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Review

IMPACT OF MATERNAL NUTRITION ON CHILD NEURODEVELOPMENT: INSIGHTS FROM RECENT STUDIES

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Background: *The initial 1000 days of human life, from conception to two years of age, are crucial for health growth and neuropsychological development. This period's primary environmental influence is maternal nutrition, which significantly impacts the development of the fetal nervous system.*
Objectives: *This review aims to synthesize current literature on the effects of dietary patterns and nutritional status of pregnant women on the neurodevelopment of their offspring.*
Methods: *Adhering to the Scale for the Quality Assessment of Narrative Review Articles (SANRA) and elements of the PRISMA guidelines, we conducted a systematic literature search in electronic databases including PubMed, Scopus, and Mendeley, focusing on publications from 2018 to 2023.*
Results: *Our review encapsulates findings from 25 peer-reviewed articles, highlighting the influence of various nutrients like polyunsaturated fatty acids (PUFAs), vitamin D, folate, iodine, and iron on child neurodevelopment. Studies also examined the effects of maternal dietary patterns, body mass index (BMI), and alcohol exposure. Key findings indicate the crucial role of balanced maternal nutrition in optimal neurodevelopmental outcomes in children.*
Discussion: *The review reveals intricate relationships between maternal dietary habits, supplementation, and child growth and neurological development. While some nutrients show clear benefits, others present mixed findings, underlining the complexity of maternal nutrition's role in child development.*
Conclusion: *The review underscores the importance of balanced maternal nutrition for favorable neurodevelopmental outcomes in offspring, calling for more detailed research to understand the nuanced roles of specific nutrients and dietary patterns*. ***Biomed Rev*** **2023; 34: 109-119**

Keywords: pregnancy, mother's diet, fatty acids, neurodevelopmental assessment, cerebral palsy, Attention Deficit and Hyperactivity Disorder (ADHD)

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INTRODUCTION

Nutritional intake during the first 1000 days of a human's life, spanning from conception to two years of age, plays a crucial role in health, growth, and neuro-psychological development. The mother provides essential nutrients and oxygen for the growth and development of the embryo and fetus through the placenta, highlighting the organism's high intrauterine sensitivity to environmental impacts. The development of the fetal nervous system is characterized by periods of rapid growth and structural change, demanding high metabolic and nutritional needs (1).

Neural tissue development is an intense process involving a series of cellular events. One of the early embryonic processes is neurulation, occurring between the 18th and 28th day post-conception (2). From the 42nd day to mid-pregnancy is the period of neurogenesis, followed by migration, differentiation, synapse formation, and apoptosis (3). These intensive processes of anatomical and functional maturation increase the susceptibility of neural tissue to environmental factors. Among these, the maternal nutritional status during pregnancy can be pivotal. Both undernutrition and overnutrition during pregnancy can adversely affect fetal growth and development. Epidemiological studies have provided evidence linking fetal exposure during intrauterine development to an obesogenic diet with an increased risk of neurobehavioral disorders in children (4).

The role of nutrients in brain function has been established. Macronutrients (proteins, carbohydrates, and fats) are the primary building blocks, while micronutrients - vitamins and mineral substances - are essential for myelination, synaptogenesis, and the production and transmission of neurotransmitters. The composition of fatty acids (FAs) in maternal nutrition during pregnancy affects the normal development of the offspring. Dietary FAs influence the development of the fetal and postnatal central nervous system, being crucial components of cellular membranes and having a primary effect on cortical maturation, synaptogenesis, and myelination. Vitamin B deficiencies can affect cellular growth and the development of neural tissue. For instance, thiamine deficiency might impair fetal brain development due to subclinical metabolic disturbances in thiamine-dependent enzyme systems involved in lipid and nucleotide synthesis in the brain (5). Folate plays a crucial role in the prevention of neural tube defects and neurogenesis, apoptosis, and the normal development of the nervous system. Choline is important for the normal functioning of the nervous system, cognitive development, attention, memory, mood in offspring, and the normal development of the neural tube in the fetus. Iron is necessary for building enzyme systems involved in oxidative processes and specific brain functions – myelination and the synthesis of serotonin and dopamine neurotransmitters.

The role of iodine in regulating brain development is well-recognized. Globally, iodine deficiency is one of the most common nutrient deficiencies, prevalent in both low and high-income countries (6). Pregnant women are a risk group for iodine deficiency. Studies show that mild to moderate iodine deficiency in pregnant women can negatively affect the neurological development of the fetus (7, 8).

This review aims to analyze the current literature on the effects of dietary patterns and nutritional status of pregnant women on the neurodevelopment of their offspring.

METHODS

For this narrative review, we adhered to the Scale for the Quality Assessment of Narrative Review Articles (SANRA) criteria (9). Additionally, elements of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were incorporated (10).

SEARCH STRATEGY AND RESEARCH SOURCES

During July-August 2023, we conducted a systematic literature search using the keywords (nutrition OR dietary patterns) AND pregnancy AND (offspring neurodevelopment OR child neurodevelopment) in electronic databases including Pub Med, Scopus, and Mendeley. We set a publication timeframe from 2018 to 2023, focusing on texts available as Abstract, Free full text, and Full text. Only articles written in English were selected. The chosen publications were exported to Rayyan, a software for systematic review management. Data extraction was conducted, with three independent reviewers (RC, AT, RB) cross-examining the textual content to identify and categorize recurrent themes and unique findings. The results were discussed with all members of the team during weekly meetings.

ELIGIBILITY CRITERIA

Our inclusion criteria were: cohort studies, subjects being pregnant women and their offspring, publication period from 2018 to 2023, articles written in English. Exclusion criteria included: reviews, case-studies, randomized controlled trials, animal studies, non-English language, irrelevant target groups (e.g., breast-feeding women, pre-pregnancy period).

STUDY SELECTION AND DATA EXTRACTION

The study selection process involved identification, screening, eligibility, and final inclusion, as depicted in the PRISMA flow diagram (Fig. 1).

Data extraction involved filling out a pre-defined table with details like: First author and publication year, Country, Sample size, Nutrient, Method for assessing maternal nutrient intake and/or nutritional status, Study outcomes, Tool/scales for neurodevelopment assessment, Main findings.

RESULTS

Study Identification and Inclusion: Our comprehensive search across electronic databases yielded a total of 537 titles. Initial screening led to the exclusion of 212 articles. A further

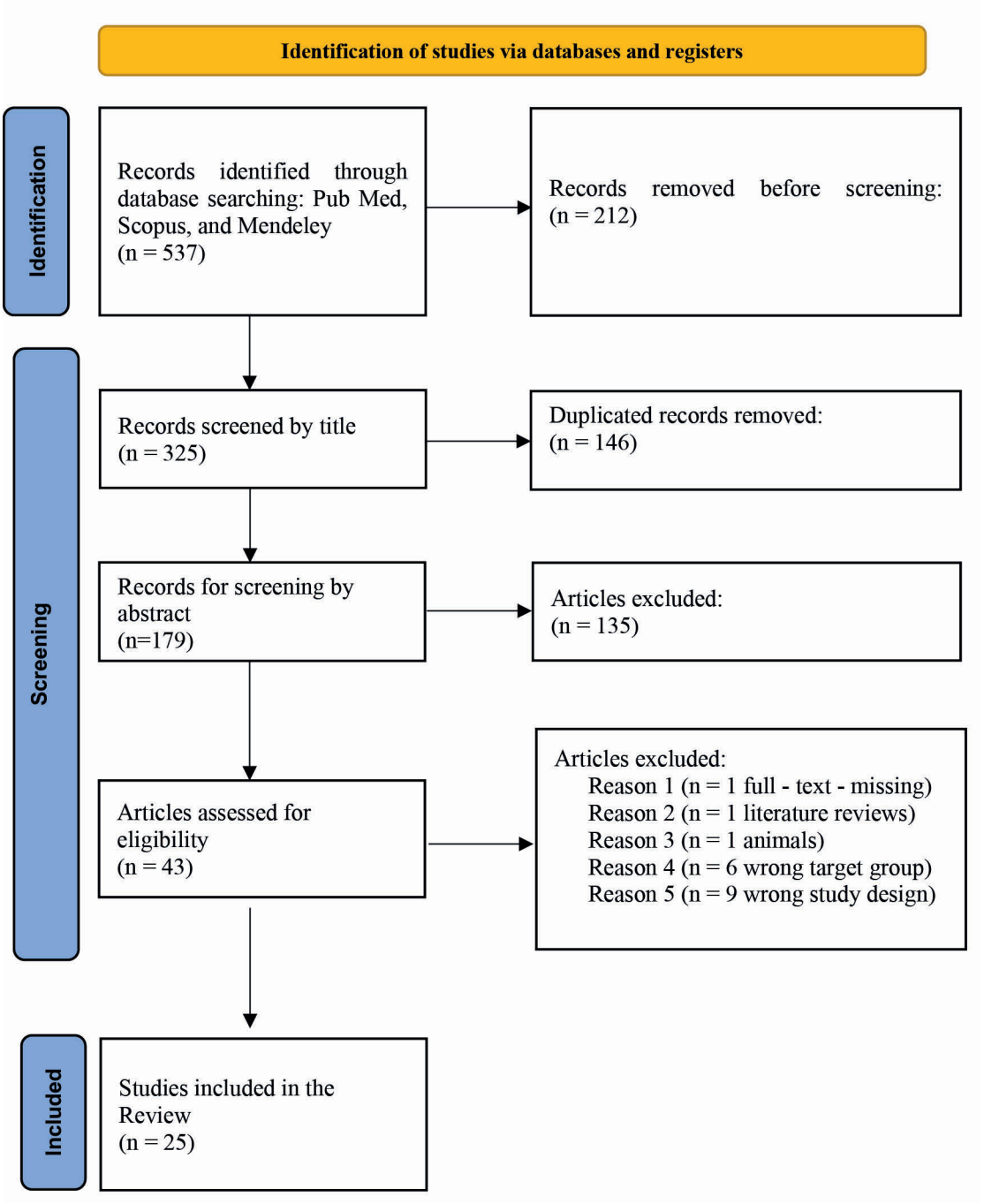


Figure 1. *Flow diagram of selection process indicating the number of publications at each stage. Color figure can be viewed at https://www.bmj.com/content/372/bmj.n160*

in-depth assessment of abstracts resulted in the exclusion of 135 articles. This process refined our pool to 43 full-text manuscripts for intensive review. Subsequent scrutiny based on our stringent inclusion criteria led to the exclusion of 18 studies. Consequently, 25 peer-reviewed articles were qualified for this final narrative review (Fig. 1).

Geographical Diversity: The selected studies exhibited a diverse geographic distribution, with notable contributions from Spain and China, alongside broad representation from European, North American, and Asian regions. This diverse geographical range provided a global perspective on maternal nutrition and its impact on child neurodevelopment.

Participant Cohort Sizes: The cohort sizes of the studies showed considerable variation. Hamazaki (2021) researched a large cohort of 159 448 mother-infant pairs (11), contrasting with Guzzardi (2022), who examined a relatively smaller cohort of about 90 pairs (12). The majority of the studies - 68% (n=17), fall within the range of up to 2000 mother-child pairs (Table 1).

Temporal Distribution of Research: The analysis of the studies on the impact of nutrition during pregnancy on the neurodevelopment of offspring found that they were conducted at different stages of pregnancy. Specifically, some studies focused on the first and second trimesters (12-16), some - spanned the second and third trimesters (11, 17-21) and other encompassed the first and third trimesters.

Age Range of Children: The age range of children in these studies varied, primarily falling between one month to eight years. Specific examples include Yan et al. (22), focusing on one-month-old infants, and Abel et al. (13) and Freitas-Vilela et al. (23), extending their research to include children up to 8 years.

Focused Areas of Research: The primary emphasis of the included studies was on the interrelation between maternal diet or nutrition during pregnancy and its subsequent effects on child neurodevelopment. In the publications we have examined, the effects on offspring neurodevelopment from the maternal intake or status of polyunsaturated fatty acids (PUFAs) (11, 18, 24, 25), folate (22, 26, 27), vitamin D (28, 29), iodine (13, 16, 30), and iron (14) have been studied. Several studies have assessed the impact of the mother's dietary pattern (15, 20, 23), her BMI (12, 17, 19, 31, 32), and microbiota (12). Irvine N et al. investigated the impact of maternal dietary intake of of choline on the memory, intelligence, and motor functions of the offspring (27). Several studies also delved into the impacts of maternal alcohol exposure (31, 33) and plasma carotenoids (34) on child neurodevelopment. In five studies, the effect of supplementation with nutrients has been assessed – iodine (13, 16), folic acid (22, 26), vitamin D (29).

Assessment of Maternal Nutrition and Nutritional Status: The Food Frequency Questionnaire (FFQ) emerged as a common tool for dietary pattern assessment across studies (15, 18, 20, 22, 35). Other methods used to assess the nutrition of the pregnant woman and her nutritional status was 24-hour dietary recall (27), dietary questionnaire (19, 22, 26, 31), serum ferritin levels (14), blood samples for folate (27), for PUFAs (25), thyroid hormones measurement (30, 35), 25(OH) D plasma concentration (28), 25(OH)D in cord blood (29), urinary iodine concentration (UIC) (16, 30). We identified a study on the effect of consuming ultra-processed foods (UPF) during pregnancy on child neurodevelopment (21).

Neurodevelopmental Assessment in Children: Neurodevelopmental progress in children was primarily evaluated using various established scales and tests, including Griffith's Mental Development Scales (12), Bayley Scales (15, 17, 18, 20, 21, 34, 35), , McCarthy Scales (16, 18, 21), Attention Deficit and Hyperactivity Disorder (ADHD) Diagnostic and Statistical Manual of Mental Disorders and Conners' Rating Scale (24), Wechsler Scales and NEPSY-II subtests (27), Kaufman Brief Intelligence Test (33, 34), Child Behavior Checklist (25, 33), Ages and Stages Questionnaire (29), Gesell Development Scale (30) (Table 1).

Different approaches are used for the assessment of the neuro-psychological development of children, which is most commonly done at the age of 1 year (36%, n=9), at the age of 2 years (32%, n=8), at the age of 8 years (32%, n=8), and less common at the age of 4 years (24%, n=6). The assessments are conducted with a frequency ranging from 1 to 5 times, with intervals between assessments ranging from 6 months to 6.5 years.

Key Study Outcomes:

• **Cognitive and Neurodevelopmental Metrics:** The primary focus was on cognitive and neurodevelopmental endpoints, with several studies evaluating aspects like verbal intelligence quotient (IQ), performance IQ, working memory, attention, executive function, and problem-solving abilities.

• **Physical Development Parameters:** Some studies, like that of Wang et al. (29), also concentrated on physical growth metrics.

• **Nutritional Influences:** The studies provided insights into the influence of maternal dietary patterns, fatty acid intake, and specific nutrients like vitamin D, folate, carotenoids, iodine, and iron on child neurodevelopment.

Table 1. *Detailed characteristics of the studies*

First Author, Year	Sample size	Age of children	Study focus	Assessment method of maternal nutrition	Pregnancy stage	Tool/scales for neurodevelopment assessment
Abel MH, 2019	39,471 mother-child pairs	8 y	Iodine intake	FFQ	First half	NA
Arija V, 2019	2,032 mother-child pairs	7-8 y	Maternal iron status and intake during pregnancy	Serum ferritin levels and FFQ	First trimester and 4-7 months gestation	NA
de Seymour JV, 2022	1,437 mother-child pairs	11.5-12.5 mo	Early pregnancy dietary patterns and their relation to pregnancy/infant outcomes	FFQ	11–14 weeks gestation	Bayley Scales
Dong X., 2023	3,115 mother-child pairs	2 y	Impact of maternal pre-pregnancy BMI and gestational weight growth on infant neurodevelopment	NA	Under 16 weeks gestation	Bayley scales (BSID-CR)
Freitas-Vilela AA, 2018	12,195 mother-child pairs	8 y	Impact of maternal dietary patterns during pregnancy on offspring's IQ	FFQ	32 weeks' gestation	Wechsler Intelligence Scale for Children
Gignac F, 2019	2,208 mother-child pairs	Birth, 1.5, 5, and 8 y	Impact of maternal nut intake during pregnancy on child neuropsychological outcomes	FFQ	First and third trimesters	Bayley Scales of Infant Development McCarthy scales of Children's Abilities; Attention Network Test (ANT); N-Back test
Groot J, 2022	190,989 live-born children	Surviving the first year of life	Association of folic acid supplementation with cerebral palsy (CP) risk	Maternal interview/ questionnaire	GWs -4 to 8, 9 to 12, and -4 to 12; midpregnancy (GWs 22-25)	NA
Guzzardi MA, 2022	90 mother-child pairs	3, 6, 12, 24, 36 mo	Association between maternal obesity, gut microbiota, and cognitive development	16S rRNA sequencing of fecal samples; Griffith's Mental Development Scales	Beginning of pregnancy and 24-28 weeks	Griffith's Mental Development Scales.
Hamazaki K, 2020	81,697 pairs at 6 mo; 77,751 pairs at 1 y	6 mo and 1 y	Impact of maternal fish consumption and PUFA intake on child neurodevelopment	FFQ	Mid-late pregnancy	NA
Hasken JM, 2022	406	6 weeks and 9 mo	Effects of maternal weight and prenatal alcohol exposure on infant outcomes	NA	During pregnancy	Brief questionnaires (AUDIT, TACE, etc.), Neurodevelopment examinations
Irvine N, 2023	309 mother-child pairs	3-5 y	Maternal folate status and choline intake during pregnancy and its effect on child neurodevelopment	Maternal RBC folate from blood samples; 24-h dietary recall;	Second trimester	Wechsler Preschool and Primary Scales of Intelligence, (WPPSI); NEPSY-II subtests; Four behavioral executive function tasks; Movement Assessment Battery for Children

First Author, Year	Sample size	Age of children	Study focus	Assessment method of maternal nutrition	Pregnancy stage	Tool/scales for neurodevelopment assessment
Krzeczkowski, 2018	808 mother-child pairs	3-4 y	Effects of maternal BMI, hyperglycemia on child IQ and behavior	Cord blood, glucose test	First trimester	WPPSI-III, BASC-II
Krzeczkowski, 2019	815 mother-child pairs	2 y	Link of gestational weight gain to offspring emotional/behavioral problems	Dietary questionnaire	2nd and 3rd trimesters	Child Behavior Checklist (CBCL-1½ to 5)
Lai, 2021	419 mother-child pairs	2 and 4.5 y	Impact of maternal plasma carotenoids on offspring cognitive development	Maternal carotenoids at delivery	26-28 weeks and third trimester	Bayley Scales of Infant and Toddler Development; Kaufman Brief Intelligence Test
López-Vicente M, 2019	580 children at age 4; 642 at age 7	4 and 7 y	Impact of omega-6:omega-3 fatty acid ratio in cord plasma on ADHD symptoms at ages 4 and 7	omega-6:omega-3 fatty acid ratio in cord plasma	At birth	ADHD DSM-IV checklist; Conners' Rating Scale-Revised
Lv S, 2022	1178 mother-child pairs	1 y	Associations of maternal dietary patterns with 1-year infant neurodevelopment	FFQ	22-26 and 30-34 weeks	Bayley-III Screening Test
Maher GM, 2022	1507 mother-child pairs	2 and 5 y	Alcohol consumption effects on child neurodevelopment	Alcohol data at 15 weeks;	15 weeks gestation	Child Behaviour Checklist; Kaufman Brief Intelligence Test
Melough MM, 2021	1019	4-6 y	Examine gestational 25(OH)D's effect on children's IQ and potential racial differences	25 (OH) D plasma concentration	16-28 weeks gestation	NA
Monaghan, 2021	1328 mother-child pairs	20 mo	Investigate maternal thyroid function and child neurodevelopment in high fish-eating population	Thyroid hormones measured; FFQ	28 weeks gestation	NA
Murcia, 2018	1803 children	4-5 y	Assess association between maternal iodine status and child cognitive and motor development	FFQ for iodine intake; UIC measured in spot samples	10–13 weeks and 28–32 weeks gestation	McCarthy Scales of Children's Abilities
Puig-Vallverdú, 2022	2377 mother-child pairs	4-5 y	Assess maternal UPF consumption's effect on child development	FFQ for UPF consumption	12-32 weeks of gestation	Bayley Scales of Infant and Toddler Development McCarthy Scales of Children's Abilities
Tore, 2019	311 mother-child pairs	7 y	Effect of maternal PUFAs during gestation on child's social behaviors	Maternal blood samples for PUFAs	Early to late pregnancy (up to week 32)	Child Behaviour Checklist 4/18
Wang, 2018	1244	6 mo, 1 y, and 2 y	Examine the impact of fetal 25 (OH) D concentration on growth, adiposity, and neurodevelopment	Measurement of 25 (OH) D in cord blood	NA	Ages and Stages Questionnaire
Wu, 2023	469 mother-child pairs	18-24 mo	Examine the impact of maternal iodine excess and thyroid hormones on infantile neurodevelopment	Measurement of maternal UIC, TSH, TSI, and nonprotein-bound serum iodine	Pregnancy to 18-24 mo postpartum	Gesell Development Scale

First Author, Year	Sample size	Age of children	Study focus	Assessment method of maternal nutrition	Pregnancy stage	Tool/scales for neurodevelopment assessment
Yan J, 2020	1186 mother-child pairs	1 mo	Examine the impact of maternal folic acid (FA) supplementation on 1-month-old infants' neurodevelopment and its potential relationship with maternal inflammatory cytokine concentrations	Questionnaires on maternal lifestyles and FA supplementation; Measurement of serum Hcy and inflammatory cytokines at 16-18 weeks of gestation	16-18 weeks of gestation	Standard neuropsychological examination table

Abbreviations: FFQ (Food Frequency Questionnaire); **MDI** (Mental Development Index); **PDI** (Psychomotor Development Index); **FPV** (Fish, Poultry and Vegetables); **PSO** (Pasta, Sweetened Beverages, Oils); **BSID-CR** (Bayley Scale of Infant Development - Chinese revision); **BMI** (Body Mass Index); **GWG** (Gestational Weight Growth); **IQ** (Intelligence Quotient); **ANT** (Attention Network Test); **EPA** (Eicosapentaenoic Acid); **DNA** (Docosahexaaenoic Acid); **PUFA** (Polyunsaturated Fatty Acid); **CP** (Cerebral Palsy); **GW** (Gestational Week); **RNA** (Ribonucleo Acid); **RBC** (Red Blood Cell); **BASC** (Behavioral Assessment System for Children); **WPPSI** (Wechsler Preschool and Primary Scale of Intelligence); **GDM** (Gestational Diabetes Mellitus); **CBCL** (Child Behavior Checklist); **SES** (Socioeconomic Status); **PPD** (Postpartum Depression); **ADHD** (Attention Deficit and Hyperactivity Disorder); **DSM** (Diagnostic and Statistical Manual); **CDI** (Communicative Development Inventory); **FT3** (Free Thyroid hormones); **UIC** (Urinary Iodine Concentration); **GCS** (General Cognitive Scale); **UPF** (Ultra-Processed Food); **AA** (Arachidonic Acid); **TSH** (Thyroid-Stimulating Hormone); **TSI** (Total Serum Iodine); **FA** (Folic Acid); **DQ** (Development Quotient); **Hcy** (Homocysteine).

• ***PUFAs***

The effect of PUFAs on neurodevelopment has been assessed through the consumption of nuts (18) and fish (11) during pregnancy. Gignac F et al. found that higher intake during the first trimester led to better child neuropsychological development (18). According to Hamazaki K et al. maternal fish intake is linked to reduced risk of delays in fine motor and problem-solving at 6 months and 1 year (11). Several studies have found that an increased omega-6/omega-3 ratio increases the risk of problem solving at 6 months and 1 year (11), increases ADHD symptoms (24), and worsens social competence and externalizing behavior (25) in 7-year-old children.

• **Vitamin D**

Melough et al. (28) found that higher maternal 25(OH)D in pregnancy positively linked to higher children's IQ at 4-6 y, while according to (29) fetal 25(OH)D had no notable association with postnatal growth or neurodevelopment at 2 years.

• **Folate**

Groot *et al*. found no association between periconceptional intake of folic acid and cerebral palsy risk, but supplementation between 9 and 12 weeks of gestation reduced the risk of cerebral palsy 26). The benefits of folic acid supplementation during pregnancy were also reported by Yang et al. They found a higher development quotient in babies born to mothers supplemented with folic acid during pregnancy (22). According to another study (27) no significant associations between maternal folate status and choline intake with children's intelligence, language, memory, or motor skills at ages 3-4 years.

• **Carotenoids**

We identified one study on the effect of maternal carotenoid intake on neurodevelopment (34). The authors reported positive association between maternal β-carotene and cognitive development at age 2, but not at age 4.5 years.

• **Iodine**

The study by Abel et al. has found that low maternal iodine intake linked to poorer language, reading, writing (13). We identified research suggesting that excessive iodine intake may also have adverse effects on infantile neurodevelopment (30). Abel et al. (13) and Murcia et al. (16) found no association between iodine supplementation during pregnancy and neurodevelopment. According to Monaghan et al. (35) there was no association between maternal thyroid function and neurodevelopment at 20 months. Some minor imbalances of FT3 may impact neurodevelopment.

• **Iron**

Maternal iron nutritional status was assessed by serum ferritin in a study by Arija V et al. (14). The authors have reported that normal maternal serum ferritin in 1st trimester and iron intake linked to better working memory and executive functioning in children.

• **Alcohol Exposure Effects**

The detrimental impact of prenatal alcohol exposure,

especially during the first trimester, was a significant finding (31, 33).

DIETARY PATTERNS

Analysis of studies of mothers' dietary patterns found that children born to mothers in the fruit and vegetables cluster had higher IQ than children of mothers in the meat and potatoes and white bread and coffee dietary clusters during pregnancy (23). de Seymour et al. reported higher pasta, sweetened beverages, oils (PSO) - scores linked to lower psychomotor development index (PDI) at 12 months and no significant associations between higher fish, poultry and vegetables (FPV) and mental development index (MDI) (15).

• **Ultra-processed food (UPF)**

An adverse effect on preschool verbal function with higher UPF consumption during pregnancy was reported (21).

• **BMI**

Analysis of the studies we identified found that the offspring of overweight/obese mothers showed more adverse neurodevelopmental outcomes compared to children born to mothers with non-normal BMI (12, 17). Another study (31) reported that higher maternal weight was associated with better cognitive and motor performance at 6 weeks. Inadequate gestational weight growth in normal pre-pregnancy BMI mothers and excessive gestational weight growth in underweight pre-pregnancy BMI mothers led to lower MDI scores (17). Pre-pregnancy BMI and gestational diabetes mellitus, but not gestational weight gain, predicted more offspring externalizing and internalizing problems (19).

DISCUSSION

Our comprehensive review of cohort studies reveals intricate relationships between maternal dietary patterns, nutritional supplementation during pregnancy, and their subsequent impact on the growth and neurological development of offspring. This discussion synthesizes key findings from various studies, highlighting the complexity and nuances of maternal nutrition's role in child development. The diverse questionnaires applied to children at different age periods, with varying follow-up durations for assessing the neuro-mental status of the children and at different intervals, hinder the comparability of results across various studies. Increasing observations during the first year of life, conducting more prolonged and regular examinations of children at specific ages through similar intervals, and using consistent questionnaires and scales for assessing neuro-mental development and behavior could provide a more precise measurement of the influence of maternal nutrition on neurodevelopment at specific stages of childhood.

Fish n-3 and n-6 PUFAs: The role of fish and n-3 PUFA intake during pregnancy is crucial yet complex. While some studies highlight the benefits for children's psychomotor development, the specific mechanisms and the optimal balance of n-3 and n-6 fatty acids remain areas for further exploration.

Vitamin D and Neurodevelopment: This area remains contentious with mixed findings. Similar to the study by Melough MM *et al.* recent meta-analyses (36, 37) demonstrate a positive correlation between high maternal vitamin D levels and better neurocognitive functions in children. However, others, such as Sass *et al*. (38), have not observed a significant effect or have identified potential negative impacts, especially with high-dose supplements. These conflicting findings underscore the need for additional research to understand the nuanced role of vitamin D in fetal brain development.

Folic Acid Supplementation: The relationship between maternal folic acid status and the risk of neural tube defects has been well-established. Groot *et al.* (26) and Yan (22) provided insights into the beneficial effects of folic acid supplementation during pregnancy on child neurodevelopment. The findings of Groot J et al., suggesting that the folate status of a pregnant woman may have an effect on cerebral palsy, are to some extent consistent with the viewpoint of McGarel et al. regarding the importance of folic acid in the mid to late stages of pregnancy for the neurological development of the fetus (39). However, contrasting results (27) indicated no significant association between maternal folate levels and neurodevelopmental outcomes in children aged 3-5, highlighting the complexity of folic acid's role in early brain development.

β-Carotene and Early Neurodevelopment: Lai *et al*. (34) provided evidence that higher maternal β-carotene levels during late pregnancy positively influence cognitive development in children at two years of age, although the study also acknowledges certain limitations and calls for more detailed future research.

Iodine Supplementation and Neurodevelopment: Abel *et al*. (13) and Murcia *et al*. (16) explored the effects of iodine status and supplementation during pregnancy. Surprisingly, their studies did not find significant benefits of iodine supplementation on children's cognitive and motor development. Murcia et al. further emphasized that while low maternal urinary iodine was linked to lower cognitive outcomes in children, the overall impact of iodine supplementation appeared inconclusive. These findings contrast with the recommendations by many

medical communities advocating for iodine supplementation during pregnancy, suggesting a potential gap in understanding the optimal dietary iodine intake and its neurodevelopmental implications.

Iron, Ferritin, and Child Neurodevelopment: The global prevalence of iron deficiency, particularly among pregnant women, has been a concern. Arija *et al.* (14) noted that normal maternal serum ferritin levels, coupled with adequate iron intake during pregnancy, were associated with improved cognitive outcomes in children. This finding underscores the importance of maintaining optimal maternal iron levels from the onset of pregnancy and suggests the need for regular monitoring and dietary adjustments to achieve better neurocognitive outcomes in children.

Maternal Dietary Patterns and Child Neurodevelopment: The studies by Freitas-Vilela *et al.* (23) and Lv *et al.* (20) draw attention to the significant impact of maternal dietary patterns on child neurodevelopment. These findings suggest that diets rich in fruits, vegetables, and aquatic products during pregnancy are associated with better cognitive and motor outcomes in children, whereas diets dominated by processed foods and meats show opposite effects.

Ultra-Processed Foods: The adverse effects of maternal consumption of ultra-processed foods during pregnancy, as shown in studies like Puig-Vallverdú et al. (21), point to the need for dietary guidance and awareness among pregnant women.

Alcohol Consumption During Pregnancy: Studies by Maher GM (33) and Hasken JM (31) explore the controversial and often understated impact of maternal alcohol consumption on child neurodevelopment, emphasizing the risks even with moderate-to-high alcohol intake during early pregnancy.

CONCLUSION

This review has systematically examined the pivotal role of maternal nutrition in the neurodevelopmental outcomes of offspring. The evidence gathered from recent studies underscores the critical influence of specific nutrients, such as PUFAs, vitamin D, folate, iodine, and iron, on the developing nervous system of the fetus and young child. Notably, our analysis also draws attention to the potential developmental risks associated with adverse maternal factors like inappropriate BMI and alcohol consumption during pregnancy.

The findings of this review have significant implications for public health policies and nutritional guidelines. They advocate for targeted nutritional interventions and education programs for expectant mothers, emphasizing the importance of a balanced diet rich in essential nutrients. Such measures are crucial for optimizing neurodevelopmental outcomes and reducing the risk of developmental disorders in children.

Furthermore, the mixed results in some areas, particularly concerning the degree of impact of certain nutrients, point to the need for more detailed research. Future studies should focus on the long-term effects of maternal nutrition, the interplay of various dietary elements, and the influence of genetic and environmental factors in neurodevelopment.

In conclusion, this review highlights the necessity of ensuring optimal maternal nutrition as a straightforward yet profound strategy for fostering better neurodevelopmental health in future generations. It calls for a collaborative effort among healthcare professionals, researchers, and policymakers to integrate these findings into effective health promotion strategies and to explore the untapped potential in this field of research.

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CONFLICT OF INTEREST STATEMENT

The authors reported no conflict of interest.

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