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Obstetric mode of delivery and risk of attention deficit hyperactivity disorder in children: insights from the Quebec pregnancy cohort

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Abstract

Background Attention deficit hyperactivity disorder (ADHD) prevalence in Canadian children increased 3.5-fold between 1999 and 2012, influenced by genetics and perinatal environmental factors. During the same period, cesarean section rates rose from 18.7% in 1997 to 29.4% in 2018, exceeding WHO guidelines and raising health concerns for women and children.

Methods This study aims to investigate the association between different obstetric modes of delivery and the risk of ADHD in children. Using data from the Quebec Pregnancy Cohort, we included all singleton liveborn infants insured by the provincial public drug insurance from 1998 to 2015. The mode of delivery was classified using ICD-9-CM/ICD-10-CM diagnosis and procedure codes, into four categories: unassisted vaginal delivery, assisted vaginal delivery, elective cesarean section, and emergency cesarean section. ADHD cases were identified as having at least one diagnosis, or one prescription filled for ADHD medication. Cox proportional hazards regression models were used to estimate the association between mode of delivery and the risk of ADHD in children, adjusted for potential confounding factors.

Results Of the 229,816 eligible singletons, 72.9% were delivered through unassisted vaginal delivery, 5.9% through assisted vaginal delivery, 3.0% through elective cesarean section, and 19.5% through emergency cesarean section. The study identified 31,225 cases of ADHD (13.6%). Using unassisted vaginal delivery as reference, the adjusted hazard ratio (aHR) of ADHD was of 1.12 (95% confidence interval (CI), 1.06–1.19; 1,284 exposed cases) for assisted vaginal delivery and 1.06 (95% CI, 1.03–1.10; 5,552 exposed cases) for emergency cesarean delivery. As for elective cesarean delivery, the aHR was of 0.96 (95% CI, 0.91–1.01; 1,486 exposed cases).

Conclusion The findings suggest that assisted vaginal delivery and emergency cesarean section are associated with an increased risk of ADHD in children, compared with unassisted vaginal delivery after adjusting for potential risk factors.

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Key points

Question What are the association of obstetric mode of delivery and the risk of attention deficit hyperactivity disorder in children?

Findings In a cohort study of 229,816 singleton liveborn infants, assisted vaginal delivery (AVD) and emergency cesarean section (CS) are associated with an increased risk of ADHD in children, compared with unassisted vaginal delivery, with adjusted hazard ratio (aHR) of 1.12 (95% confidence interval (CI), 1.06–1.19; 1,284 exposed cases) for AVD and 1.06 (95% CI, 1.03–1.10; 5,552 exposed cases) for emergency CS.

Meaning Our findings suggest that emergency CS and AVD are associated with a statistically and clinically significant increased risk of ADHD in children compared to VD. Using the overall rate of ADHD of 13.6% observed in this study, emergency CS increases the risk of ADHD to 14.4% and AVD increases the risk of ADHD to 15.2%.

Keywords Assisted/unassisted vaginal delivery, Emergency/elective caesarean section, Attention deficit hyperactivity disorder (ADHD), Population-based, Quebec pregnancy cohort

Background

Attention deficit hyperactivity disorder (ADHD) is the most prevalent neurodevelopmental disorder in children, [1] characterized by inattention, hyperactivity, and impulsivity, leading to functional limitations. In the United States, 9.4% of children aged 2–17 are diagnosed with ADHD [2]. Quebec, Canada, reported the highest increase in ADHD among four provinces evaluated, [3] with prevalence rising 3.5-fold in 2012 (3.73%) compared to 1999 (1.08%) [3]. While ADHD etiology remains unclear, genetics, [4] environmental factors, and their interaction, especially during the perinatal period, are implicated [5].

The rate of cesarean section (CS) is increasing worldwide [6]. In Canada, the CS rate has increased from 18.7% in 1997 to 29.4% in 2018, [7] surpassing the World Health Organization's recommended range of 10–15% [8]. The increasing CS rates raise concerns regarding subsequent health implications in women and children [9]. CS has been associated with adverse health outcomes in offsprings, namely: obesity, [10] type 1 diabetes, [11] asthma, [12] and allergies [13]. Recent studies suggest a 23% increased risk of autism spectrum disorders (ASD) and a 14% increased risk of ADHD with CS compared to vaginal delivery (VD) [14]. However, these findings lack the control of confounding factors such as maternal ADHD history, delivery complications, and healthcare utilization. Additionally, several studies had relatively small sample sizes, and did not distinguish between emergency and elective CS, nor unassisted and assisted VD [14, 15].

In this longitudinal population-based cohort, we aimed to examine the association between the obstetric mode of delivery and ADHD risk in offsprings. We specifically distinguished between types of CS and VD as they present different clinical circumstances and indications [16, 17].

Methods

Study design

A cohort of live-born children was constructed using data from the Quebec Pregnancy Cohort (QPC).

Data sources and study population

Study data were obtained from the Quebec Pregnancy Cohort (QPC), which is a longitudinal population-based cohort with prospectively collected data on all pregnancies covered by the province's public prescription drug insurance plan between January 1st 1998, and December 31st 2015. Individual information related to all pregnant women and children is obtained from province-wide databases and is linked by a unique personal identifier. The QPC links four administrative databases: *Régie de l'assurance maladie du Québec* (RAMQ), which includes medical (diagnoses, procedures, indicator of socio-economic status) and pharmaceutical data (drug name, start date, dosage, duration); *Maintenance et exploitation de données pour l'étude de la clientèle hospitalière* (MedEcho), which includes hospitalization data (diagnoses, procedures, gestational age, birth weight); the Quebec Statistics database (ISQ), which includes sociodemographic information as well as birth and death registers [18]. The RAMQ medication database in the QPC represents 17% of women between aged 15-45 [19].

The first day of the last menstrual period (LMP) is defined as the first day of gestation using the gestational age which was validated using ultrasound measures from patient charts [19]. All pregnancies were prospectively followed up 12 months before the LMP, during pregnancy, and until December 31st 2015. Data on mothers and children following the end of pregnancy were also collected. The QPC is thoroughly described in Bérard and Sheehy [18].

In this study, we identified all singleton liveborn infants, whose mothers were covered by the RAMQ drug plan for at least 12 months before LMP and during pregnancy. Multiple pregnancies were excluded as they

are associated with increased risk of ADHD [20]. Pregnancies exposed to known teratogens were also excluded since prenatal exposure to teratogenic substances increases the risk of developing ADHD [21]. We also excluded pregnancies for which the delivery code was missing.The cohort entry date was defined as the child date of birth.

Exposure

Mode of delivery was identified from the RAMQ and MedEcho databases and defined as unassisted VD (UVD), assisted VD (AVD), elective CS, and emergency CS. AVD was defined as a VD assisted with forceps or vacuum to deliver. Emergency CS was defined as CS after the attempt to deliver vaginally. The reference category for our analyses was UVD. We identified the mode of delivery using the 9th and 10th editions of the International Classification of Diseases (ICD-9-CM, ICD-10-CM) along with the Canadian Classification of Health Interventions (CCI) and the physician-based procedure codes (Supplemental Table S1).

Outcome

The primary outcome was the diagnosis of ADHD during the follow-up period. ADHD was identified based on at least one physician diagnosis coded with ICD-9 (314.x) or ICD-10 (F90.x), or by the presence of a filled prescription for a medication commonly used to treat ADHD, identified by Anatomical Therapeutic Chemical (ATC) codes. The medications included are: amphetamine (ATC code N06BA01), dexamphetamine (ATC code N06BA02), lisdexamfetamine (ATC code N06B12), methylphenidate (ATC code N06BA04), atomoxetine (ATC code N06BA09), and guanfacine (ATC code C02AC02). Prescription data have been validated and compared to maternal reports in the QPC, where the positive predictive value of prescription drug data was ≥87% (95%CI: 70-100%) and the negative predictive value was ≥92% (95%CI: 86-98%) [22].

Follow up

Follow-up time was defined as the number of days from birth until the earliest of the following events: (1) ADHD diagnosis or first ADHD-related prescription (event), (2) death (censoring), (3) loss of public drug insurance coverage (censoring), or (4) the end of the study period (December 31, 2015) (censoring).

Covariates

Multiple potential confounders were selected a priori based on their association with mode of delivery or ADHD from previous literature: (1) infant characteristics including child sex, birth year (calendar year), low birth weight (LBW, ≤2500 g), and preterm birth (≤37 weeks); (2) mother sociodemographic characteristics including maternal age, area of residence (urban or rural), and health insurance status (welfare recipients or worker); (3) maternal comorbidities including chronic/gestational diabetes, chronic/gestational hypertension, asthma, epilepsy, obesity, thyroid disorder, we also included the use of folic acid and diagnosis of infection during pregnancy; (4) mother psychiatric conditions including depression, mood, and anxiety disorders, maternal ADHD, and other psychiatric disorders; (5) maternal lifestyle including dependence and abuse of tobacco, alcohol, and other drugs; (6) maternal healthcare usage including obstetrician pregnancy follow-up, number of medications used during the pregnancy, number of visits to general practitioner (GP), number of different specialists visits, and hospitalization or emergency department visits; and (7) pregnancy, delivery and labor complications variables including fetal distress, fetal malpresentation, obstructed, and prolonged labor, umbilical and membrane cord complications, and other complications (Supplemental Table S4). Labor complications were included in the multivariate analyses to account of their potential relationship with both birth type and the risk of ADHD.

Maternal covariables were identified 12 months before the LMP and during pregnancy unless otherwise specified. They were defined as one medical service claim or hospitalization using the corresponding code per the ICD-9-CM/ICD-10-CM or one filled prescription for disease-specific medications (Supplemental Table S5).

Statistical analyses

We conducted descriptive analyses to compare the cohort population characteristics based on the mode of delivery using the t-tests or the chi-square tests for continuous variables and categorical variables, respectively. In the main analysis and the sensitivity analyses, crude (HR) and adjusted hazard ratios (aHR) with 95% confidence intervals (95%CI) were calculated using the Cox proportional hazards regression models.

Sensitivity analyses

Various sensitivity analyses were conducted to assess the robustness of our results. These analyses included: (1) considering only children who were diagnosed with ADHD at 3 years and older irrespective of filled ADHD prescriptions; (2) including only children who had a confirmed ADHD diagnosis by a psychiatrist or a neurologist regardless of ADHD prescriptions filled; (3) restricting the study population to children who never had an ASD diagnosis, as they show high concurrent comorbidity with ADHD, while sharing many common symptoms; [23] (4) including only children who had ≥2 ADHD prescription fillings regardless of ADHD diagnosis; (5) stratifying analyses according to the sex of the child to assess

sex differences; and (6) excluding mothers with a diagnosis of ASD or a diagnosis and/or prescription of ADHD to account for the contribution of maternal genetics.

The models for both the main cohort and the sensitivity analyses were adjusted for the variables as above. Finally, to address potential imbalances in covariates across the four modes of delivery, we applied inverse probability weighting (IPW) within the main multivariate Cox model. IPW adjusts for confounding by balancing covariates across groups, effectively reducing bias and ensuring that the comparisons between groups are made on an equal footing. Statistical analyses were performed using SAS software (SAS Institute Inc. Version 9.4).

Results

Study cohort

Of the 229,816 eligible liveborn singletons, the majority (77.5%) were delivered vaginally and among them 7.6% were AVD. A total of 51,736 neonates were delivered through CS, of which 86.5% underwent emergency CS and 13.5% elective CS (Fig. 1, 2). Overall, CS had a prevalence of 22.5%, and the increasing rate from 1998 to 2015 is illustrated in supplementary Figure S1.

Outcome

In total, we identified 31,225 cases of ADHD (13.6%) with a mean age at the ADHD identification being at 7.98 years old (median 8.00). Among ADHD cases, 43.6% of them being identified with both an ADHD diagnosis and a prescription for an ADHD medication ($n = 13,599$). However, 5,344 (17.1%) cases had only the medication and 12,282 (39.3%) only the diagnosis (data not presented). Mothers who delivered through CS were older and had more comorbidities such as diabetes, hypertension, and asthma compared to mother who had a VD (Table 1). Those mothers also had more healthcare services utilization in the year before and during their pregnancies. Mother delivering by AVD and emergency CS had a higher prevalence of pregnancy and delivery complications. Children born through elective CS were more likely to be preterm and have LBW (Table 1). The mean follow-up time for each exposure group is detailed

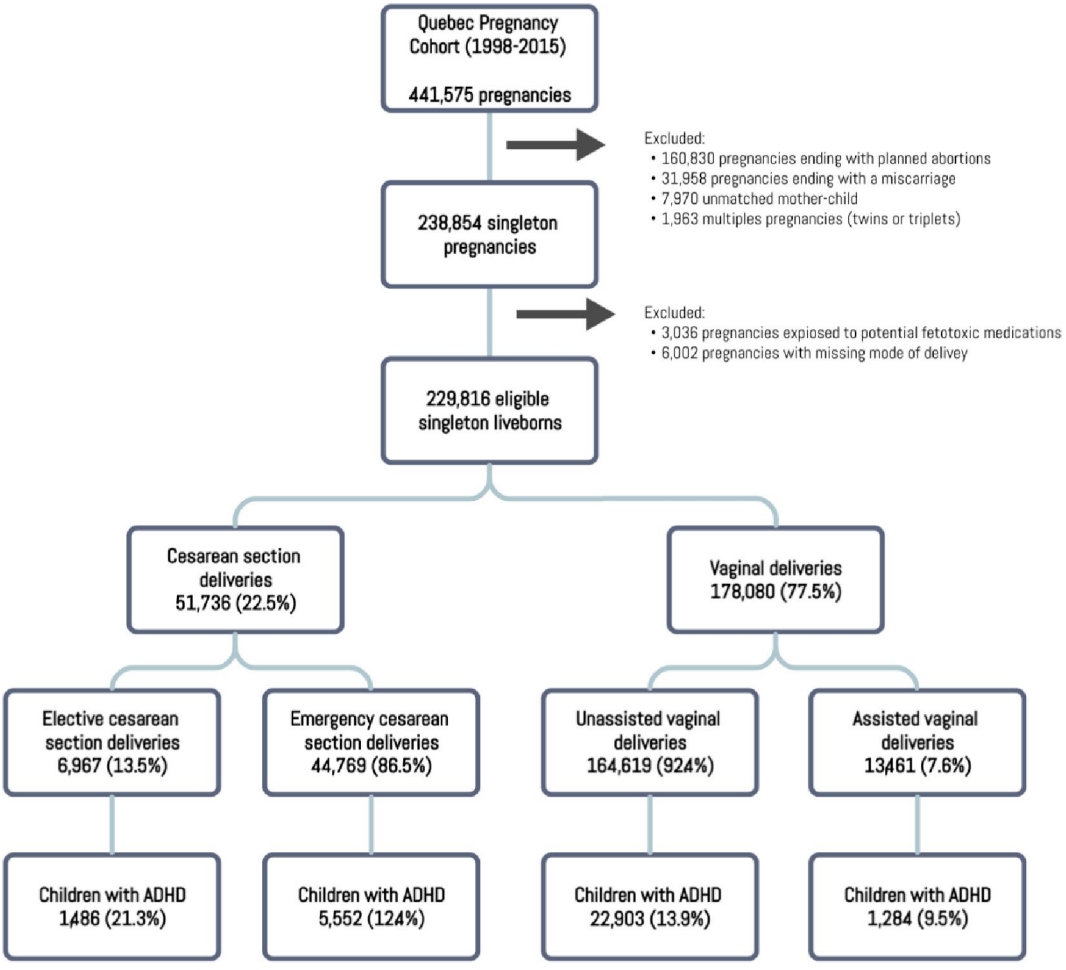

Fig. 1 Study flow chart. Legend: Abbreviations: ADHD, Attention deficit hyperactivity disorder

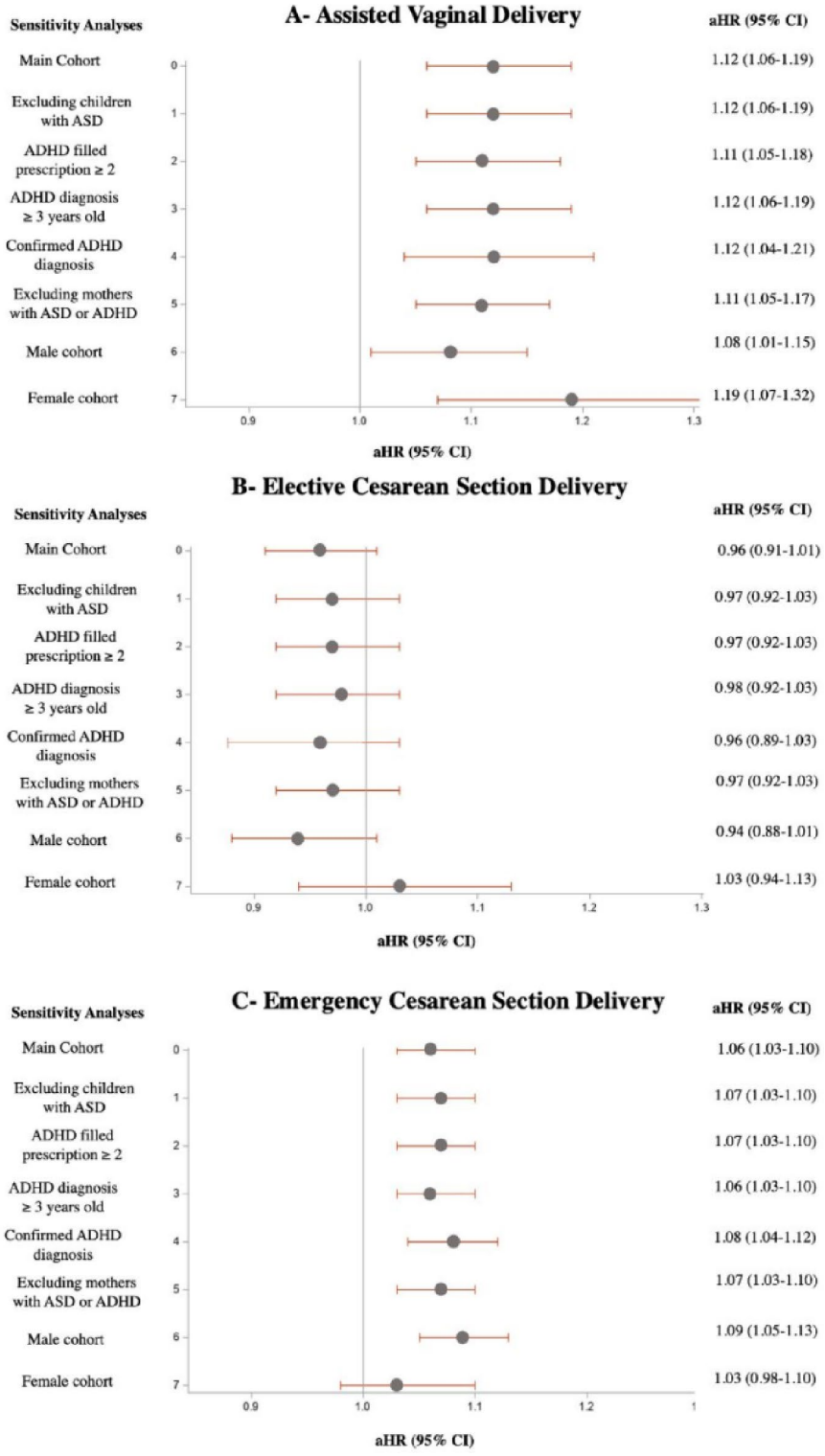

Fig. 2 Sensitivity analysis: Forest plot for the association between modes of delivery and risk of ADHD compared to unassisted vaginal delivery. Legend: Abbreviation: aHR, Adjusted hazard ratio; CI, Confidence intervals

Table 1 Characteristics of the study population according to each mode of delivery

Study characteristics	Unassisted vaginal delivery *n* = 164,619 (71.6%)[1]	Assisted vaginal delivery *n* = 13,461 (5.9%)	Elective cesarean delivery *n* = 6,967 (3.0%)	Emergency cesarean delivery *n* = 44,769 (19.5%)
Infant ADHD	22,903 (13.9)	1,284 (9.5)	1,486 (21.3)	5,552 (12.4)
Infant sex (Male)	82,981 (50.4)	7,524 (55.9)	3,716 (53.3)	23,886 (53.4)
Low birth weight (≤ 2500 g)	7,724 (4.7)	515 (3.8)	1,313 (18.9)	3,740 (8.4)
Preterm birth (≤ 37 Weeks)	10,089 (6.1)	600 (4.5)	1,564 (22.5)	4,382 (9.8)
Maternal age (years), mean ± SD	27.9 ± 5.5	28.0 ± 5.5	29.4 ± 5.7	29.5 ± 5.7
Welfare recipient	39,135 (23.8)	2,292 (17.0)	1,521 (21.8)	9,799 (21.9)
Rural dweller	28,810 (17.5)	2,351 (17.5)	1,359 (19.5)	7,476 (16.7)
Chronic or gestational diabetes	10,995 (6.7)	967 (7.2)	615 (8.8)	4,625 (10.3)
Chronic or gestational hypertension	12,067 (7.3)	1,190 (8.8)	1,090 (15.7)	5,417 (12.1)
Asthma	25,649 (15.6)	1,984 (14.7)	1,240 (17.8)	7,571 (16.9)
Epilepsy	2,519 (1.5)	160 (1.2)	177 (2.5)	739 (1.7)
Obesity	1,260 (0.8)	88 (0.7)	131 (1.9)	729 (1.6)
Thyroid disorders	9,603 (5.8)	1000 (7.4)	363 (5.2)	3,342 (7.5)
Folic acid[2]	6,024 (3.7)	751 (5.6)	283 (4.1)	2,679 (6.0)
Maternal infection during pregnancy	39,243 (23.8)	2,548 (18.9)	2,201 (31.6)	10,711 (23.9)
Depression and mood anxiety disorder	26,211 (15.9)	2,294 (17.0)	1,203 (17.3)	7,843 (17.5)
Other psychiatric disorders[3]	6,062 (3.7)	536 (4.0)	255 (3.7)	1,803 (4.0)
Mother history of ADHD[4]	456 (0.3)	77 (0.6)	6 (0.1)	152 (0.3)
Alcohol dependence	654 (0.4)	38 (0.3)	26 (0.4)	175 (0.4)
Tobacco dependence	5,456 (3.3)	448 (3.3)	203 (2.9)	1,441 (3.2)
Other drugs dependence	1,649 (1.0)	174 (1.3)	65 (0.9)	478 (1.1)
0	59,501 (36.1)	4,838 (35.9)	2,526 (36.3)	15,260 (34.1)
1–2	63,334 (38.5)	4,937 (36.7)	2,584 (37.1)	15,757 (35.2)
≥ 3	41,784 (25.4)	3,686 (27.4)	1,857 (26.7)	13,752 (30.7)
Pregnancy follow-up by obstetrician	102,415 (62.2)	7,355 (54.6)	5,597 (80.3)	33,956 (75.9)
0	102,997 (62.6)	11,289 (83.9)	1,162 (16.7)	34,056 (76.1)
1–2	8,475 (5.2)	71 (0.53)	773 (11.1)	1,452 (3.2)
≥ 3	53,147 (32.3)	2,101 (15.6)	5,032 (72.2)	9,261 (20.7)
0	2,780 (1.7)	226 (1.7)	11 (0.2)	482 (1.1)
1–2	95,019 (57.7)	7,637 (56.7)	2,422 (34.8)	19,872 (44.4)
≥ 3	66,820 (40.6)	5,598 (41.6)	4,534 (65.1)	24,415 (54.5)
ED visit or hospitalization	42,683 (25.9)	4,109 (30.5)	338 (4.9)	14,016 (31.3)
Fetal distress	4,435 (2.7)	1,004 (7.5)	409 (5.9)	3,083 (6.9)
Fetus malpresentation	5,132 (3.1)	765 (5.7)	770 (11.1)	9,588 (21.4)
Obstructed labor	4,275 (2.6)	1,087 (8.1)	18 (0.3)	1,729 (3.9)
Prolonged labor	10,504 (6.4)	2,228 (16.6)	834 (12.0)	9,299 (20.8)
Umbilical cord complications	38,111 (23.2)	3,304 (24.5)	225 (3.2)	7,745 (17.3)
Membrane complications	31,603 (19.2)	3,928 (29.2)	592 (8.5)	10,523 (23.5)
Other complications	80,966 (49.2)	10,198 (75.8)	407 (5.8)	13,108 (29.3)

Abbreviations: ADHD, Attention deficit hyperactivity disorder; SD, standard deviation

[1]Values represent the number (percentage) unless otherwise indicated. [2]Folic acid usage 6 months before or during pregnancy. [3]Schizophrenia, schizotypal and delusional disorders, dissociative and conversion disorders, phobic disorders, obsessive compulsive disorder, dysthymic disorder, neurasthenia, somatoform disorders, disorders of adult personality and behavior, unspecified nonpsychotic mental disorder. [4]Maternal ADHD was identified as one diagnosis using the ICD-9/ICD-10 or one prescription filled for ADHD medications identified using Anatomical Therapeutic Chemical (ATC)

Classification System codes (supplemental Table S2 and Table S3). [5]Number of other medications used during pregnancy other than medication used to assess maternal comorbidities [6]List of birth, pregnancy, and labor complications in supplemental Table S4

in Supplemental Table S6. The median follow-up duration varied between the groups, with the longest follow-up observed in the elective CS group (1,997 days), followed by VD (1,695 days). In contrast, the emergency CS group had a median follow-up time of 1,546 days, and the assisted VD group had the shortest median follow-up time at 1,387 days.

Birth through AVD (aHR 1.12, 95%CI 1.06–1.19; 1,284 exposed cases) and emergency CS (aHR 1.06, 95%CI 1.03–1.10; 5,552 exposed cases) significantly increased

the risk of ADHD in offsprings when compared to UVD (Table 2). No association between elective CS and the risk of ADHD was observed (aHR 0.96, 95%CI 0.91–1.01; 1,486 exposed cases) when compared with UVD (Table 2).

Prespecified sensitivity analyses

Overall, results from sensitivity analysis demonstrated the robustness of the findings identified in our main analyses. When excluding children diagnosed before 3 years of age, a very slight decrease (2%) of ADHD risk (aHR 0.98, 95%CI 0.92–1.03) was observed in offspring born via elective CS but this finding did not reach statistical significance (supplemental Table S7).

When restricting the study population to children with a confirmed diagnosis by a psychiatrist or a neurologist, children born via emergency CS where significantly more at risk of ADHD when compared to UVD (aHR 1.08, 95%CI 1.04–1.12) (supplemental Table S8). This association was stronger than we observed in our main analyses (Table 2).

When performing analyses among children without diagnosis of ASD (supplemental Table S9) and children with ≥2 prescriptions for ADHD medications (supplemental Table S10), we found similar results for the association between the obstetric mode of delivery and the risk of ADHD as in the main adjusted analysis (Table 2).

When stratified by the child's sex, the results showed that girls had a slightly higher risk of ADHD than boys when born via AVD, with respective aHRs of 1.19 (95% CI 1.07–1.32) and 1.08 (95% CI 1.01–1.15) (Supplemental Table S11). For girls, no protective association of elective CS was observed (aHR 1.03, 95% CI 0.94–1.13), while the protective effect remained in boys (aHR 0.94, 95% CI 0.88–1.01) (Supplemental Table S11). Conversely, birth via emergency CS was linked to a significantly higher risk of ADHD in boys (aHR 1.09, 95% CI 1.05–1.13), with a similar, though non-significant, risk observed in girls (aHR 1.03, 95% CI 0.98–1.10) (Supplemental Table S11). Finally, the sensitivity analysis conducted among children whose mothers had never been diagnosed with ADHD or ASD yielded results consistent with the main analysis (Supplemental Table S12).

Moreover, the association between mode of delivery and risk of ADH estimated using the IPW approach was consistent with the results from the multivariate Cox model (Supplementary Table S13). Kaplan Meier curves adjusted for IPW and stratified by mode of delivery are shown in Supplementary Figure S2. Both methods showed an increased risk of ADHD associated with AVD and emergency CS, and a significantly reduced risk linked to elective CS compared to UVD.

Discussion

Main findings

This study examined the association between the mode of delivery and ADHD risk ADHD in a population-based cohort. After adjusting for potential confounders, AVD and emergency CS significantly increased ADHD risk in offsprings compared with those born via UVD.

Interpretation

Our findings are consistent with the literature. Axelsson et al. observed elevated ADHD risk in offspring born by elective CS (aHR 1.10, 95%CI, 1.04–1.16) and emergency CS (aHR 1.11,95%CI 1.05–1.17). A matched-sibling analysis identified a weakened association for elective (aHR 1.03,95%CI, 1.04–1.16) and emergency CS (aHR 1.09, 95%CI 1.04–1.16) compared to VD [22]. Similarly, Zhang et al. reported an 8% reduction in ADHD risk with elective CS (95%CI 0.81–1.06) and a 7% increase with emergency CS (95%CI 0.95–1.20), consistent with our findings, although not statistically significant [24]. Our study adjusted for significant confounders, including maternal comorbidities like ADHD history and healthcare utilization, potentially explaining the concordance with matched-sibling analyses [22, 23, 25]. A recent meta-analysis highlighted the overestimation of the association between CS and ADHD risk due to uncontrolled confounders, such as maternal psychiatric disorders [14]. Notably, mothers with ADHD have an elevated risk of CS and having a child with ADHD, underscoring the importance of considering ADHD history when assessing the link between delivery mode and ADHD risk in children [26].

The literature on the association between AVD and ADHD is limited. Curran et al. studied the association in a British cohort where a protective effect was found (aHR 0.76, 95%CI, 0.32–1.80)), [27] while in the Swedish cohort, ADHD risk was 3% higher in children born via AVD (95%CI, 0.92–1.14) [25]. The Swedish study was more comparable to ours in terms of sample size and data source.

Strengths and limitations

Our study was conducted in a population-based cohort (QPC), allowing us to obtain a large sample size and limit recall and selection biases. The QPC includes validated exposure, outcomes, and potential confounders data including filled prescriptions, [28] gestation age, [19] and birth weight [19]. We thoroughly adjusted for many potential confounding factors related to the indication for CS including maternal ADHD and complications during pregnancy, delivery, and labor. However, we cannot rule out the possibility of residual confounding knowing that different trajectories may lead to emergency CS or

Table 2 The association between mode of delivery and attention deficit hyperactivity disorder

Variables	Total infants *n* = 229,816	Infants with ADHD *n* = 31,225	ADHD follow-up no. of person-years	Crude HR (95%CI)	Adjusted HR (95%CI)
Mode of delivery					
Unassisted vaginal delivery	164,619	22,903	181,879.0	Ref.	Ref.
Assisted vaginal delivery	13,461	1,284	9,445.7	1.29 (1.22–1.36)	1.12 (1.06–1.19)
Elective cesarean delivery	6,967	1,486	13,095.9	0.96 (0.91–1.01)	0.96 (0.91–1.01)
Emergency cesarean delivery	44,769	5,552	40,432.9	1.17 (1.13–1.20)	1.06 (1.03–1.10)
Infant characteristics					
Infant sex (Male)	118,107	20,837	160,029.9	1.90 (1.86–1.95)	1.89 (1.85–1.94)
Low birth weight (≤ 2500 g)	13,292	2,527	18,314.2	1.24 (1.19–1.29)	1.28 (1.21–1.34)
Preterm birth (≤ 37 Weeks)	16,635	3,018	22,492.8	1.18 (1.14–1.22)	1.06 (1.01–1.11)
Calendar time (Year)	NA	NA	NA	1.05 (1.04–1.05)	1.07 (1.06–1.08)
Maternal characteristics					
Age at the first day of gestation (year)					
< 18	3,017	785	6,226.9	Ref.	Ref.
18–24	60,556	11,850	93,654.5	1.25 (1.17–1.35)	1.23 (1.15–1.33)
25–34	132,259	15,679	122,989.9	1.05 (0.98–1.13)	0.97 (0.90–1.04)
≥ 35	33,984	2,911	21,982.2	0.76 (0.71–0.83)	0.71 (0.66–0.77)
Welfare recipient	52,747	10,429	77,870.1	1.71 (1.67–1.76)	1.79 (1.75–1.84)
Rural dweller	39,996	5,609	45,150.4	1.15 (1.12–1.18)	1.04 (1.01–1.08)
Maternal comorbidities in the year prior to or during the pregnancy					
Chronic/gestational diabetes	17,202	1,894	13,343.1	1.01 (0.96–1.06)	1.00 (0.95–1.05)
Chronic/gestational hypertension	19,764	3,208	24,297.6	1.24 (1.19–1.28)	1.14 (1.10–1.19)
Asthma	36,444	7,327	56,208.7	1.28 (1.25–1.32)	1.19 (1.16–1.23)
Epilepsy	3,595	903	6,968.6	1.20 (1.13–1.29)	1.07 (1.00-1.14)
Obesity	2,208	466	3,507.6	1.22 (1.11–1.34)	1.21 (1.10–1.33)
Thyroid disorders	14,308	1,434	10,262.3	1.09 (1.03–1.15)	1.00 (0.95–1.06)
Folic acid1[1]	9,737	842	5,951.2	1.06 (0.99–1.14)	0.93 (0.87-1.00)
Infection during pregnancy	54,703	9,426	74,303.7	1.07 (1.04–1.09)	1.02 (1.00-1.05)
Maternal psychiatric disorders in the year prior to or during pregnancy					
Depression/mood anxiety disorder	37,551	6,866	51,750.7	1.32 (1.28–1.35)	1.23 (1.19–1.27)
Other psychiatric disorders[2]	8,656	1,822	13,282.8	1.26 (1.20–1.32)	1.04 (0.98–1.10)
Mother history of ADHD[3]	691	66	352.1	2.73 (2.12–3.47)	1.88 (1.48–2.40)
Maternal lifestyle in the year prior to or during the pregnancy					
Alcohol dependence	893	185	1,370.2	1.00 (0.87–1.16)	0.94 (0.81–1.08)
Tobacco dependence	7,548	1,481	11,258.5	1.18 (1.12–1.25)	1.19 (1.13–1.25)
Other drugs dependence	2,366	490	3,455.7	1.16 (1.06–1.27)	1.03 (0.93–1.14)
No. of other medications used during pregnancy[4]					
0	82,125	9,625	78,269.4	Ref.	Ref.
1–2	86,612	12,409	98,396.4	1.08 (1.05–1.11)	1.06 (1.03–1.09)
≥ 3	61,079	9,191	68,187.7	1.26 (1.22–1.29)	1.16 (1.12–1.20)
Healthcare usage					
Pregnancy follow-up by obstetrician	149,323	18,860	145,713.4	0.88 (0.86–0.90)	0.92 (0.90–0.94)
General practitioner visits in the year prior to or during pregnancy					
0	149,504	11,508	74,804.4	Ref.	Ref.
1–2	10,771	1,929	16,530.3	0.70 (0.67–0.73)	1.07 (1.01–1.13)
≥ 3	69,541	17,788	153,518.7	0.90 (0.89–0.93)	1.19 (1.15–1.24)
No. different specialist visits in the year prior to or during pregnancy					
0	3,499	125	894.6	Ref.	Ref.
1–2	124,950	15,822	125,769.2	1.54 (1.29–1.83)	1.50 (1.26–1.79)
≥ 3	101,367	15,278	118,189.6	1.69 (1.42–2.01)	1.55 (1.30–1.85)
ED visit or hospitalization	61,146	6,537	42,588.3	1.42 (1.38–1.46)	1.24 (1.20–1.28)
Pregnancy, delivery and labor complications[5]					
Fetal distress	8,931	992	7,425.4	0.99 (0.93–1.06)	0.99 (0.93–1.06)

Table 2 (continued)

Variables	Total infants *n* = 229,816	Infants with ADHD *n* = 31,225	ADHD follow-up no. of person-years	Crude HR (95%CI)	Adjusted HR (95%CI)
Fetus malpresentation	16,255	1,905	13,545.6	1.05 (1.00-1.10)	0.98 (0.93–1.03)
Obstructed labor	7,109	709	4,981.1	0.96 (0.89–1.03)	0.90 (0.83–0.97)
Prolonged labor	22,865	2,620	19,023.4	1.10 (1.05–1.14)	1.01 (0.97–1.05)
Umbilical cord complications	49,385	5,360	38,428.7	0.89 (0.86–0.92)	0.85 (0.82–0.88)
Membrane complications	46,646	4,616	32,272.6	0.99 (0.96–1.02)	0.93 (0.90–0.96)
Other complications	104,679	8,969	61,889.8	1.07 (1.04–1.09)	0.94 (0.91–0.97)

Abbreviations: ADHD, attention deficit hyperactivity disorder; ref, reference; HR, hazard ratio; CI, confidence intervals; NA, not applicable

[1]Folic acid usage 6 months before or during pregnancy. [2]Schizophrenia, schizotypal and delusional disorders, dissociative and conversion disorders, phobic disorders, obsessive compulsive disorder, dysthymic disorder, neurasthenia, somatoform disorders, disorders of adult personality and behavior, unspecified nonpsychotic mental disorder. [3]Maternal ADHD was identified as one diagnosis using the ICD-9/ICD-10 or one prescription filled for ADHD medications identified using Anatomical Therapeutic Chemical (ATC) Classification System codes (supplemental Tables S2 and S3). [4]Number of other medications used during pregnancy other than medication used to assess maternal comorbidities. [5]List of birth, pregnancy, and labor complications in supplemental Table S4

AVD. However, the robustness of our findings was confirmed within the performed sensitivity analyses.

Our study has certain limitations. Information on paternal characteristics and key maternal lifestyle factors during pregnancy and the neonatal period (such as alcohol, tobacco, illicit drugs, breastfeeding) were not available, which may have introduced residual confounding. Additionally, we deliberately excluded covariates from the child first year of life, as these factors could lie on the causal pathway between mode of delivery and ADHD, and their inclusion might have resulted in over adjustment bias. However, we used proxies including diagnostic codes for alcohol, tobacco, and drug abuse and dependence. As we did not have data on over-the-counter folic acid use, we used prescription fillings for folic acid as a proxy.

The statistically significant differences in ADHD risk were observed primarily in the groups with shorter follow-up durations. This may be explained by the higher occurrence of ADHD diagnoses in these groups, likely due to the earlier detection of the condition within the study period. The follow-up duration itself is unlikely to introduce detection bias, as the increased risk in shorter follow-up groups suggests a true difference in the timing of ADHD diagnoses rather than an artifact of prolonged observation.

Given that ADHD diagnoses in the QPC are not validated, we included the use of indication-specific medication for ADHD to assess the outcome status of offsprings and conducted multiple sensitivity analyses as described above, the results of which were consistent with our main findings. Moreover, our team has previously shown that prescription claims database in Quebec is accurate and reliable [28]. Additionally, the QPC includes mothers of lower socioeconomic status, which may influence the generalizability of our results. However, these women and children are comparable to the general population of Quebec in terms of comorbidities and healthcare utilization [18]. Lastly, our findings may only be generalizable to populations where most CS are performed for specific medical indications [29].

Clinical implications and biological plausibility

The relationship between mode of delivery and neonatal neurodevelopment remains incompletely understood. One hypothesized pathway involves alterations in microbial colonization. Emergency CS typically occurs after the onset of labor, during which the neonate is likely exposed to maternal microbiota and elevated levels of stress-related hormones, similar to VD [30]. However, the observed association observed between emergency CS, but not in elective CS, and ADHD in this study cannot be explained by these mechanisms. Both AVD and emergency CS are associated with heightened perinatal stress, which may compromise oxygen delivery to the fetus, potentially resulting in hypoxia and subsequent hypoxic-ischemic brain injury [31]. Perinatal hypoxia has been implicated in long-term neurodevelopmental disorders, including ADHD [32]. Disruption of oxygen supply during critical periods of brain development may interfere with the establishment and maturation of neural networks involved in attention regulation and executive function– domains frequently impaired in individuals with ADHD [33]. Moreover, AVD procedures such as forceps or vacuum extraction are associated with an increased risk of mechanical brain injuries, including intracranial hemorrhages or subdural hematomas, which may contribute to adverse neurodevelopmental outcomes, including ADHD [34]. Similarly, emergency CS perform in the context of fetal distress or other intrapartum complications may elevate the risk of birth trauma. Although the underlying mechanisms are multifactorial and not yet fully elucidated, the link between delivery mode and ADHD risk likely reflects a complex interplay of biological and perinatal stress-related factors.

Conclusions

In this large population-based cohort study, we observed a statistically significant association between emergency CS and AVD and an increased risk of ADHD in offspring, compared to VD. However, the absolute difference in ADHD incidence was relatively small, and the findings should be interpreted with caution. Given the observational design and potential for residual confounding, these results do not establish causality but suggest the need for further research to explore underlying mechanisms and confirm the findings in other populations. Clinicians and policymakers should consider these findings as part of a broader evidence base when evaluating delivery practices.

Abbreviations

ADHD	Attention deficit hyperactivity disorder
aHR	Adjusted hazard ratio
ASD	Autism spectrum disorders
AVD	Assisted vaginal delivery
CCI	Canadian Classification of Health Interventions
CI	Confidence interval
CS	Caesarean section
HR	Hazard ratio
ICD-9-CM	International Classification of Diseases 9th edition
ICD-10-CM	International Classification of Diseases 10th edition
ISQ	Institut de la Statistique du Québec (Quebec Statistics database)
LBW	Low birth weight
LMP	Last menstrual period
Med-Echo	Quebec hospitalization databases
QPC	Quebec Pregnancy Cohort
RAMQ	Régie de l'assurance maladie du Québec (Quebec Health Insurance)
UVD	Unassisted vaginal delivery
VD	Vaginal delivery

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12884-025-07687-w.

Supplementary Material 1

Author contributions

A.B. and O.S. conceived and developed the theory. O.S. conceived the statistical analysis plan. M.F. performed the analyses and all authors discussed and reviewed the results. O.S., M.F. and J.Z. wrote the manuscript with the input of J.G. All authors reviewed and commented the manuscript.

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Data availability

The data used in this study cannot be shared because of legal restrictions set by the Quebec Ministry of Health. These restrictions are outlined under the Act respecting Health Services and Social Services (Chapter R-22.1), which regulates access to health-related information for researchers. This legislation imposes strict guidelines on how sensitive health data can be accessed, handled, and shared, ensuring the privacy and protection of individuals' personal health information. Consequently, researchers are legally bound by these regulations, which prevent the dissemination of the data outside of the specific terms of use authorized by the Ministry.

Declarations

Ethics approval and consent to participate

The study was approved by the Sainte-Justine's Hospital Ethics Committee (project authorization number: 2010 – 248, 2976). The Quebec "*Commission d'accès à l'information*" authorized database linkages (reference numbers: 09 15 98 (06 17 83, 06 17 11, 05 18 82, 05 03 12, and 04 02 16)). Consent forms are not required for studies utilizing Quebec's provincial health insurance and hospitalization databases, as all data have been anonymized to ensure patient confidentiality.

Competing interests

The authors declare no competing interests.

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References

1. Rowland AS, Lesesne CA, Abramowitz AJ. The epidemiology of attention-deficit/hyperactivity disorder (ADHD): a public health view. Ment Retard Dev Disabil Res Rev. 2002;8(3):162–70.
2. Danielson ML, Bitsko RH, Ghandour RM, et al. Prevalence of Parent-Reported ADHD diagnosis and associated treatment among U.S. Children and adolescents, 2016. J Clin Child Adolesc Psychol. 2018;47(2):199–212.
3. Vasiliadis HM, Diallo FB, Rochette L, et al. Temporal trends in the prevalence and incidence of diagnosed ADHD in children and young adults between 1999 and 2012 in Canada: A data linkage study. Can J Psychiatry. 2017;62(12):818–26.
4. Faraone SV, Mick E. Molecular genetics of attention deficit hyperactivity disorder. Psychiatr Clin North Am. 2010;33(1):159–80.
5. Thapar A, Cooper M, Eyre O, et al. What have we learnt about the causes of ADHD? J Child Psychol Psychiatry. 2013;54(1):3–16.
6. Betran AP, Ye J, Moller AB et al. Trends and projections of caesarean section rates: global and regional estimates. BMJ Glob Health. 2021;6(6).
7. Canadian Institute for Health Information. Caesarean Section Rate [indicator]. Accessed March 28. 2023. Available from: https://www.cihi.ca/en/indicators/caesarean-section-rate
8. World Health Organization (WHO). WHO Statement on Caesarean Section Rates. WHO/RHR/15.02. World Health Organization 2015. Available from: https://www.who.int/publications/i/item/WHO-RHR-15.02
9. Sandall J, Tribe RM, Avery L, et al. Short-term and long-term effects of caesarean section on the health of women and children. Lancet. 2018;392(10155):1349–57.
10. Li HT, Zhou YB, Liu JM. The impact of Cesarean section on offspring overweight and obesity: a systematic review and meta-analysis. Int J Obes (Lond). 2013;37(7):893–9.
11. Cardwell CR, Stene LC, Joner G, et al. Caesarean section is associated with an increased risk of childhood-onset type 1 diabetes mellitus: a meta-analysis of observational studies. Diabetologia. 2008;51(5):726–35.
12. Thavagnanam S, Fleming J, Bromley A, et al. A meta-analysis of the association between caesarean section and childhood asthma. Clin Exp Allergy. 2008;38(4):629–33.
13. Bager P, Wohlfahrt J, Westergaard T. Caesarean delivery and risk of atopy and allergic disease: meta-analyses. Clin Exp Allergy. 2008;38(4):634–42.
14. Xu LL, Zhang X, Zhou GL, et al. Meta-analysis found that studies May have overestimated caesarean section risks for attention-deficit hyperactivity disorder by ignoring confounding factors. Acta Paediatr. 2020;109(2):258–65.
15. Curran EA, O'Neill SM, Cryan JF, et al. Research review: birth by caesarean section and development of autism spectrum disorder and attention-deficit/

hyperactivity disorder: a systematic review and meta-analysis. J Child Psychol Psychiatry. 2015;56(5):500–8.
16. Renz-Polster H, David MR, Buist AS, et al. Caesarean section delivery and the risk of allergic disorders in childhood. Clin Exp Allergy. 2005;35(11):1466–72.
17. Ali UA, Norwitz ER. Vacuum-assisted vaginal delivery. Rev Obstet Gynecol. 2009;2(1):5–17.
18. Berard A, Sheehy O. The Quebec pregnancy Cohort–prevalence of medication use during gestation and pregnancy outcomes. PLoS ONE. 2014;9(4):e93870.
19. Vilain A, Otis S, Forget A, et al. Agreement between administrative databases and medical charts for pregnancy-related variables among asthmatic women. Pharmacoepidemiol Drug Saf. 2008;17(4):345–53.
20. McDougall MR, Hay DA, Bennett KS. Having a co-twin with attention-deficit hyperactivity disorder. Twin Res Hum Genet. 2006;9(1):148–54.
21. de Zeeuw P, Zwart F, Schrama R, et al. Prenatal exposure to cigarette smoke or alcohol and cerebellum volume in attention-deficit/hyperactivity disorder and typical development. Transl Psychiatry. 2012;2(3):e84.
22. Axelsson PB, Clausen TD, Petersen AH, et al. Investigating the effects of Cesarean delivery and antibiotic use in early childhood on risk of later attention deficit hyperactivity disorder. J Child Psychol Psychiatry. 2019;60(2):151–9.
23. Frisell T, Oberg S, Kuja-Halkola R, et al. Sibling comparison designs: bias from non-shared confounders and measurement error. Epidemiology. 2012;23(5):713–20.
24. Zhang T, Brander G, Mantel A, et al. Assessment of Cesarean delivery and neurodevelopmental and psychiatric disorders in the children of a Population-Based Swedish birth cohort. JAMA Netw Open. 2021;4(3):e210837.
25. Curran EA, Khashan AS, Dalman C, et al. Obstetric mode of delivery and attention-deficit/hyperactivity disorder: a sibling-matched study. Int J Epidemiol. 2016;45(2):532–42.
26. Haervig KB, Mortensen LH, Hansen AV, et al. Use of ADHD medication during pregnancy from 1999 to 2010: a Danish register-based study. Pharmacoepidemiol Drug Saf. 2014;23(5):526–33.
27. Curran EA, Cryan JF, Kenny LC, et al. Obstetrical mode of delivery and childhood behavior and psychological development in a British cohort. J Autism Dev Disord. 2016;46(2):603–14.
28. Zhao JP, Sheehy O, Gorgui J, et al. Can we rely on pharmacy claims databases to ascertain maternal use of medications during pregnancy?? Birth Defects Res. 2017;109(6):423–31.
29. Boerma T, Ronsmans C, Melesse DY, et al. Global epidemiology of use of and disparities in caesarean sections. Lancet. 2018;392(10155):1341–8.
30. Tribe RM, Taylor PD, Kelly NM, et al. Parturition and the perinatal period: can mode of delivery impact on the future health of the neonate? J Physiol. 2018;596(23):5709–22.
31. Getahun D, Rhoads GG, Demissie K, et al. In utero exposure to ischemic-hypoxic conditions and attention-deficit/hyperactivity disorder. Pediatrics. 2013;131(1):e53–61.
32. Obeagu EI, Obeagu GU. Hypoxia in pregnancy: implicatons for fetal development. Int J Curr Res Chem Pharm Sci. 2024;11(8):1–12.
33. Piesova M, Mach M. Impact of perinatal hypoxia on the developing brain. Physiol Res. 2020;69(2):199–213.
34. Kostic S, Ivanovic K, Jovanovic I et al. Neurodevelopment of children born with forceps Delivery-A single tertiary clinic study. Med (Kaunas). 2024;60(11).

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