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SYSTEMATIC REVIEW | MATERNAL HEALTH

The Effect of Maternal Vitamin D Status on Fetal Growth and Stunting: A Systematic Review

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ABSTRACT

Background and Objective: Impaired fetal growth and stunting remain immense public health problems involving maternal nutrition during pregnancy, as linear growth failure in children is the most common form of undernutrition across the world. Although both are preventable through adequate prenatal care and nutrition, impaired fetal growth and stunting continue to be implicated in multiple child health morbidities, physical, and psychological functioning. Recent knowledge and requirements for normal fetal and neonatal development are lacking. This systematic review investigates the effects of maternal vitamin D status on fetal growth and stunting.

Methods: We reviewed three widely-used publications databases: the National Institutes of Health's PubMed, Clarivate Analytics' Web of Science, and Google Scholar using pre-established inclusion and exclusion criteria and keyword search strategy. Studies from 2010 to 2020 were included if they reported vitamin D levels on pregnant women, indicated growth outcomes and used quantitative measurements. We excluded non-English language studies, studies with ambiguous outcomes, studies that did not specify vitamin D intake, and studies that involved other maternal health complications. The search was implemented using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

Results: Out of a total of 2,481 studies reviewed, we identified 8 studies on vitamin D and fetal growth and stunting. Published literature addressing maternal vitamin D status on fetal growth and stunting remains ambiguous. Five studies demonstrated improvements in fetal and humerus z-scores, which are known proxies for fetal growth, in groups with higher vitamin D status. Three studies found no statistical significance between vitamin D levels and fetal growth. Vitamin D status and ethnicity were correlated; vitamin D interacts with calcium levels in pregnant mothers to improve bone mineralization and fetal growth.

Conclusion and Implications for Translation: Further studies are needed to understand the relationship between maternal vitamin D, ethnicity, and fetal growth and the long-term effects of maternal vitamin D levels on neonatal, early childhood, and adolescent growth.

Keywords: • Prenatal • Nutrition • Vitamin D • Stunting • Stunted • Fetal growth • Fetal • Antenatal • Maternal

1. Introduction

Fetal growth restriction and stunting have become substantial nutrition challenges, as linear growth failure remains the most common form of undernutrition globally.[1] For these conditions, the intergenerational cycles with maternal health and nutrition during pregnancy.[1] Fetal growth restriction is a condition characterized by smaller than expected fetuses, diagnosed by a pregnant mother's fundal height the distance from the top of the pubic bone to the top of the uterus.[2] Stunting is the impaired growth and development in early childhood from nutrition that presents as a child's height-for-age being two standard deviations below the World Health Organization (WHO) growth standards medium.[3] Impaired fetal growth and stunting are often caused by malnutrition in the pregnant mother, and stunting currently affects 26% of children under 5 years old globally.[4] Fetal growth restriction is often caused by inadequate nutrition and affects 10% of all pregnancies globally.[5] Fetal growth restriction and stunting are significant global health challenges, as impaired growth and stunting increase the risks of various morbidities, poor cognitive and psychological functioning, and mortality.[4] Although it is widely known that maternal nutritional status correlates with impaired growth in fetuses and neonates, it only recently came to light that vitamin D may play a large role in preventing impaired growth if taken in adequate amounts during pregnancy.[6] One of the earliest studies in this field conducted in 2016 highlighted the effect of low vitamin D levels on pregnancy outcomes, and how vitamin D intake may be associated with stunting due to its role in bone and skeletal growth and formation.[7] Adequate vitamin D intake during pregnancy may improve health outcomes for neonates, particularly for fetal growth and stunting, by improving fetal bone mineralization in the womb and regulating other mineral functions.[7]

Pregnant women and infants have an increased risk of being vitamin D deficient, and this is exacerbated in countries by poor nutrition profiles.[8] As the fetus' vitamin D levels are entirely reliant on the mother's levels due to the placental transfer of the vitamin, it is essential that pregnant women are not only aware of the importance of vitamin D, but also have adequate daily intake.[9] While studies have shown that vitamin D deficiency increases the risk of stunting 4-fold, and can cause skeletal growth issues, the literature and the WHO guidance are largely ambiguous about the effect of vitamin D on fetal growth.[7] Despite the WHO currently not recommending vitamin D as a prenatal supplement, Young et al. showed that vitamin D levels above the Estimated Average Requirement (EAR) in Canada correlate with longer fetal femurs, demonstrating the effect of vitamin D on fetal growth.[5] Vitamin D deficiency is cyclic and pregnant women who are deficient pass along their deficiency to their children, along with many other adverse health outcomes caused by vitamin D deficiency.[1]

Vitamin D also regulates calcium and phosphorous levels ensuring proper functioning hand-in-hand with calcium with one compensating for the other when levels are inadequate.[6] Vitamin D is necessary to complete bone mineralization in fetal skeletons; it also prevents further adverse health outcomes and chronic disease following pregnancy.[6]

One of six WHO Global Nutrition Targets is to reduce stunting by 40% by the year 2025.[4] To achieve this target, consistent efforts are needed to educate women of child-bearing age about the importance of prenatal care and adherence to prenatal nutrition recommendations to ensure healthy children.[4] Research into the effects of vitamin D intake during pregnancy on impaired fetal growth and stunting is new. Systematic reviews are increasingly important in health care; they help clinicians to keep up-to-date with their field and are often used as starting points for developing clinical practice guidelines.[10] In addition, grant-making agencies and funders leverage systematic reviews to justify further research and program development.[10] An understanding of current research may provide important information needed to plan programs or policies to reduce the burden of stunting and impaired child growth, especially in the developing world. In this paper, we sought to systematically review published literature examining the effect of maternal vitamin D status on fetal growth and stunting.

2. Methods

The PRISMA checklist of items to include in a systematic review was used.[10]

2.1. Eligibility

A systematic review of the literature was performed with the main source of data being the electronic databases PubMed, Web of Science, and Google Scholar with the developed strategy for English articles from 2010 to 2020. Commentaries, opinion articles, reviews, and books were excluded.

2.2. Identification of Studies

Study designs included were and randomized trials. To be included, studies must have observed and reported quantitative measurements. A broad search strategy was used to prevent search and selection biases. A combination of the following search terms was used: stunting/stunted, growth retardation, vitamin D, height, maternal, nutrition, prenatal, and antenatal (Table 1).

Table 1: Full PubMed Search Strategy developed using advanced search of the indicated search terms

Search: **stunting, growth, vitamin D, maternal, prenatal** ((((("growth disorders"[MeSH Terms] OR ("growth"[All Fields] AND "disorders"[All Fields])) OR "growth disorders"[All Fields]) OR "stunting"[All Fields]) OR "stunted"[All Fields]) AND (((((("growth and development"[MeSH Subheading] OR ("growth"[All Fields] AND "development"[All Fields])) OR "growth and development"[All Fields]) OR "growth"[All Fields]) OR "growth"[MeSH Terms]) OR "growths"[All Fields]) AND ((("vitamin d"[MeSH Terms] OR "vitamin d"[All Fields]) OR "ergocalciferols"[MeSH Terms]) OR "ergocalciferols"[All Fields]) AND (((((("maternally"[All Fields] OR "maternities"[All Fields]) OR "maternity"[All Fields]) OR "mothers"[MeSH Terms]) OR "mothers"[All Fields]) OR "maternal"[All Fields]) AND (("prenatal"[All Fields] OR "prenatally"[All Fields]) OR "prenatals"[All Fields])

2.3. Study Selection

Following a literature search of the above search terms, duplicate and irrelevant papers were discarded and the abstracts of the remaining papers were examined for relevance. Elements considered during the assessment of relevance included Population, Intervention, Comparison, Outcome, and Type of Study (PICOT). Case-control studies were excluded. Abstracts were assessed to determine if a quantitative measurement was included and the studies abided by the inclusion criteria. A set of eight eligible studies was selected and the following information was collected in a table: study design, follow-up period, sample size, source and date of data collection, and results (prevalence of stunting, weight-for-length, weight-for-height, other anthropometric measures) (Table 2).

In all, 2,481 studies were identified (Figure 1). Upon review, 1,590 studies were found to be duplicates and removed yielding 136 abstracts of studies involving fetal growth or stunting outcomes from maternal vitamin D status. Of the 136 studies, 73 were excluded for non-relevance and reporting of ambiguous outcomes. Of the remaining 63 studies, 55 were excluded due to ineligibility as per the inclusion and exclusion criteria indicated (Table 3). Specifically, studies were excluded because they: (1) did not involve mothers with vitamin D intake (n=13); (2) did not specify vitamin D intake amount (n=22); (3) were non-English (n=6); (4) did not report fetal growth or stunting prevalence or had ambiguous outcomes (n=11); and (5) were review studies (n=3). In the end, eight studies were included in the systematic review.

2.4. Risk of Bias

The risk of bias in randomized-control trials (2 studies) was assessed using the Cochrane Risk of Bias Tool. Biases that were assessed were selection, reporting, performance, detection, and attrition bias.[11] Bias in studies other than randomized control trials (6 studies) were assessed using the ROBINS-I risk of bias tool developed in 2016.[12] Based on our assessment, we believe that the evidence presented in this review is not affected by bias that may have been present in the individual studies.

3. Results

3.1. Description of Studies

Two randomized, double-blind, placebo-controlled trials were included in this review. Most of the studies used the WHO growth standards as the objective standard in their study (5). Two studies did not include a growth standard and one study

Table 2: Characteristics of included studies

Study (Author, Year and Journal of publication, Country of Study)	Study Title	Study Design	Sample Size (N)	Key Findings	Summary
Roth et al., 2018, *New England Journal of Medicine,* Bangladesh	Vitamin D Supplementation in Pregnancy and Lactation and Infant Growth	Randomized controlled trial	1164 infants, 1300 mothers	Prenatal maternal vitamin D supplementation had no significant effect on infant length or other anthropometric outcomes by year 1 of age, no significant effects of any vitamin D dose on preterm birth, low birth weight, or small for gestational age.	No significant effect.
Miliku et al., 2016, *American Journal of Clinical Nutrition,* The Netherlands	Maternal vitamin D concentrations during pregnancy, fetal growth patterns, and risks of adverse birth outcomes	Prospective cohort study	7098	Compared with mothers with second-trimester 25(OH) D concentrations in the highest quartile, those with 25(OH) D concentrations in the lower quartiles had offspring with third-trimester fetal growth restriction, leading to a smaller head circumference, shorter body length, and lower body weight at birth.	Lower quartile concentrations of vitamin D are associated with fetal growth restriction.
Toko et al., 2016, *Nutrients,* Kenya	Maternal Vitamin D Status and Adverse Birth Outcomes in Children from Rural Western Kenya	Prospective cohort study	63 mothers, 54 infants	Deficient plasma 25(OH) D levels were associated with a four-fold higher risk of stunting in neonates (p=0.04). Within this population subset, newborns were over four times as likely to be stunted at birth when born to a mother with a deficient plasma 25(OH) D level at enrollment.	Stunting increased four-fold in fetuses with plasma vitamin D deficient mothers.
Young et al., 2012, *American Journal of Clinical Nutrition,* USA	Maternal vitamin D status and calcium intake interact to affect fetal skeletal growth in utero in pregnant adolescents	Prospective cohort study	171	Maternal 25(OH) D>50 nmol/L was significantly positively associated with fetal femur and humerus Z scores.	Vitamin D is associated with increased bone growth in fetal skeletons.
Eggemoen et al., 2017, *British Journal of Nutrition,* Norway	Vitamin D levels during pregnancy and associations with birth weight and body composition of the newborn: a longitudinal multiethnic population-based study	Prospective cohort study	719	After adjusting for ethnicity, 25(OH) D was no longer associated with any growth outcomes. No independent relation between maternal vitamin D levels and any of the neonatal anthropometric measures.	No significant effect.

(Contd...)

Table 2: ***(Continued)***

Study (Author, Year and Journal of publication, Country of Study)	Study Title	Study Design	Sample Size (N)	Key Findings	Summary
Ong et al., 2016, *British Journal of Nutrition,* Singapore	The association of maternal vitamin D status with infant birth outcomes, postnatal growth, and adiposity in the first 2 years of life in a multi-ethnic Asian population: the Growing Up in Singapore Towards healthy Outcomes (GUSTO) cohort study	Prospective cohort study	910	No statistically significant associations were observed between maternal vitamin D status and any of the birth outcomes – small for gestational age, preterm birth, weight-for-age z-scores, length-for-age z-scores, circumferences of the head, abdomen, and mid-arm at birth or postnatally.	No significant effect.
Vafaei et al., 2019, *Bone,* Iran	Positive effect of low dose vitamin D supplementation on growth of fetal bones: A randomized prospective study	Randomized controlled trial	140	Growth in fetal femur length (FL) was statistically significant in the second and third trimester, proximal metaphyseal diameter (PMD)-FL, midshaft diameter (MSD)-FL, distal metaphyseal diameter (DMD)-FL, and fetal humerus length (HL) were significantly higher in the intervention group at the 2nd and 3rd trimesters. In addition, amounts of growth in PMD-HL, MSD-HL, and DMD-HL were significantly higher in the intervention group.	During the 2nd and 3rd trimesters, fetal growth is associated with the vitamin D intervention group.
Roth et al., 2013, *Journal of Pediatrics,* Bangladesh	Maternal Vitamin D3 Supplementation during the Third Trimester of Pregnancy: Effects on Infant Growth in a Longitudinal Follow-Up Study in Bangladesh	Prospective cohort study	160	Maternal vitamin D3 supplementation during the third trimester of pregnancy enhanced early postnatal linear growth in a cohort of infants in Bangladesh. The mean length-for-age z-score (LAZ) at 1 year of age remained significantly higher in the vitamin D group, and changes in LAZ indicated significantly accelerated growth during the first 4 weeks in the vitamin D group compared with placebo.	Increased maternal vitamin D increased LAZ scores significantly in infants up to 1 year.

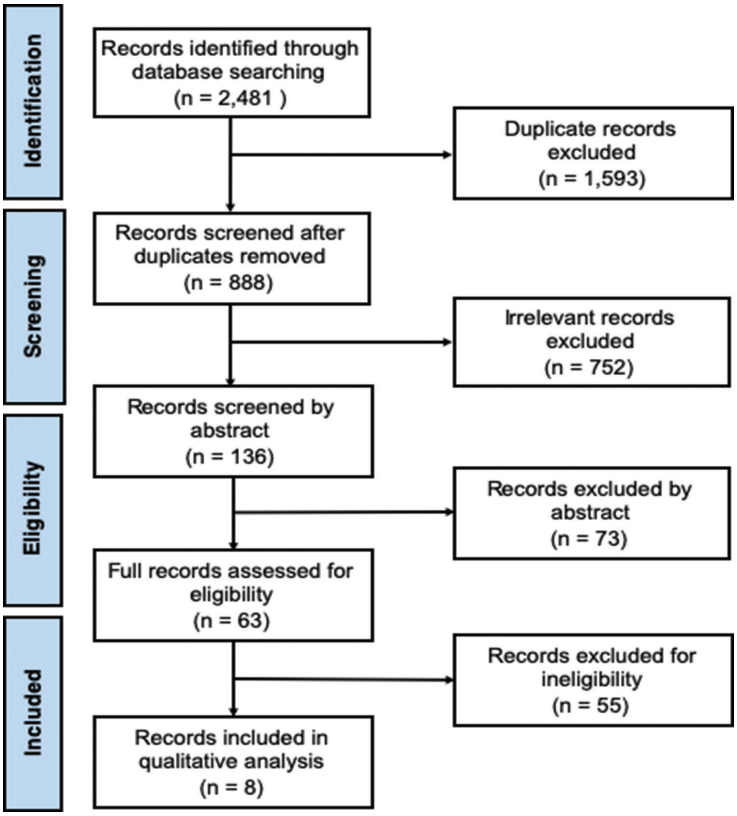

Figure 1: Flow diagram of literature search indicating exclusions at each stage

used Northern European fetal measurements as the growth standard.

3.2. Study Characteristics

Studies were heterogeneous in the following terms:

1. *Growth references/standards.* Two growth standards were used in the studies analyzed. These include growth standards from the WHO (4 studies) and northern European growth standards (1 study). In several studies, no growth standard comparison was provided (3 studies). This provided a limitation for comparing results from studies that differed in growth standard use.
2. *Ethnic groups and nationalities.* Studies used samples that included different ethnic groups, including groups from the following countries: Bangladesh (2 studies), Netherlands (1 study), Kenya (1 study), USA (1 study), Singapore (1 study), and Iran (1 study). One study used a multiethnic sample.
3. *Age.* All studies included women from all child-bearing age groups, with the youngest group being pregnant adolescents.
4. *Year.* Studies included in the review were published between 2012 and 2019.
5. *Study Design.* Study designs of the included studies include randomized control trials, population-based prospective cohort studies, and longitudinal studies.

3.3. Study Trends

The earliest study was published in 2012 (Table 3). The period from 2016 to 2019 was characterized by an increase in studies investigating the effect of maternal vitamin D on fetal and early childhood growth. Thus, the remainder of the studies were published between 2016 and 2019. Of the studies included in the final

Table 3: Inclusion and exclusion criteria used to select studies for the review

Inclusion Criteria	Exclusion Criteria
Quantitative measurements	Ambiguous outcome, objective, or participant inclusion criteria
Recommendations based on study findings	Did not involve mothers with vitamin D intake
Clear outcomes of growth or stunting	Did not specify vitamin D intake amount
Pregnant or reproductive-age women	Non-English
Observed vitamin D status and levels	Other maternal health complications
Conducted between 2010 and 2020	Animal studies
Published studies	Case-control studies or reviews

analysis, 4 were conducted in Asia, 2 were in Europe, 1 was in Africa, and 1 was in North America.

Overall, 5 studies found that maternal vitamin D has a significant effect on fetal growth, length for age z-scores, anthropometric growth measures, and fetal growth. Three studies found no significant effect.

3.4. Individual Study Outcomes

Vitamin D Supplementation in Pregnancy and Lactation and Infant Growth

In the Bangladeshi study of 1,164 infants, there were no significant differences in length for age z-scores, anthropometric measures, and fetal growth measures across vitamin D supplementation groups and placebo groups. Infant follow-up after one year demonstrated a prevalence of stunting of 16%.[13]

Maternal Vitamin D Concentrations During Pregnancy

A Dutch prospective cohort study of 7,098 mothers and offspring found that mothers with 25-hydroxyvitamin D3 (25(OH)D), the form of vitamin D produced by hydroxylation in the liver, concentrations in the lower quartiles produced offspring with a higher incidence of fetal growth restriction, shorter body length, lower body weight at birth, and children who were small for gestational age. Low maternal 25(OH)D concentrations were found to be associated with small size and fetal growth impairments.[14]

Maternal Vitamin D Status and Adverse Birth Outcomes

In a Kenyan longitudinal study of 63 women, deficient plasma 25(OH)D levels were found to produce a four-fold higher risk of stunting in infants. Both weight-for-age and weight-for-length z-scores increased by 0.01 and 0.02 units respectively with each nmol/L increase in 25(OH)D plasma concentrations.[7]

Maternal Vitamin D Status and Calcium Intake Interact to Affect Fetal Skeletal Growth in Utero

In this United States longitudinal study of 171 women, z-scores for fetal femur and humerus bones, fetal humerus z-scores, and length at birth were found to be significantly greater in neonates of pregnant mothers with greater 25(OH)D concentrations. Most pressingly, calcium and vitamin D were thought to interact and compensate for the suboptimal status of the other nutrient.[6]

Vitamin D Levels During Pregnancy and Newborn Birth Weight and Body Composition

This Norwegian multiethnic study of 719 pregnant women found that maternal 25(OH)D was positively correlated with birth weight before adjustment for ethnicity, but no longer correlated after adjustment. Crown-heel length, head circumference, abdominal circumference, and ponderal index were all found to be not associated with maternal vitamin D status.[15]

Maternal Vitamin D Status with Infant Birth Outcomes and Postnatal Growth

A Singaporean study of 910 mothers found no significant associations between maternal vitamin D levels and size for gestational age, weight-for-age z-scores, and length-for-age z scores. Postnatal growth outcomes of weight and length from three to 24 months were not significantly different between maternal vitamin D levels. A non-statistically significant trend was found between vitamin D deficiency and shorter infant length and lower weight.[16]

Effect of Low Dose Vitamin D Supplementation on Growth of Fetal Bones

A study of 140 Iranian women found that proximal metaphyseal diameter, midshaft diameter, and

distal metaphyseal diameter were increased in the intervention group with higher maternal vitamin D. Humerus and femur lengths were increased significantly in the second and third trimesters for the intervention group.[17]

Maternal Vitamin D3 Supplementation during the Third Trimester of Pregnancy

In a Bangladeshi study of 160 pregnancies, length-for-age z-scores were found to be 0.44 higher in the intervention group receiving vitamin D. Change in length-for-age z-scores from birth to one month were significantly increased in the intervention group but no significant changes were observed after one month. Stunting was less prevalent in the intervention group than the placebo group, with 17% compared to 31% respectively. Length, weight, head circumference, and femur length at birth did not significantly differ between the groups.[18]

Trends of Studies

In synthesizing the findings of the above eight studies, the effect of maternal vitamin D status on fetal growth and stunting remains unclear. A trend of increases in the fetal femur and humerus length-for-age z-scores was established in four studies and other anthropometric measures showed statistical significance in five of the studies. However, three studies found no statistically significant differences in fetal growth or stunting corresponding to maternal vitamin D status. The trend of increased fetal femur and humerus length-for-age z-scores can be an indication of positive fetal growth associated with maternal vitamin D status but requires more research to confirm these results. Further, in this review, studies using 25-hydroxyvitamin D3 (25(OH)D) were more likely to find an effect of vitamin D concentrations on fetal growth and stunting. However, due to the small sample size, this observation warrants more research into the effect of different vitamin D compounds and forms on fetal growth and stunting.

A pressing finding emphasized by Eggemoen et al. is the impact of ethnicity on the effect of maternal vitamin D status on fetal growth.[15] Ethnicity and prenatal vitamin D status are necessary considerations as vitamin D status greatly differs between ethnicities. In the study conducted by Miliku et al., mothers of Turkish or Moroccan ethnicity maintained the lowest hydroxyvitamin D 25(OH) D concentrations.[14] Therefore, further research is required to understand if prenatal vitamin D requirements are only pertinent to particular ethnic groups for healthy fetal growth. The studies examined in this review involve a variety of ethnic groups, which may explain the lack of consensus among results.

The study conducted by Young et al. indicated that vitamin D alone might not have the same interactions with fetal growth and stunting that may be produced by vitamin D coupled with calcium.[6] Therefore, a new research question investigating the combined effect of calcium and vitamin D on fetal growth and stunting is warranted to potentially explain the mixed results of the above studies. As mentioned by Young et al., many studies fail to account for the combined effects and interactions of calcium and vitamin D when investigating their individual effects on neonates.[6]

4. Discussion

There remains a gap in the literature confirming the effects of prenatal vitamin D status and supplementation on fetal growth, postnatal growth, and early childhood stunting. While research into vitamin D and pregnancy has been ongoing for decades, its effect on growth has only recently come to light. Fetal growth restriction and stunting remain considerable health issues, and this research provides a basis not only for further research into stunting and its prevention but also for a public health intervention to disseminate this information. The studies included in this systematic review indicate that the effect of maternal vitamin D on fetal growth and stunting remains unclear but requires more research to understand its effect on specific ethnicities and when coupled with calcium. More specific studies addressing these questions may provide clearer results. Further, a trend of improved fetal femur and humerus z-scores may indicate that vitamin D has an impact on fetal growth that requires more investigation. Finally, more research is required on the effect of different vitamin

D forms on fetal growth and stunting, as studies in this review investigating 25-hydroxyvitamin D3 (25(OH) D) were more likely to find a relationship between vitamin D and growth. Despite ambiguous findings that potentially suggest a trend of the involvement of vitamin D on fetal growth and stunting, awareness about vitamin D in prenatal care can prevent other adverse health outcomes such as stillbirth, premature birth, low birth weight, gestational diabetes, and preeclampsia.[7] Nutritional awareness could therefore improve health outcomes in both mothers and their infants. However, in other regions, access to foods rich in vitamin D may be hindered by poverty or availability, presenting an additional challenge to improving pregnancy outcomes with vitamin D intake.

Vitamin D levels involved in prenatal care may be of particular value in low-income countries. In Kenya, over 51% and 21% of women were insufficient and deficient in their vitamin D serum concentrations, respectively.[7] This translated into 74% and 30% of infants being vitamin D insufficient and deficient, respectively.[7] Many factors influence the awareness of the importance of vitamin D, such as education, employment, ethnicity, and marital status.[19] Accurate nutrition counseling for pregnancy is the first step in disseminating the importance of vitamin D, potentially for fetal growth, but also for preventing stillbirth, low birth weight, gestational diabetes, and preeclampsia.[7] By increasing awareness and understanding of the potential importance of vitamin D for fetal growth and other health outcomes, the health literacy of pregnant women will also increase.

Vitamin D concentration is determined by two sources: sunlight exposure and dietary intake of vitamin D.[19] These factors must be utilized together for adequate intake, as reliance on only one source is not robust. Instead, nutrition awareness about vitamin D may be effective in increasing intake, as one study has shown that women who were made aware of the importance of the vitamin made an active effort to obtain it from sunlight exposure and diet.[19] While this trend requires more research, an active effort to adjust dietary practices may improve health outcomes in both mother and child. More research is needed to confirm the interaction between maternal vitamin D and fetal growth, but vitamin D as a prenatal requirement is essential to compensate for a lack of calcium, ensure bone mineralization and growth, and increase birth weight.[6]

4.1. Limitations

This systematic review has some limitations. There is the potential for reporting bias due to the incomplete retrieval of literature addressing this topic beyond the three databases we reviewed. Future studies should include more databases and a review of grey literature, which was not included in the scope of this review. However, we believe that the bulk of the peer-reviewed literature may be covered in our selected major databases. Another limitation is the heterogeneity of the studies, as studies differed in design, protocol, levels of vitamin D, population, sample size, growth standard comparison, and the method used to assess vitamin D status. For example, we excluded case-control studies as they were few and had extremely small sample sizes. Fetal growth restriction (FGR) and intrauterine growth restriction (IUGR) were initially used when sifting through literature, but produced no further results than the search terms included in our study. We found that FGR and IUGR were not regularly used in the few studies and were therefore excluded and replaced with growth retardation and stunting/stunted, which produced all results relating to the topic. As the literature in this field gains more traction, these limitations will be less prominent. Finally, selection bias may be present in this review due to the review of only English language studies. Due to the use of 3 databases, it is possible that some published non-English language studies may not have been included. However, the effect of this bias is limited because the databases selected are generally comprehensive.

5. Conclusion and Implications for Translation

The results from this systematic review indicate the need for further investigation into the effect of maternal vitamin D status on fetal and neonatal growth and stunting. An investigation is also needed on the need for prenatal vitamin D specific to ethnicity and on the interaction between calcium and vitamin D for fetal growth outcomes. Further, this review identified the gap in research for longitudinal

studies that monitor fetal and early childhood growth until adolescence as a result of maternal vitamin D status. This review provides the foundation for such research to fill the gap within scientific literature on the fetal growth effects of maternal vitamin D status.

Compliance with Ethical Standards

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Key Messages

- The effect of maternal vitamin D status on fetal growth and stunting remains unclear and requires further research.
- A trend of improved fetal femur and humerus z-scores may indicate that vitamin D has an impact on fetal growth.
- Despite unclear findings, vitamin D may be used in prenatal care to compensate for a lack of calcium and promote healthy fetal growth.

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