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Original article

Nutrition education for expectant mothers: Nourishing the future

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Abstract:
Background: This review explores the importance of preconception education, examining its impact on maternal health, fetal development, and long-term well-being. The effectiveness of appropriate nutritional interventions, along with the role of different nutrients and their influence on epigenetics in the preconception period, are discussed with reference to the current scientific literature.
Objective: Women should enter pregnancy in the healthiest possible condition. Nutrition is increasingly recognized as important for reproductive health. Preconception nutrition education for women not only influences the immediate health of the mother and her offspring but also has the potential for transgenerational impact. It is of paramount importance for mothers to receive evidence-based nutrition education.
Results: Nutrients that influence healthy reproduction and lifelong health include vitamin B complex, in particular B1, B6, folate, B13, and B12; antioxidants (vitamins C and E); minerals such as iron, zinc, magnesium, selenium, iodine, and copper; and essential fatty acids. Recent studies have shown that a healthy diet, minimal consumption of fast food and foods with a high glycemic load, can normalize the course of pregnancy. These beneficial nutrients also reduce the risk of neural tube defects, autism, dyslexia, Down syndrome, childhood cancer, obesity, and fetal cell membrane defects associated with maternal diabetes. Research on paternal diet and its impact on health is limited. A woman's metabolism is seriously influenced by activity and affection. Modern foods are often processed beyond cellular recognition, which can lead to neurological and physical illnesses and mortality. A history of starvation or deprivation in early life can be passed from grandmothers to grandchildren through epigenetic inheritance across generations.

Keywords: nutrition, pregnancy, nutrition education, maternal health, conception, preconception period

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Introduction

Preconception nutrition is a fundamental aspect of reproductive health, significantly impacting maternal well-being and fetal development. Ensuring a balanced and nutrient-rich diet before conception is a preventive measure that promotes healthier pregnancies, better birth outcomes, and the long-term health of both the mother and her offspring. The focus on preconception nutrition underscores the importance of raising awareness and education regarding the importance of dietary choices in the preconception period. Preconception nutrition is a critical factor in determining the health development of both the mother and her offspring. Compelling evidence supports the importance of preconception nutrition and explores its profound impact on maternal well-being, reproductive outcomes, and the long-term health of the offspring. Drawing on current published scientific evidence, this study highlights key findings and emphasizes the pivotal role of informed preconception nutritional choices [1]. Preconception nutrition involves optimizing a woman's health before pregnancy to create an environment favorable for fetal development. Adequate nutrition during this period is associated with a reduced risk of congenital anomalies, preterm birth, and low birth weight. A well-balanced and nutrient-rich diet before conception is associated with regular menstrual cycles and optimal reproductive health. Adequate intake of essential nutrients maintains the hormonal balance necessary for successful conception and a healthy pregnancy [2]. Nutritional status before conception significantly influences fetal development. Key nutrients such as folate, iron, calcium, and essential fatty acids promote the development of a healthy embryo and may prevent neural tube defects and other congenital anomalies. A study by Ramakrishnan et al. in their 2012 systematic review examined the impact of women's nutrition before and during early pregnancy on maternal and fetal outcomes and provided valuable information on how maternal nutrition influences both maternal health and infant outcomes during early pregnancy [3]. Adequate nutrition before conception is a key factor in reducing maternal mortality and improving infant survival because it enhances a mother's ability to carry a pregnancy to term and promotes overall infant health and well-being [4]. Educational programs on preconception nutrition provide women with knowledge about the critical role of nutrition in reproductive health (*Figure 1*).

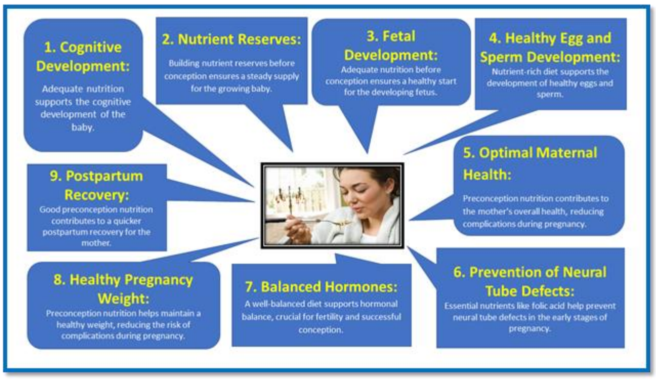

Figure 1. Factors to consider when illustrating the importance of preconception nutrition

Methods

A narrative review method was employed to examine the literature on maternal nutrition education and its impact on maternal and child health. PubMed, Web of Science, and Google Scholar were searched for original research articles, reviews, and guidelines on this topic. The search strategy included a combination of keywords and phrases, including "Nutrition education AND mothers," "Maternal nutrition education," "Maternal nutrition knowledge," "Child nutrition outcomes AND maternal education," "Maternal dietary habits AND child health," "Nutrition education programs AND maternal health," "Maternal and child nutrition interventions," "Nourishing the future through maternal nutrition," and "Maternal diet AND child development." Only articles published in English were considered. The initial search identified approximately 16,716 articles, of which 7,151 were published in the last 5 years. Of these, 391 articles focused on clinical trials. Our review focused on studies examining the impact of maternal diet on maternal and child health outcomes, including both observational studies and interventional trials. In addition, the review included studies evaluating educational interventions aimed at improving maternal nutrition knowledge and eating habits. Articles were selected for inclusion in the review based on their relevance to the research question and the quality of the evidence presented. Articles were screened by title, abstract, and full text to determine their eligibility for inclusion. Data extraction and synthesis were conducted to identify key findings and topics across the published sources. Although the review adopted a systematic approach to literature search, it should be noted that the evidence synthesis followed a narrative rather than a systematic review methodology.

Maternal health and preconception nutrition. The period before conception creates conditions for optimal nutrient storage, ensuring the mother's physiological readiness for pregnancy. Adequate nutrition before pregnancy is associated with a reduced risk of gestational complications such as preeclampsia and gestational diabetes, highlighting the importance of holistic maternal well-being. The benefits of preconception nutrition extend beyond pregnancy, impacting the long-term health of both mother and child. A healthy start in life lays the foundation for lifelong well-being, reducing the risk of chronic diseases later in life [5,6].

1) *Folic acid in preconception nutrition*. Folic acid, a synthetic form of folate, has gained notoriety for its significant impact on preconception health. Folic acid plays a multifaceted role, highlighting its importance in the prevention of neural tube defects (NTDs) and promoting overall reproductive health. Based on seminal research and current scientific literature, the mechanisms, benefits, and consequences of folic acid supplementation are important during the critical preconception period. Folic acid is widely recognized as an essential nutrient for preconception health, significantly reducing the risk of NTDs [7]. Nutrition education programs emphasize the importance of adequate folic acid intake through diet and supplements *(Figure 2)*.

a) Prevention of neural tube defects by folic acid int supplementation. NTDs, such as spina bifida and anencephaly, occur with an incidence of 0.5 to 2 per 1000 pregnancies, with varying degrees of disability for the affected child [8]. The neural tube is the embryonic structure that gives rise to the brain and spinal cord. It is now well established that folic acid deficiency (absolute or relative) is a predisposing factor to this type of malformation. Several randomized controlled trials (RCTs) have shown that a high dose of folic acid (4 mg) is an essential factor in preventing the recurrence of NTDs and significantly prevents the first occurrence of NTDs at a lower dose (0.4 mg). The pioneering work of Czeizel and Dudas (1992) laid the foundation for understanding the relationship between folic acid and the prevention of NTDs. This study demonstrated a significant reduction in the incidence of NTDs with folic acid supplementation during the periconceptional period [9]. Subsequent studies, including the 1991 Medical Research Council Vitamin Study, have consistently confirmed these findings and announced the preventative role of folic acid against devastating congenital anomalies [10]. The neural tube closes during the first 28 days of pregnancy, often before a woman is even aware of her pregnancy. Therefore, it is crucial for women of childbearing age to have adequate folate levels before conception.

b) Mechanisms of action of folic acid. Folic acid is a precursor to tetrahydrofolate, a coenzyme involved in one-carbon metabolism. This process is essential for the synthesis of purines and pyrimidines, which are the building blocks of DNA [11]. DNA synthesis is fundamental to the process of rapid cell division, especially in the developing tissues and organs of the embryo. Adequate levels of folate ensure the availability of these nucleotides for DNA replication and repair during embryonic development. Folate is also involved in the synthesis of certain amino acids, including methionine, which is critical for methylation reactions (a process associated with gene regulation). DNA methylation is crucial for the control of gene expression during development, including the proper regulation of genes involved in neural tube closure.

Furthermore, folate is required for the conversion of homocysteine to methionine through a process known as remethylation. Elevated homocysteine levels are associated with an increased risk of NTDs. Proper methylation reactions, facilitated by folic acid, promote neural tube closure early in embryonic development. By supporting these fundamental processes, folate promotes proper cell division, DNA replication, and the regulation of genes critical for neural tube formation and closure, ultimately preventing NTDs in the developing embryo. This mechanism is described in studies such as the review by Blom et al. (2006), which highlights the importance of timely folic acid supplementation by women [12].

c) Beyond neural tube defects. While the prevention of NTDs is a hallmark of folic acid supplementation, emerging research suggests broader health benefits of folic acid in the preconception period. Folic acid plays a key role in homocysteine metabolism, and elevated homocysteine levels have been associated with adverse reproductive outcomes, including pregnancy loss and preeclampsia (Ray et al., 1999) [13]. The role of folic acid in reducing these risks further emphasizes its importance in the preconception period [7].

d) Recommended timing and dosage of folic acid. For maximum preventive benefit, women are advised to take folic acid supplements before conception and during the first weeks of pregnancy. Ideally, supplementation should begin at least one month before conception and continue throughout the first trimester. The recommended daily intake varies, but a generally accepted recommendation is 400 mcg of folate. Women at increased risk may be advised to take higher doses. In addition to supplements, it is important to consume foods rich in natural folate. These include leafy greens, legumes, fortified cereals, and citrus fruits. However, getting enough folate from food alone can be difficult; hence, supplementation is often recommended [14].

e) Challenges and considerations. Despite compelling evidence, challenges remain in achieving universal folic acid supplementation. Cultural differences, socioeconomic factors, and limited access to healthcare contribute to inequalities in folic acid awareness and intake. Targeted public health interventions and campaigns are crucial to addressing these gaps and ensuring equitable access to preconception care. Folic acid serves as a beacon in preconception care, particularly in the prevention of NTDs. Convincing scientific evidence supports its role in early fetal development and suggests broader impacts on reproductive outcomes. Maintaining awareness, removing barriers to care, and integrating folic acid supplementation into routine preconception care are critical to advancing maternal and fetal health to promote healthier pregnancies and reduce the incidence of preventable congenital anomalies.

2) *Iron and vitamin B12 in the preconception period.* Iron and vitamin B12 are essential micronutrients that play a key role in many physiological processes, making them critical components of the preconception diet [15]. They are important for maternal well-being and fetal development. Several studies highlight the importance of maintaining optimal levels of these nutrients in the preconception period. These nutrients are essential for preventing anemia in women, which is associated with adverse pregnancy outcomes. Education about iron-rich foods and supplements helps women meet their needs in nutrients during the preconception period [16] (*Figure 2*).

a) Prevention of iron deficiency and anemia. Anemia developed from iron deficiency remains a global health problem, particularly among women of childbearing age. The preconception period represents a strategic window for addressing and preventing iron deficiency, as maternal iron status directly impacts the health of both the mother and the developing fetus. The WHO report on iron deficiency anemia (2001) emphasized the critical importance of adequate iron stores for optimal pregnancy outcomes. The association between maternal iron deficiency anemia and adverse outcomes such as preterm birth and low birth weight is well established [17]. Preconception nutrition education should emphasize the importance of consuming iron-rich foods and, where necessary, taking supplements to ensure women enter pregnancy with adequate iron stores [18].

b) Vitamin B12 and neurological development. Vitamin B12 plays a critical role in DNA synthesis, neurological function, and red blood cell formation. Its importance for preconception health is highlighted by studies linking maternal vitamin B12 deficiency to an increased risk of NTDs [19]. Furthermore, insufficient vitamin B12 levels during the preconception period have been associated with impaired cognitive development in offspring [3]. Ensuring adequate vitamin B12 intake is particularly important for women following vegetarian or vegan diets, as this nutrient is primarily found in animal products. Preconception education should highlight dietary sources of vitamin B12 and consider supplementation for high-risk populations.

c) Synergistic effects. Iron and vitamin B12 act synergistically, with a deficiency of one nutrient potentially exacerbating the effects of the other. For instance, vitamin B12 deficiency can lead to impaired iron absorption, thereby further compromising maternal and fetal well-being. Iron is an essential component of the heme component of hemoglobin in red blood cells, which is responsible for oxygen transport and delivery to various cells in the mother and fetus. Vitamin B12, on the other hand, is essential for cell division, DNA synthesis, red blood cell formation, and neuronal development in the fetus. Therefore, comprehensive preconception nutrition education should consider the interactions and complementarities of these two nutrients and promote a balanced and varied diet.

d) Challenges and development directions. Despite the recognized role of iron and vitamin B12 in maintaining preconception health, challenges remain, such as dietary restrictions, cultural traditions, and limited access to healthcare. Future interventions should address these challenges, promote dietary diversity, and tailor nutrition education to the needs of different population groups [3]. Iron and vitamin B12 are essential pillars of preconception nutrition, influencing maternal health and fetal development. Comprehensive preconception nutrition education, including nutrition strategies and, where necessary, supplementation, is crucial to ensuring optimal levels of these nutrients. As we gain a deeper understanding of the complex links between nutrition and reproductive outcomes, prioritizing iron and vitamin B12 in preconception care plays a key role in ensuring a healthier pregnancy and improving long-term health outcomes for both the mother and her offspring.

3) *Omega-3 fatty acid in preconception.* Omega-3 fatty acids in the preconception period. Omega-3 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), have attracted attention for their multifaceted health roles, particularly in the preconception period. Scientific literature on omega-3 fatty acids is important for maternal well-being, proper fetal development, and better reproductive health [20]. Omega-3 fatty acids, particularly DHA, play a key role in fetal brain and vision development [21]. Nutrition education helps women include sources such as fatty fish, flaxseed, and walnuts in their diets for good fetal development [20] (*Figure 3*).

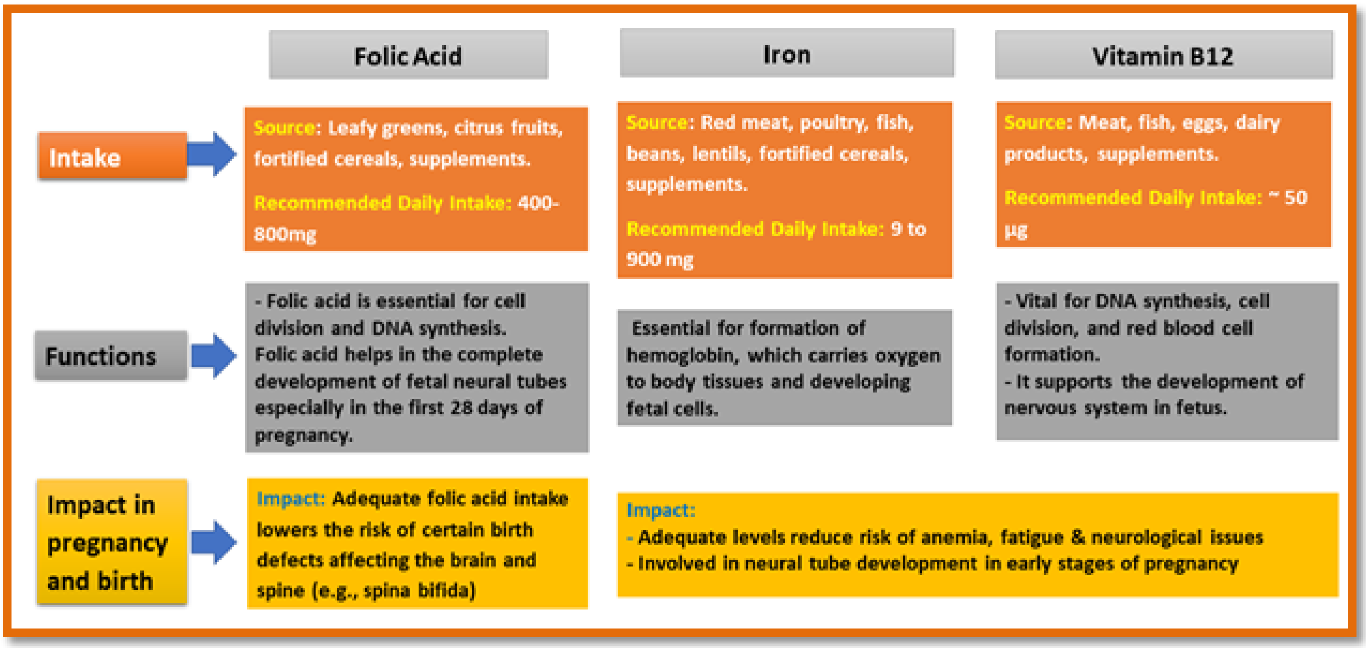

Figure 2. The role of folic acid, iron, and vitamin B12 in preconception health

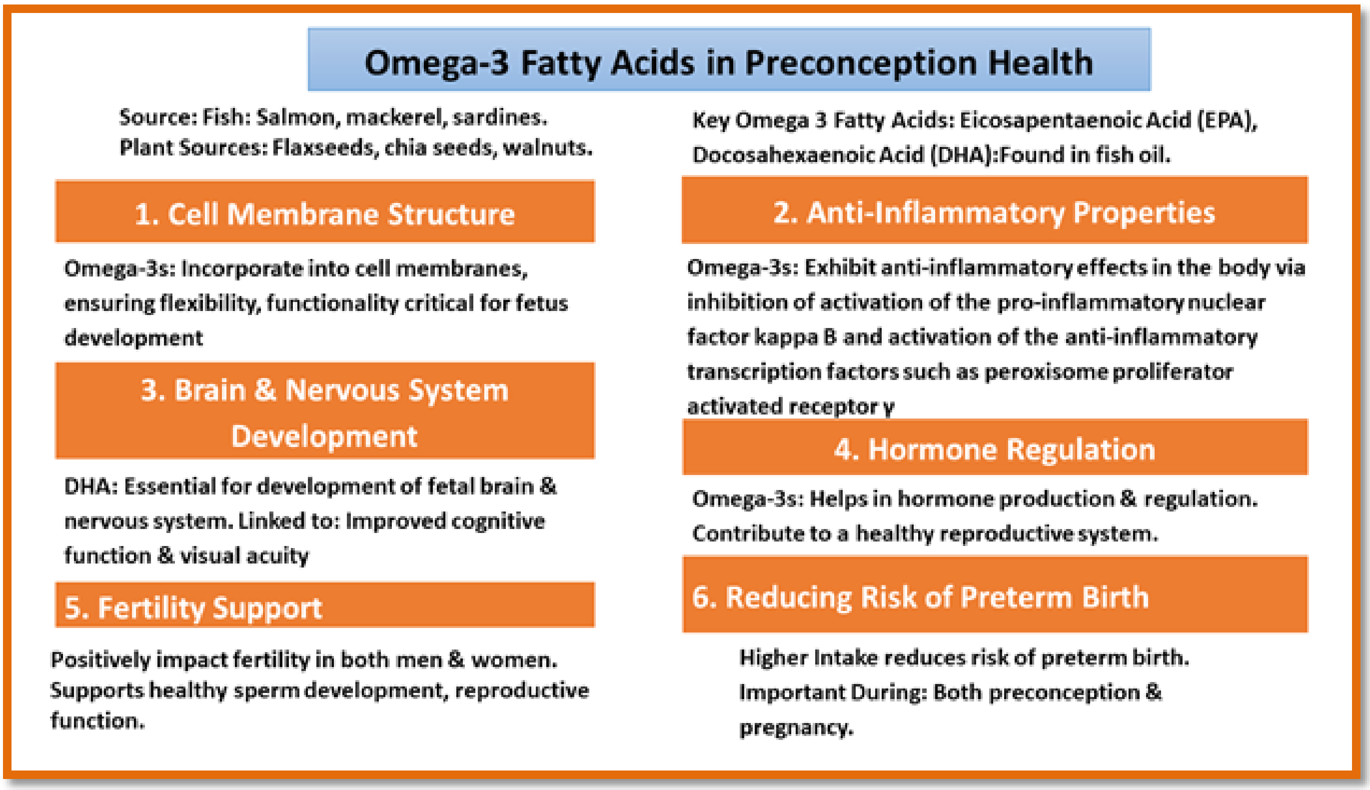

Figure 3. The importance and key functions of omega-3 fatty acids in preconception health

a) Maternal health benefits. Omega-3 fatty acids have been associated with numerous health benefits for women of childbearing age. Omega-3 fatty acids are essential nutrients found in certain foods, particularly fatty fish such as salmon, mackerel, and sardines, as well as flaxseed, chia seeds, and walnuts. Research has shown that omega-3 fatty acids influence brain health and may have potential positive effects on mental well-being [22].

b) Fetal neurodevelopment. DHA, an important omega-3 fatty acid, is a vital component of neuronal membranes and is critical for fetal brain and vision development. In their 2010 RCT, Makrides et al. investigated the effects of docosahexaenoic acid (DHA) supplementation during pregnancy on both maternal depression and young children's neurodevelopment. The study detected no significant difference in the incidence or severity of maternal depression between the DHA supplementation group and the control group, thereby providing evidence suggesting that prenatal DHA supplementation may not have a significant effect on reducing maternal depression. Furthermore, it also showed that DHA supplementation during pregnancy did not result in significant improvements in young children's neurodevelopment in their early life. Measures of cognitive development, language skills, motor skills, and overall developmental milestones did not differ significantly between the DHA supplementation group and the control group. These findings prompt careful consideration of the DHA supplementation role in prenatal care and call for public health recommendations. Although DHA is important for overall health, this study suggested that supplementation during pregnancy may not provide significant benefits for maternal mental health or infant neurodevelopment [23].

c) Reduction in preterm birth. Emerging evidence suggests a potential link between omega-3 fatty acids and a reduced risk of preterm birth. A review by Imhoff-Kunsch et al. summarizes the results of various studies indicating that omega-3 supplementation may help reduce the incidence of preterm birth [24]. This has important implications for preconception care of pregnant women, which aims to address one of the leading causes of neonatal mortality and morbidity.

d) Sources of omega-3 fatty acids. Informing women about dietary sources of omega-3 fatty acids is crucial for their preconception care. Oily fish, flaxseed, chia seeds, and walnuts are examples of nutrient-rich foods that can be included in a balanced diet. The study by Cholewski et al. (2018) discusses preconception diet. However, it also contains information on the sources of omega-3 fatty acids, their chemical composition, and bioavailability; and this information is quite relevant for dietary recommendations both before and during pregnancy. The importance of including a variety of omega-3 sources in the diet to ensure a balanced intake of different types of omega-3 fatty acids, such as EPA and DHA, is emphasized. This recommendation is consistent with the general principle of dietary diversity to meet needs in nutrients [25].

e) Challenges and considerations. While the benefits of omega-3 fatty acids are clear, there are also challenges, including concerns about mercury levels in some fish species and access to affordable and sustainable sources [26]. Addressing these issues is crucial to ensuring equitable access to the benefits of omega-3 fatty acids as part of preconception care for future mothers. Omega-3 fatty acids play a key role in preconception health, positively impacting both maternal and fetal health. As we continue to understand the complex links between nutrition and reproductive health, inclusion of the omega-3 fatty acids into programs of preconception nutrition education and care can significantly contribute to healthier pregnancies and improved well-being for future generations throughout their lives.

4) *The role of calcium and vitamin D in preconception nutrition.* Calcium and vitamin D are essential components of the preconception diet, profoundly impacting maternal health, fetal development, and long-term well-being. The individual and synergistic roles of calcium and vitamin D in the preconception period are critical for bone health, pregnancy outcomes, and overall reproductive health. Mansur et al. (2022) highlighted the importance of calcium and vitamin D intake for both maternal and fetal bone health [27]. However, RCTs, such as the study by Cooper et al. (2016), published in The Lancet Diabetes & Endocrinology, found no statistically significant association between maternal vitamin D intake and offspring bone health at the population level [28]. A reanalysis of the data from the Cooper et al. study, as discussed in Moon et al. (2017) suggests that, although overall population effects were not observed, vitamin D supplementation in the third trimester may have had some beneficial effects on offspring bone health [29]. This indicates that the timing of maternal vitamin D supplementation during pregnancy may be a critical factor influencing offspring bone development. Thus, while ensuring adequate calcium and vitamin D intake remains important for maternal and fetal bone health, current research highlights the need for further investigation of the timing and dosage of vitamin D supplementation to optimize offspring bone health outcomes. Educational programs emphasize the inclusion of dairy products, leaf vegetables, and sunlight exposure (*Figure 4*).

a) Calcium. Calcium is a cornerstone of bone health, and ensuring adequate intake during the preconception period is essential for skeletal development in both the mother and fetus. Adequate calcium intake before and during pregnancy may reduce the risk of osteoporosis in women later in life [30]. Furthermore, Scholl et al. suggested that maternal calcium intake influences fetal bone mineral content and calcium stores, which support the growth and development of the child's skeleton and teeth [31]. Calcium also plays an important role in the transmission of nerve impulses, supporting communication between nerve cells and the proper functioning of the nervous system. Furthermore, calcium is necessary for blood clotting, a process that becomes particularly important during childbirth [32]. Ensuring adequate calcium levels helps prevent excessive bleeding during labor and delivery [33]. Some studies suggest that calcium may play a role in blood pressure regulation. Maintaining normal blood pressure is important for overall cardiovascular health, which may contribute to a healthy pregnancy [34]. Preconception nutrition education should emphasize the inclusion of calcium-rich foods, such as dairy products and leafy greens, in the diet to support skeletal health.

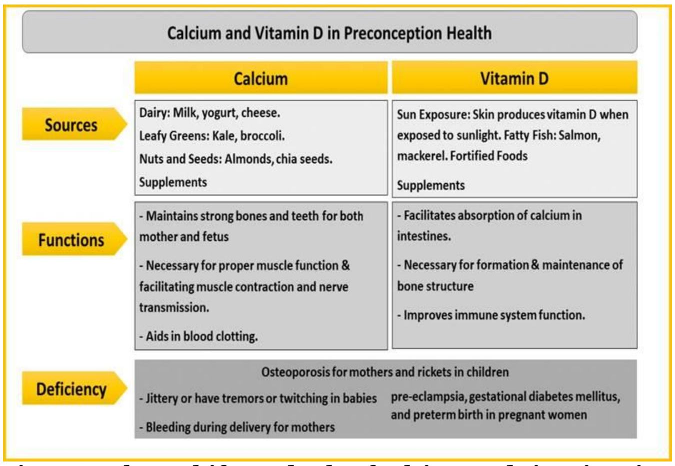

Figure 4: The multifaceted role of calcium and vitamin D in preconception health

b) Vitamin D. Vitamin D plays a critical role in the absorption and utilization of calcium. The synthesis of active vitamin D in the skin, induced by sunlight exposure, enhances the absorption of dietary calcium in the intestine. The synergy between vitamin D and calcium is crucial for maintaining optimal bone density and preventing conditions such as osteoporosis. Beyond its classic role in bone health, emerging research suggests that vitamin D may have immunomodulatory effects, potentially affecting fertility and pregnancy outcomes. A study by Gokosmanoglu (2020) highlights the link between vitamin D deficiency and conditions such as polycystic ovary syndrome (PCOS), suggesting a role for vitamin D in broader aspects of reproductive health [35]. Although exposure to sunlight is a natural source of vitamin D, factors such as geographic location, seasonal variations, and cultural traditions can contribute to deficiency. Maintaining adequate vitamin D levels during preconception and pregnancy, either through sunlight exposure, dietary sources, or supplements as needed, is recommended by American College of Obstetricians and Gynecologists (ACOG).

c) Challenges and considerations. Challenges associated with achieving optimal calcium and vitamin D levels include dietary preferences, lactose intolerance, and limited sun exposure [36]. Specialized interventions and nutrition education programs should address these challenges, ensuring equal access to these essential nutrients. As research continues to uncover the multifaceted roles of calcium and vitamin D, continued efforts to provide prenatal care will be critical to raising healthier generations [37].

Epigenetics and transgenerational effects. Beyond immediate maternal and fetal outcomes, preconception nutrition has implications for the long-term health of the offspring. Epigenetic mechanisms elucidated in studies such as the one by Waterland and Jirtle (2004) suggest that maternal nutrition before conception can affect gene expression in offspring, potentially influencing health across generations [38]. Research has examined maternal nutrition at different stages of pregnancy, which may directly or indirectly influence physiological and epigenetic changes in fetal tissues, which in turn may have serious consequences after birth. The impact of malnutrition during pregnancy on children conceived during the Dutch famine of 1944–1945 demonstrated that nutrient restriction can irreversibly impact adult health [39]. Kaminen-Ahola et al. in 2010 reported that pre- or postfertilization alcohol exposure in mice affects gene expression in the offspring and can negatively impact postnatal body weight and cranial size [40]. Similarly, studies conducted on cattle, sheep, or mice have shown that maternal diet and maternal nutrition during late pregnancy can negatively impact epigenetically sensitive genes, postnatal offspring body composition, growth rate, and insulin sensitivity [41,42]. Methyl supplementation in the diet of pregnant mice increased methylation levels of the agouti gene, which subsequently led to a change in coat color (from brown to yellow) and obesity in the neonates [41,42]. These studies clearly established that prenatal diet has transgenerational effects on the offspring through epigenetic modifications.

The field of epigenetics has uncovered how environmental factors, including maternal nutrition, can influence gene expression in offspring. Epigenetic modifications such as DNA methylation and acetylation regulate the expression of imprinted genes in a parent-of-origin-effect way, such that alleles inherited from one parent are expressed, while alleles inherited from the other parent are suppressed [43,44]. To explain the evolution of genomic imprinting, Moore and Haig (1991) hypothesized that paternal genes evolved to promote fetal growth, whereas maternal genes suppress fetal growth to allocate maternal resources to future pregnancies [45]. Therefore, imprinted genes are expected to play a significant role in fetal growth and development. Waterland and Jirtle (2004) demonstrated that maternal diet can influence epigenetic marks of metabolism-related genes, influencing the health of subsequent generations. This highlights the enduring influence of preconception nutrition on the epigenetic programming of offspring [38].

Maternal malnutrition and associated diseases. Nutritional value is restored by consuming unprocessed, free-range animals and seafood, along with whole-grain foods, bran and germ, fruits, nuts, and seeds. Undernutrition may arise from a lack of such diversity in food types. The Developmental Origins of Health and Disease (DOHaD) hypothesis postulates that events occurring early in development, including the preconception period, can influence long-term health outcomes. Research based on the Barker hypothesis suggests that unfavorable maternal nutrient stores before conception may influence the risk of chronic diseases in offspring, thereby emphasizing the importance of preconception health [46]. Therefore, poor nutrition before conception, including prenatal nutrition measured by birth weight, increases susceptibility to metabolic syndrome, which includes obesity, diabetes, insulin insensitivity, hypertension, and hyperlipidemia, as well as coronary artery disease and stroke [46]. The period of rapid postnatal growth is associated with high energy intake, which is a risk factor, as well as with a high-energy Western pattern diet. The mechanism of this association involves hypotheses of thrifty gene, bet hedging, predictive adaptive response of the fetus, and drifting phenotype; while the cause of this metabolic syndrome is likely multifactorial, as many nuclear DNA and cellular RNA sequences act in conjunction with environmental influences. Epidemiological data suggest that transgenerational epigenetic inheritance is a possible mechanism, whereby a history of early life fasting or deprivation is observed in a grandparent and transgenerational effects are noted in their grandchildren [46].

Intergenerational nutrient programming. The concept of intergenerational nutrient programming, often referred to as epigenetic programming, suggests that nutritional factors encountered before conception and early in life can influence the health of not only that individual but also, potentially, subsequent generations. This idea is rooted in epigenetics, which studies changes in gene expression that are not related to changes in the underlying DNA sequence. In 2010, Vicky King et al. demonstrated that maternal nutrient levels influence not only the offspring but also the health of subsequent generations. This phenomenon, known as nutrient programming, highlights the dynamic interaction between maternal nutrition, fetal development, and the transmission of health across generations [47]. While folate, iron, vitamin B12, calcium, vitamin D, and omega-3 fatty acids remain the cornerstone of maternal nutrition programs due to their robust evidence base, a growing body of research highlights the importance of a broader range of micronutrients and dietary factors. Iodine plays a critical role in thyroid function and nervous system development; selenium promotes antioxidant protection and placental health; and zinc is vital for immune regulation and cell growth. Furthermore, maternal diet influences the composition of the gut microbiome, which in turn shapes immune development and metabolic health in the offspring. Minor dietary components such as polyphenols and plant-derived bioactive compounds are increasingly recognized for their potential epigenetic and metabolic benefits. Thus, a comprehensive nutrition education program for expectant mothers should go beyond typical nutrients and incorporate these emerging dietary factors, thereby providing a holistic approach to the health of the mother and future generations [47].

Interventions and programs. Several successful interventions have demonstrated the positive impact of preconception nutrition education [48]. These programs often employ a multifaceted approach, combining educational sessions, dietary counseling, and personalized meal planning. Digital platforms, mobile apps, and social media are increasingly used to reach a wider audience and make information accessible. Individual responses to nutrition programs may vary, and genetic factors also influence health outcomes. Pregnant women and those planning to conceive should consult with healthcare providers for personalized nutrition and lifestyle recommendations. In addition to emerging evidence on the role of nutrients in reproductive and fetal health, several nutrition education programs already exist to support women preparing for pregnancy. The World Health Organization's Antenatal Care Framework emphasizes the importance of early nutrition counseling, folic acid supplementation, and lifestyle modification as integral components of maternal health. National programs, such as the Special Supplemental Nutrition Program for Pregnant Women in the United States and community-based antenatal counseling initiatives in low-income and medium-income countries, have demonstrated success in improving maternal nutrition knowledge and diet quality. The use of mobile health (mHealth) apps and digital counseling platforms provides easily accessible, personalized nutrition advice. Overall, programs that combine individualized counseling, culturally appropriate nutrition advice, and integration into routine maternal health care are the most feasible and effective. Such approaches ensure that expectant mothers are able to adhere to evidence-based dietary habits with stronger commitment and sustainability.

Interventions and long-term health. Evidence suggests that targeted preconception interventions, such as nutrition education programs, can break the cycle of adverse health outcomes that are transmitted across generations. Implementing educational strategies that empower women to make informed nutritional choices before conception can promote positive cascading health effects across generations. Educating women about nutrition during the preconception period extends beyond immediate health benefits, holding the potential to shape the health trajectories of future generations. Transgenerational impacts observed through epigenetic modifications, Developmental Origins of Health and Disease (DOHaD) principles, and nutrient programming highlight the need for comprehensive preconception care. As we explore the reproductive health landscape, continued efforts in preconception educational strategies and interventions will play a critical role in promoting sustainable health outcomes that will reverberate across generations [49].

Healthy eating issues in the preconception period

a) Socioeconomic disparities. Socioeconomic disparities in preconception health refer to differences in the health and well-being of individuals or communities based on their socioeconomic status. These differences can manifest in various aspects related to the period before conception, including access to healthcare, lifestyle, and overall health indicators. Socioeconomic factors significantly influence access to healthcare and nutrition. Women from lower socioeconomic backgrounds may face difficulties in obtaining nutritious foods and accessing quality healthcare, which impacts their ability to adhere to optimal nutrition practices before conception. Access to preconception counseling, which includes discussing health risks and optimizing health before pregnancy, may be limited for women with lower socioeconomic status [50]. Recognizing and addressing socioeconomic inequalities in preconception health is crucial for ensuring equal access to healthcare and improving outcomes for all individuals and communities. Policymakers, healthcare providers, and public health initiatives play a critical role in developing interventions and strategies aimed at reducing these disparities.

b) Cultural differences. Cultural beliefs and practices related to nutrition and health can vary significantly. Adapting preconception nutrition education to different cultural contexts is crucial to ensure that the information provided is relevant, respectful, and consistent with cultural norms and preferences [51].

c) Limited access to healthcare. Limited access to healthcare, particularly in rural or medically underserved areas, is a significant barrier to preconception care. Women facing geographic or financial constraints may be unable to receive personalized nutrition advice and interventions [52].

d) Technological inequalities. In the era of digital health, there is an increasing reliance on technology to disseminate health information. However, inequalities in access to technology and literacy may leave certain populations without the benefits of online nutrition resources and mobile apps designed for preconception education [53].

e) Behavioral change resistance. Encouraging behavior change is the primary goal of preconception nutrition education. However, resistance to change, ingrained habits, and a lack of perceived importance can hinder the adoption of healthier eating practices among women in the preconception period [54].

f) Nutrient absorption and bioavailability. In addition to focusing on essential nutrients, it is equally important to consider their absorption and bioavailability. Factors such as cooking methods, food combinations, and meal timing can significantly influence nutrient absorption. Educational programs for expectant mothers, including community workshops and digital platforms, often integrate practical guidance on nutrient-preserving cooking methods, balanced meal preparation, and food selection strategies. For example, programs can teach techniques such as steaming vegetables instead of boiling them, pairing iron-rich foods with sources of vitamin C to improve absorption, or minimizing overcooking to preserve heat-sensitive vitamins. By combining scientific knowledge with practical skills, these initiatives help expectant mothers optimize nutrient intake and support the well-being of both mother and fetus.

Future directions regarding healthy eating issues in the preconception period

a) Community-based approaches. Community-based approaches involve engaging local communities in the design and implementation of preconception nutrition education programs. Community-based interventions allow for greater cultural sensitivity and promote sustainable change by leveraging existing social networks [55].

b) Integrated health services. Integrating preconception nutrition education into standard health services can improve accessibility. Collaborative efforts among health care providers, community organizations, and policymakers can promote the incorporation of nutrition recommendations into standard health care practices [49].

c) Inclusive digital health. An expression 'the first 1,000 days' refers to a critical period in a child's life, from conception through the first two years of life. Research has shown that during this period, various health promotion interventions, including behavioral interventions and optimal treatment of underlying medical conditions in parents, can lay the foundation for optimal health, growth, and neural development throughout the lifespan of their offspring. Future efforts should focus on ensuring inclusivity in digital health interventions. This involves developing user-friendly, culturally sensitive digital platforms, taking into account differences in technology access and literacy across populations [56].

d) Behavioral economics strategies. Applying behavioral economics principles to preconception education programs can overcome resistance to behavior change. Strategies such as nudges, incentives, and personalized feedback can motivate women to adopt and maintain healthier diets [57].

e) Policy advocacy. Advocacy for policies that prioritize health and nutrition education before conception is crucial. Policy initiatives can address socioeconomic inequalities, expand access to healthcare, and promote community-based solutions, fostering a supportive environment for preconception care for pregnant women [49]. Overcoming the challenges of preconception nutrition education requires a multifaceted and collaborative effort. By addressing socioeconomic, cultural, and technological inequalities and implementing innovative strategies, we can pave the way for more inclusive, effective, and accessible preconception nutrition initiatives. These efforts are critical to ensuring healthier pregnancies and improving long-term health outcomes for both mothers and their offspring.

Conclusion

The importance of preconception nutrition cannot be overstated for maintaining maternal health, optimizing reproductive outcomes, and shaping the health trajectories of future generations. While the existing literature provides valuable insights, it is crucial to recognize the nuances and complexities in this field, including null findings and areas requiring further investigation. Combining data from diverse studies highlights the need for comprehensive education and interventions during the preconception period. As we move toward the era of personalized medicine, understanding and harnessing the potential of preconception nutrition are integral steps toward creating a healthier and more resilient population. However, it is important to acknowledge that the existing data are not without limitations. Null findings and conflicting results remind us of the complexities involved and the need for further research to refine our knowledge. Preconception nutrition education for women is a fundamental aspect of promoting maternal and fetal health, requiring support from multiple sectors, organizations, and governments. Empowering women with the importance of nutrition before pregnancy lays the foundation for a healthier start in life for the next generation. As research continues to uncover the complex links between nutrition and reproductive health, ongoing education and intervention efforts will be critical to ensuring the well-being of women before conception and their future children. Only through a coordinated multidisciplinary approach can we truly realize the potential of preconception nutrition to shape healthier future generations.

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