)	.33	0.89 (0.71 to 1.11)	.30
Wave 4 (6–7 y)	1.30 (1.05 to 1.60)	.01	1.33 (1.08 to 1.64)	.008	1.30 (1.06 to 1.60)	.01	1.26 (1.01 to 1.56)	.04
Wave 5 (8–9 y)	1.31 (1.08 to 1.59)	.007	1.30 (1.07 to 1.58)	.008	1.26 (1.04 to 1.53)	.02	1.21 (0.99 to 1.48)	.07
Maternal concerns about general development								
Wave 1 (0–1 y)	1.09 (0.84 to 1.40)	0.53	1.23 (0.96 to 1.59)	0.11	1.19 (0.92 to 1.54)	0.18	1.18 (0.91 to 1.54)	0.21
Wave 2 (2–3 y)	0.88 (0.72 to 1.07)	.19	0.95 (0.78 to 1.16)	.60	0.90 (0.74 to 1.09)	.27	0.89 (0.73 to 1.08)	.24
Wave 3 (4–5 y)	1.04 (0.89 to 1.22)	.63	1.09 (0.92 to 1.28)	.31	1.03 (0.88 to 1.21)	.73	1.06 (0.90 to 1.24)	.50
Wave 4 (6–7 y)	0.97 (0.80 to 1.18)	.99	1.06 (0.88 to 1.28)	.54	1.00 (0.82 to 1.21)	.99	1.01 (0.83 to 1.23)	.89
Asthma								
Wave 1 (0–1 y)	0.77 (0.43 to 1.37)	.37	0.96 (0.53 to 1.74)	.89	0.73 (0.41 to 1.31)	.29	0.79 (0.44 to 1.41)	.42
Wave 2 (2–3 y)	0.89 (0.71 to 1.11)	.28	0.97 (0.78 to 1.21)	.80	0.85 (0.68 to 1.06)	.15	0.86 (0.69 to 1.08)	.19
Wave 3 (4–5 y)	0.96 (0.80 to 1.16)	.66	1.03 (0.85 to 1.23)	.78	0.93 (0.77 to 1.12)	.45	0.93 (0.77 to 1.12)	.42
Wave 4 (6–7 y)	0.99 (0.84 to 1.18)	.95	1.06 (0.89 to 1.25)	.53	0.97 (0.81 to 1.16)	.72	0.97 (0.81 to 1.15)	.69
Wave 5 (8–9 y)	1.03 (0.88 to 1.22)	.69	1.07 (0.91 to 1.26)	.40	1.01 (0.86 to 1.19)	.90	1.00 (0.85 to 1.18)	.99
Sleeping problems								
Wave 1 (0–1 y)	0.91 (0.77 to 1.06)	.22	0.93 (0.80 to 1.09)	.36	0.91 (0.78 to 1.06)	.24	0.94 (0.80 to 1.10)	.45
Wave 2 (2–3 y)	0.96 (0.83 to 1.12)	.63	1.00 (0.86 to 1.16)	.96	0.97 (0.84 to 1.13)	.71	0.99 (0.85 to 1.16)	.94
Wave 3 (4–5 y)	0.99 (0.85 to 1.16)	.95	1.05 (0.90 to 1.22)	.53	0.98 (0.84 to 1.14)	.77	1.02 (0.87 to 1.19)	.81
Wave 4 (6–7 y)	1.02 (0.76 to 1.37)	.88	1.06 (0.79 to 1.41)	.71	0.97 (0.72 to 1.30)	.84	1.00 (0.74 to 1.34)	.98
Wave 5 (8–9 y)	1.16 (0.87 to 1.54)	.31	1.19 (0.89 to 1.59)	.25	1.12 (0.84 to 1.50)	.45	1.13 (0.84 to 1.53)	.41
	Coef (95% CI)	*P*	Coef (95% CI)	*P*	Coef (95% CI)	*P*	Coef (95% CI)	*P*
BMI								
Wave 2 (2–3 y)	0.04 (−0.04 to 0.12)	.29	0.04 (−0.04 to 0.12)	.30	−0.01 (−0.09 to 0.07)	.81	−0.01 (−0.09 to 0.07)	.74
Wave 3 (4–5 y)	0.07 (−0.02 to 0.16)	.11	0.07 (−0.02 to 0.15)	.14	0.00 (−0.09 to 0.09)	.99	0.01 (−0.08 to 0.09)	.87
Wave 4 (6–7 y)	0.12 (0.05 to 0.19)	.001	0.13 (0.06 to 0.20)	.001	0.05 (−0.02 to 0.13)	.14	0.07 (−0.01 to 0.14)	.07
Wave 5 (8–9 y)	0.13 (0.05 to 0.22)	.002	0.15 (0.06 to 0.23)	.001	0.05 (−0.03 to 0.14)	.19	0.08 (0.00 to 0.16)	.048

Adjusted models: Model 1, child born preterm (<37 weeks of pregnancy) and/or low birth weight (<2500 g). Model 2, socioeconomic position, mother's language other than English, mother aged <25 years, and ≥2 children in household at wave 1 (child 0–1 year). Model 3, ventilator and/or intensive care required for child after birth. Model 4, includes variables from all 3 models. Coef (95% CI), standardized coefficients from linear regression analysis (with 95% confidence intervals [CIs]); OR (95% CI), odds ratio from logistic regression analysis (with 95% CIs).

was small on average (7%–15% of 1 SD for child BMI), and the effect was robust to adjustment for birth and social factors, but it was lost when maternal BMI and breastfeeding at wave 1 were taken into account.

Post-hoc mediation analysis (using the "sureg" command in Stata to enable analysis with multiply-imputed data, as per http://www.ats.ucla.edu/stat/stata/faq/mi_indirect2.htm) showed that maternal BMI (and not maternal breastfeeding) mediated the relationship between cesarean delivery and the child being overweight and obese, accounting for 62.9% of the total effect at child age 8 to 9 years.

TABLE 4 Socio-Emotional Outcomes for Children Born Via Cesarean Delivery, Across 4 Adjusted Models

Variable	Cesarean Delivery Compared With Non–Cesarean Delivery (Reference Group)							
	Model 1		Model 2		Model 3		Model 4	
	Adjusted for Preterm, LBW, Use of Ventilator, Intensive Care After Birth		Adjusted for Social Vulnerability		Adjusted for Maternal BMI and Breastfeeding		Full Adjusted Model	
	Coef (95% CI)	P	Coef (95% CI)	P	Coef (95% CI)	P	Coef (95% CI)	P
Temperament								
Irritability (0–1 y)	−0.05 (−0.13 to 0.03)	.23	−0.04 (−0.12 to 0.04)	0.33	−0.04 (−0.12 to 0.04)	.30	−0.03 (−0.12 to 0.05)	.42
Cooperation (0–1 y)	0.02 (−0.06 to 0.11)	.57	0.03 (−0.05 to 0.12)	0.47	0.00 (−0.08 to 0.09)	.98	0.01 (−0.08 to 0.10)	.85
Approachability/sociability								
Wave 1 (0–1 y)	0.03 (−0.05 to 0.11)	.47	0.02 (−0.06 to 0.10)	0.61	0.04 (−0.04 to 0.12)	.34	0.02 (−0.06 to 0.10)	.65
Wave 2 (2–3 y)	0.02 (−0.06 to 0.10)	.59	0.01 (−0.07 to 0.09)	0.82	0.03 (−0.04 to 0.11)	.39	−0.01 (−0.09 to 0.07)	.82
Wave 3 (4–5 y)	0.03 (−0.05 to 0.11)	.45	0.02 (−0.05 to 0.10)	0.57	0.02 (−0.05 to 0.10)	.56	0.01 (−0.07 to 0.09)	.82
Wave 4 (6–7 y)	0.05 (−0.02 to 0.13)	.17	0.04 (−0.04 to 0.11)	0.32	0.05 (−0.03 to 0.12)	.21	0.04 (−0.04 to 0.12)	.33
Persistence								
Wave 2 (2–3 y)	0.01 (−0.07 to 0.08)	.88	0.02 (−0.06 to 0.09)	.68	0.00 (−0.08 to 0.07)	.92	0.00 (−0.08 to 0.08)	.99
Wave 3 (4–5 y)	0.07 (−0.01 to 0.14)	.07	0.04 (−0.03 to 0.11)	.30	0.07 (−0.01 to 0.14)	.07	0.05 (−0.02 to 0.13)	.16
Wave 4 (6–7 y)	0.06 (−0.01 to 0.13)	.08	0.04 (−0.03 to 0.12)	.23	0.06 (−0.01 to 0.14)	.10	0.05 (−0.03 to 0.12)	.20
Wave 5 (8–9 y)	−0.03 (−0.11 to 0.04)	.39	−0.04 (−0.11 to 0.04)	.31	−0.05 (−0.13 to 0.02)	.18	−0.04 (−0.12 to 0.04)	.30
Reactivity								
Wave 2 (2–3 y)	−0.04 (−0.12 to 0.04)	.28	0.02 (−0.07 to 0.10)	.72	−0.05 (0.13 to 0.03)	.20	−0.01 (−0.09 to 0.07)	.77
Wave 3 (4–5 y)	−0.02 (−0.09 to 0.06)	.70	0.03 (−0.05 to 0.10)	.50	−0.02 (−0.10 to 0.06)	.63	0.00 (−0.07 to 0.08)	.95
Wave 4 (6–7 y)	−0.04 (−0.12 to 0.04)	.27	−0.01 (−0.09 to 0.07)	.80	−0.05 (−0.13 to 0.03)	.19	−0.02 (−0.10 to 0.06)	.57
Wave 5 (8–9 y)	0.02 (−0.05 to 0.09)	.59	0.03 (−0.04 to 0.10)	.43	0.01 (−0.07 to 0.08)	.89	0.01 (−0.06 to 0.08)	.85
Introversion								
Wave 5 (8–9 y)	−0.05 (−0.13 to 0.04)	.27	−0.05 (−0.13 to 0.03)	.23	−0.04 (−0.12 to 0.04)	.36	−0.04 (−0.12 to 0.05)	.38
Social development								
Social competence (2–3 y)	0.01 (−0.06 to 0.09)	.71	−0.03 (−0.11 to 0.04)	.40	0.01 (−0.07 to 0.09)	.81	−0.02 (−0.09 to 0.06)	.66
Prosocial skills (4–5 y)	0.02 (−0.05 to 0.09)	.62	0.00 (−0.08 to 0.07)	.96	0.02 (−0.06 to 0.09)	.67	0.00 (−0.08 to 0.07)	.96
Prosocial skills (6–7 y)	0.11 (0.03 to 0.18)	.004	0.08 (0.01 to 0.15)	.02	0.10 (0.02 to 0.17)	.01	0.09 (0.02 to 0.16)	.02
Prosocial skills (8–9 y)	0.03 (−0.04 to 0.11)	.33	0.03 (−0.05 to 0.10)	.49	0.03 (−0.04 to 0.10)	.40	0.02 (−0.05 to 0.09)	.56
Mental health								
Externalizing problems								
Wave 2 (2–3 y)	−0.06 (−0.13 to 0.02)	.13	−0.01 (−0.08 to 0.07)	.82	−0.05 (−0.13 to 0.02)	.15	−0.02 (−0.10 to 0.05)	.55
Wave 3 (4–5 y)	−0.06 (−0.13 to 0.01)	.09	−0.01 (−0.08 to 0.06)	.80	−0.07 (−0.15 to 0.00)	.04	−0.04 (−0.11 to 0.04)	.32
Wave 4 (6–7 y)	−0.04 (−0.12 to 0.03)	.27	0.00 (−0.07 to 0.07)	.99	−0.05 (−0.12 to 0.03)	.19	−0.02 (−0.10 to 0.05)	.57
Wave 5 (8–9 y)	−0.02 (−0.10 to 0.05)	.49	0.01 (−0.06 to 0.09)	.72	−0.04 (−0.11 to 0.03)	.30	−0.01 (−0.08 to 0.07)	.89
Internalizing problems								
Wave 2 (2–3 y)	0.01 (−0.07 to 0.09)	.80	0.06 (−0.02 to 0.13)	.16	0.02 (−0.06 to 0.09)	.71	0.05 (−0.03 to 0.13)	.22
Wave 3 (4–5 y)	−0.03 (−0.11 to 0.04)	.38	0.01 (−0.07 to 0.08)	.82	−0.03 (−0.11 to 0.04)	.39	−0.01 (−0.09 to 0.07)	.83
Wave 4 (6–7 y)	0.00 (−0.08 to 0.07)	.92	0.03 (−0.04 to 0.11)	.35	−0.02 (−0.09 to 0.05)	.63	0.00 (−0.07 to 0.08)	.96
Wave 5 (8–9 y)	0.06 (−0.02 to 0.14)	.13	0.09 (0.02 to 0.17)	.02	0.03 (−0.05 to 0.11)	.42	0.06 (−0.02 to 0.13)	.15
Quality of life								
Wave 2 (2–3 y)	−0.02 (−0.12 to 0.07)	.62	−0.03 (−0.12 to 0.06)	.49	−0.05 (−0.14 to 0.04)	0.31	−0.04 (−0.13 to 0.06)	.44
Wave 3 (4–5 y)	−0.04 (0.13 to 0.04)	.29	−0.06 (−0.14 to 0.03)	.18	−0.05 (−0.14 to 0.03)	0.21	−0.04 (−0.13 to 0.04)	.32
Wave 4 (6–7 y)	0.00 (−0.07 to 0.08)	.91	−0.04 (0.12 to 0.04)	.29	0.00 (−0.07 to 0.08)	0.92	−0.01 (−0.09 to 0.07)	.78
Wave 5 (8–9 y)	−0.08 (−0.15 to 0.00)	.04	−0.11 (−0.18 to −0.04)	.004	−0.06 (−0.13 to 0.01)	0.10	−0.08 (−0.15 to −0.01)	.03

Adjusted models: Model 1, child born preterm (<37 weeks of pregnancy) and/or low birth weight (<2500 g). Model 2, socioeconomic position, mother's language other than English, mother aged <25 years, and ≥2 children in household at wave 1 (child aged 0–1 year). Model 3, ventilator and/or intensive care required for child after birth. Model 4, includes variables from all 3 models. Coef (95% CI), standardized regression coefficients from linear regression analysis (with 95% confidence intervals).

Long-term Childhood Socio-Emotional Outcomes

Childhood socio-emotional outcomes associated with cesarean delivery from birth to 9 years are shown in Table 4. Overall, there were few differences in socio-emotional outcomes between birth modes in the fully adjusted models. There was no effect of cesarean delivery on child temperament. However, children delivered by cesarean delivery tended to score higher on prosocial behavior (eg, whether children are considerate of other people's feelings, share readily, or are helpful if someone is hurt) than other children at age 6 to 7 years (but not at earlier or later ages), and this effect was consistent across all 4 adjusted models. In the model accounting for maternal BMI and breastfeeding, children delivered by cesarean delivery seemed to have lower externalizing problems at age 4 to 5 years; however, this effect was not evident in the unadjusted or fully adjusted models. Likewise, in the model accounting for social vulnerability, children delivered by cesarean delivery seemed to have higher internalizing problems at age 8 to 9 years; however this effect was not evident in any of the other partially or fully adjusted models. Finally, children delivered by cesarean delivery tended to have lower quality of life at age 8 to 9 years. This effect was significant in the fully adjusted model, and in all except the model adjusted for maternal BMI and breastfeeding.

DISCUSSION

This study used prospective data from a large cohort of children broadly representative of the general Australian population, gathered over a 9-year period. When accounting for birth factors, social vulnerability, maternal BMI, and breastfeeding, we found few differences in the long-term health and developmental outcomes of children delivered by cesarean delivery compared with those delivered vaginally. The finding that children born by cesarean delivery were more likely to have a medical condition at age 2 to 3 years and use prescribed medication at 6 to 7 years are difficult to interpret because these associations were not consistent throughout the 5 waves of the study. Similarly, the association between cesarean delivery and increased child BMI at age 8 to 9 years was a relatively small effect that seemed to be mediated through maternal BMI rather than mode of birth. For children delivered by cesarean delivery, an effect of lower parent-reported quality of life emerged at age 8 to 9 years, but once again this effect was relatively weak and was not present in the earlier age groups. Intriguingly, we did find that children delivered by cesarean delivery had better parent-reported global health at 2 to 3 years of age, which contrasted with the lower quality of life finding at age 8 to 9 years. We also found that these children rated slightly higher on the prosocial scale at the beginning of school at age 6 to 7 years.

Cesarean delivery was not associated with any increase in the odds for asthma in this study. A previous meta-analysis reported the odds for asthma in children delivered by cesarean delivery were 1.2 (95% confidence interval: 1.14 to 12.6) times higher, although there was evidence of heterogeneity in the studies.[18] An assessment of the individual publications revealed that the larger studies drew on retrospective data and/or data from national databases.[19] Analyses from prospective studies, in which children were followed up from birth, revealed no evidence of an association between birth mode and asthma, including wheezing or atopy.[20] Thus, our findings were in line with previous evidence from these cohort studies.

Although previous studies have shown a moderate association between childhood obesity and cesarean delivery,[13] the mechanisms underlying this association have not been tested, although 2 key theories have been postulated. Mothers who have undergone cesarean delivery may be more likely to experience illness or pain after delivery, potentially affecting the initiation and maintenance of breastfeeding or even a perception of reduced breast milk supply.[21–24] A substantial body of literature has demonstrated the association between early breastfeeding and decreased rates of physical and mental health child difficulties.[21,22,24] It is possible that lower rates of breastfeeding after cesarean delivery may result in child overweight/obesity. It has also been postulated that differences in gut microbiota may regulate obesity.[25] Infants delivered vaginally may acquire bacterial communities resembling their mothers' vaginal microbiota, whereas those delivered by cesarean delivery are more similar to those found on the skin surface,[26–28] and these differences may persist for 6 months.[29]

In the present study, an association between cesarean delivery and higher childhood BMI was first evident when children were age 7 to 8 years and persisted to age 8 to 9 years. However, the association between cesarean delivery and childhood overweight seemed to be fully explained by maternal BMI and not by maternal breastfeeding. Women who are overweight and obese during pregnancy are more likely to undergo cesarean delivery,[30] and maternal overweight and obesity are among the strongest risk factors for childhood obesity.[31,32]

The 2 positive effects associated with cesarean delivery were unexpected. The prosocial subscale of the Strengths and Difficulties Questionnaire examines children's positive functioning rather than behavioral problems; it seeks parental responses to whether children readily share (eg, treats, toys, pencils) with other children; whether they are helpful if someone is hurt or upset; are kind to other children; or volunteer to help parents or teachers. The difference we identified between the 2 groups was evident at only 1 time point. Because the families of children born by cesarean delivery were less likely to be at social disadvantage, it is possible that these differences between groups were explained by other environmental factors not included in our analyses, such as parenting practices, parent mental health, or the home environment. Alternatively, studies have shown that parents of a child born with perinatal risk may be more "protective" or attentive of their child given the high-stress context of birth complications.[33] We urge caution in the interpretation of this finding, given that the stability and mechanism of this effect are not clear from our results.

A key strength of our study was the use of the large prospective and population-representative sample available in LSAC, with a wide variety of measures across childhood accessible for study. However, this study was an opportunistic trial, and LSAC was not specifically designed to address the question of mode of birth and childhood outcomes. Consequently, the study was limited by a lack of information regarding mothers' experience of previous cesarean delivery, and more detailed information about whether the index birth was an emergent or elective caesarean delivery might have been valuable. The other variable not available for study in this data set was the use of antibiotics either for prophylaxis in women screened positive for group B *Streptococcus* or at the time of cesarean delivery. However, since the current protocols were extant in Australia at the time of the study and have not changed, the results reflect current practice and are thus reassuring.

CONCLUSIONS

This study suggests that some of the previously reported associations between birth by cesarean delivery and adverse childhood health outcomes may be explained by influences other than mode of birth. For example, the association between cesarean delivery and childhood obesity might actually be mediated by maternal obesity and not by the mode of birth. These data should provide reassurance to women and maternity health care providers.

ACKNOWLEDGMENTS

Research at the Murdoch Childrens Research Institute is supported by the Victorian Government's Operational Infrastructure Support Program. This article used unit record data from Growing Up in Australia, the LSAC. The study is conducted in partnership between the Australian Government Department of Social Services (formerly the department of Families, Housing, Community Services and Indigenous Affairs), the Australian Institute of Family Studies, and the Australian Bureau of Statistics. The Parenting Research Centre is supported by funding from the Victorian Government, and the Murdoch Childrens Research Institute receives funding from the Victorian Government's Operational Infrastructure Support Program. We thank all parents and children who took part in the study.

ABBREVIATION

LSAC: Longitudinal Study of Australian Children

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PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: This study was supported by Bupa Health Foundation. Dr Westrupp was supported by the National Health and Medical Research Council–funded Centre of Research Excellence in Child Language (#1023493).

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

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Pediatrics 2015;136;e1285
DOI: 10.1542/peds.2015-1400 originally published online October 12, 2015;