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Impact of Vitamin D3 Deficiency on Liver and Adipose Tissue in Pregnant Mice

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Abstract:

Vitamin D is a critical nutrient integral to various physiological processes such as bone health, immune function, and gene regulation. Its deficiency is linked to a range of health complications, underscoring the need to understand its effects on pregnant individuals and fetal development.

This review article focuses on the consequences of Vitamin D3 deficiency, specifically on the liver and adipose tissue in pregnant mice. The study aims to uncover the molecular, cellular, and physiological changes occurring in these tissues due to Vitamin D3 deficiency.

Keywords: Adipose Tissue, Fetal Development, Liver Health, Maternal Health, Pregnancy, Vitamin D3 Deficiency

Introduction:

Vitamin D3, often referred to as cholecalciferol, undergoes synthesis in the skin upon exposure to sunlight and is additionally attainable through dietary sources. It transforms into its active state, calcitriol, which subsequently binds to the vitamin D receptor (VDR), orchestrating the modulation of a multitude of genes. The liver and adipose tissue hold pivotal roles in the realm of metabolism, and an emerging body of evidence posits that a dearth of vitamin D3 during pregnancy possesses the potential to exert repercussions on these tissues, consequently exerting influences on the well-being of mothers as well as the developmental trajectory of fetuses (Alwan et al., 2021).

Vitamin D, a secosteroid that is synthesized in skin and sequentially metabolized in liver and kidneys in humans, has been well-known for its function in maintaining calcium and phosphorus homeostasis and promoting bone mineralization. However, the ubiquitous distribution of intracellular vitamin D receptor across diverse tissues and the emerging epidemiological evidence documenting increased risks of hypertension cardiovascular disease and selected cancers associated with vitamin D deficiency underscore the pleiotropic actions of vitamin D. Evidence is also accumulating for a role of vitamin D in maintaining normal glucose homeostasis. For instance, in both animal and human studies, vitamin D depletion was significantly related to insulin resistance and impaired insulin secretion. Notably, this condition is reversible upon repletion of vitamin D (**Alwan et al., 2021**).

2. Vitamin D3 Deficiency in Pregnancy:

Vitamin D is a secosterol hormone recognized primarily for its role in calcium homeostasis. 25-hydroxyvitamin D (25-OH-D) is an important measure of physiologic vitamin D status and has a half-life of about 2 weeks. The active form of vitamin D, 1,25-(OH)2D3 is produced through hydroxylation of 25-OH-D in the kidney or placenta and has a very short half-life measured in minutes. Thus, most studies have focused on assessment of vitamin D influence upon disease using 25-OH-D levels. However, recent evidence suggests that vitamin D and especially a deficiency of vitamin D, may be involved in adverse pregnancy outcomes. We recently reported an association between low maternal 25-OH-D and early-onset, severe preeclampsia (EOSPE) (Robinson et al.,2010).

Vitamin D is an essential fat soluble vitamin and a key modulator of calcium metabolism in children and adults. Because calcium demands increase in the third trimester of pregnancy, vitamin D status becomes crucial for maternal health, fetal skeletal growth, and optimal maternal and fetal outcomes. Vitamin D deficiency is common in pregnant women (5–50%) and in breastfed infants (10–56%), despite the widespread use of prenatal vitamins, because these are inadequate to maintain normal vitamin D levels (≥32 ng/mL). Adverse health outcomes such as preeclampsia, low birthweight, neonatal hypocalcemia, poor postnatal growth, bone fragility, and increased incidence of autoimmune diseases have been linked to low vitamin D levels during pregnancy and infancy (Mulligan et al., 2010).

2.1 Sources and Causes of Deficiency:

There are two sources of ViD for humans. An exogenous one is provided by the diet in the form of vitamins D2 and D3. In the endogenous production, cholecalciferol (D3), the main source of ViD, is synthesized in the skin by the action of ultraviolet B (UVB) radiation through the photolysis of 7-dehydrocholesterol and transformed into vitamin D3. Sufficient exposure to sunlight or UVB radiation is up to 18IU/cm2 in 3 hours. This process takes place in two phases: the first one occurs in the deep layers of the dermis and consists in the photo conversion of 7-dehydrocholesterol into pre-vitamin D or pre-calciferol. In the second phase, there is a chemical isomerization depending on body temperature, and pre-vitamin D slowly and progressively turns into vitamin D3, which has high affinity for the ViD carrier protein (DBP), and the pre-vitamin D, with lower binding affinity, remains in the skin. Upon reaching the skin capillary network, ViD is transported to the liver and binds with DBP, where it starts its metabolic transformation. The two types of ViD undergo complex processing to be metabolically active Initially, the pre-hormone is hydroxylated in the liver at the carbon 25 position through the action of vitamin D-25-hydroxylase 1a (1-OHase), which constitutes an enzyme system dependent on cytochrome P-450 (CYP27B) present in liver microtomes and mitochondria, and originates 25-hydroxyvitamin D (25(OH)D), the most abundant circulating form of ViD, Its mean blood concentration is 20-50ng/mL (50-125nmol/L) and it has an average life of approximately 3-4 weeks. It is estimated that its circulating pool is in dynamic equilibrium with reserves of 25(OH)D (muscle and adipose tissue), which makes blood levels a reliable indicator of the state of the ViD reserves in the body, under normal circumstances, the percentage of conversion into 25(OH)D is low, with a distribution of almost 50% in the fat and muscle compartments.
When there is excess intake of ViD, most of it is stored in the fatty deposits (Urrutia & Solé., 2015).

During fetal life, the body tissues and organs go through critical development periods that coincide with periods of rapid cell division. Fetal programming is a process through which a stimulus or insult, during a certain development period, would have effects throughout life. This term is used to describe the mechanisms that determine fetal adaptation to changes that accompany the gene-environment interaction during specific periods of fetal development (Cunningham & Cameron.,2003)

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Recent evidence indicates that nutrients can modify the immune and metabolic programming during sensitive periods of fetal and postnatal development. Thus, modern diet patterns could increase the risk of immune and metabolic dysregulation associated with the increase of a wide range of non-communicable diseases. Among these nutrients, ViD is emphasized, and its effects on fetal programming and gene regulation might explain why it has been associated with many health benefits throughout life (Hossein & Holick.,2012).

2.2 Maternal Health Implications:

A new study finds that women who develop severe preeclampsia tend to have lower blood levels of vitamin D than healthy pregnant women raising the possibility that the vitamin plays a role in the complication. Preeclampsia rates are elevated during winter months, when sunlight-dependent 25(OH) D productions are reduced. Vitamin D supplementation reduces preeclampsia risk, compared to un supplemented controls, Preeclampsia is associated with low circulating levels of IGF-I and 1,25(OH) 2D and, in vitro, IGF-1 increases 1,25(OH) 2D production by primary human syncytio trophoblasts from placentas from normal pregnancies but not from preeclampsia pregnancies (Habeeb et al.,2023).

Vitamin D is known to influence insulin secretion. 1,25(OH) 2D regulates insulin secretion by pancreatic β-cells and thereby affects circulating glucose levels, As expected, low concentration of 25(OH) D is a risk factor for insulin resistance, glucose intolerance, and features of metabolic syndrome in norm glycemic subjects. Vitamin D deficiency during early pregnancy significantly increases the risk for gestational diabetes in later pregnancy (Bell et al.,1985)

Vitamin D may influence the course of infectious diseases during pregnancy. Low 25(OH) D levels are correlated with increased bacterial vaginosis in the first trimester. Bacterial vaginosis is more prevalent in black women, who typically have lower serum 25(OH) D concentrations and have a six-fold higher chance of vitamin D deficiency, compared with white women. Vitamin D has effects on the immune system, cytokines, and antibacterial peptides that are likely to regulate the bacterial flora. Nutritional vitamin D status has very recently been linked to the human innate immune system and its ability to contain Mycobacterium tuberculosis (Kaushal & Magon.,2013).

3. Effects on Liver Tissue:

3.1 Role of Vitamin D3 in Liver Function:

During pregnancy, the placenta is probably the most prominent site for extra-renal activation of vitamin D, it appears that the extra renal function of vitamin D has more to do with immune function than with calcium metabolism and homeostasis. Despite these observations, it was concluded that the condition of vitamin D deficiency led to weakness and malnutrition and was not a direct effect of vitamin D on the immune system. The mechanism of action of these processes and health derangements would not be understood until the advent of molecular biology. Vitamin D appears to affect immune function in two ways upregulation of the innate immune system; and, downregulation of the adaptive immune system. Focusing on the innate immune system first, a major mechanism of action of vitamin D is via an endogenous antimicrobial peptide called cathelicidin LL-37 (Liu et al.,2006).

Recent evidence indicates that nutrients can modify the immune and metabolic programming during sensitive periods of fetal and postnatal development. Thus, modern diet patterns could increase the risk of immune and metabolic dysregulation associated with the increase of a wide range of non-communicable diseases, among these nutrients, ViD is emphasized, and its effects on fetal programming and gene regulation might explain why it has been associated with many health benefits throughout life (Hossein, 2013).

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3.2 Molecular Changes in Vitamin D3 Deficiency:

Although the importance of vitamin D receptor signaling in normal fetal and adipose tissue development is undeniable, little is known about how maternal status impacts offspring. In the current pilot study, we sought to use a mouse model to: (Johnson et al.,2010) explore the impact of maternal vitamin D deficiency during the perinatal period on the development of adipose tissue in male offspring; (Cho et al.,2013) elucidate the potential mechanisms by which vitamin D exerts its adipogenic control by examining several genes associated with adipogenesis and adipose function; (Walsh et al.,2013) investigate how potential vitamin D-mediated changes in adipose tissue development and function impact the systemic inflammation linking obesity to metabolic abnormalities.

3.3 Implications for Maternal Liver Health:

Vitamin D metabolites are known to influence adipokine production and the inflammatory response in adipose tissue (Arnson et al.,2013). As adipocytes expand, they produce and secrete several inflammatory cytokines and chemokines such as TNF-α, interleukin-6 (IL-6), monocyte chemotactic protein-1 (MCP-1), and leptin (Gregor et al.,2011) and there is evidence for chronic inflammation as the causal link between obesity and its related metabolic conditions (Jung & Choi.,2014).

Therefore, these molecules were measured in our study to indirectly assess the indirect effects of the metabolic health of offspring adipose tissue. The observed absence of widespread inflammation, like the absence of effects on body or adipose pad weights, is also likely due to the animal model we used. Notwithstanding, we noted greater serum concentrations of resistin and IL-2 in the offspring of vitamin D deficient mothers. Similar to leptin, circulating concentration of the adipocyte-derived protein resistin increases proportionally with adiposity (Marcotorchino et al.,2012). In both rodent models and humans, resistin has also been associated with the progression of insulin resistance. However, the degree to which it influences the development of insulin resistance in humans is uncertain, with current evidence suggesting a likely indirect effect (Iqbal et al.,2005). The relationship between vitamin D and resistin is unclear, as studies have shown both positive and negative associations (Roth et al.,2012). As mentioned above, the animals in the current study were all lean and vitamin D sufficient, and thus, the observed increases in circulating resistin concentrations were surprising. We do not currently have a good explanation for this finding. The pro-inflammatory cytokine IL-2 is primarily associated with T-cell function and protection against autoimmune disease (Schimpl et al.,2002). While a positive association between obesity and circulating concentrations of IL-2 has been noted, IL-2's role in obesity or its subsequent metabolic complications remain elusive. Previous studies have demonstrated that VDR signaling inhibits the expression of IL2 in T-cells (Alroy, et al.,1995) Since the mechanisms governing these processes are dependent on the formation of a VDR-RXR heterodimer, the local availability of 1,25-dihydroxyvitamin D is essential. As the offspring were vitamin D sufficient, it is unlikely that this was a complicating factor.

4. Impact on Adipose Tissue:

4.1 Adipose Tissue Metabolism and Vitamin D3:

There is some evidence that vitamin D could be involved in lipid mobilization and utilization in adipose tissue. An early study observed that 1,25(OH)2D3 induced a significant increase in lipoprotein lipase activity and of its mRNA level in 3T3-L1 adipocytes (Al-Gayyim, and Al-Habib, 2020), Concurrently, fatty acid synthase, which catalysis adipocyte lipogenesis, is down-regulated by 1,25(OH)2D3 in 3T3-L1 cell, in vivo functional studies of VDR suggest that the receptor could inhibit lipid mobilization and utilization. VDR-null mice were reported to be resistant to high-fat diet-

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induced obesity, probably due to increases in fatty acid b-oxidation in white adipose tissue and the expression of uncoupling proteins in brown fat and of overall energy expenditure (Wong et al., 2009).

On the other hand, targeted expression of VDR in adipocytes induces obesity in mice without changes in food intake, which is mainly caused by a marked decrease in energy expenditure together with reduced lipolysis and b-oxidation in adipose tissue, In addition, the expression of genes involved in lipid metabolism, including hormone-sensitive lipase, adipose TAG lipase and uncoupling proteins 1, 2 and 3, is suppressed in VDR transgenic mice(Wong et al.,2011), Data on the effects of vitamin D in lipid metabolism in human subjects are scarce.

A study of a small number of non-obese healthy subjects (n 10) has shown that vitamin D supplementation (2000 IU cholecalciferol/d), together with a low dietary Ca intake for 7 d, had no effect on energy expenditure, substrate metabolism or the expression of genes related to fat metabolism, such as hormone-sensitive lipase, fatty acid synthase and uncoupling protein 2 in adipose tissue, despite a significant increase in serum 1,25-OH2D3 levels (Boon et al.,2006).

The potential role of vitamin D in modulating inflammation in obesity and other chronic diseases has received increasing attention. Evidence has accumulated that 1,25(OH)2D3 has potent immune regulatory effects, such as inhibiting the production of IL-6, IL-8 and interferon-g by peripheral blood mononuclear cells from psoriatic patients (Inoue et al.,1998). It has also been shown that 1,25(OH)2D3 down-regulates the gene and protein expression of toll-like receptor (TLR) 2 and TLR-4 in human monocytes (Do et al.,2008), 1,25(OH)2D3 also suppresses peripheral blood mononuclear cells' proliferation and induces apoptosis in peripheral blood mononuclear cells of healthy subjects and inflammatory bowel disease patients (Martinesi et al.,2008).

Both 1,25(OH)2D3 and 25(OH)D3 have been shown to reduce lipopolysaccharide-induced TNF-a and IL-6 production, probably by inhibiting p38 MAPK activation in human monocytes/ macrophages (Zhang et al.,2012),Conversely, 1,25(OH)2D3-deficient T-cells isolated from CYP27B1 knockout mice are predisposed to overexpress IL-17(Bruce et al.,2011), while VDR-null mice display a failure of T-cell homing to the gut with low levels of IL-10 in inflammatory bowel disease (Ding et al.,2012). Furthermore, in peripheral blood mononuclear cells from type-2 diabetic patients having a proinflammatory profile, 1,25(OH)2D3 is reported to act in an anti-inflammatory manner to decrease the expression of TNF-a, IL-1, IL-6 and IL-8(Giulietti et al.,2007). In vivo, aged mice treated with vitamin D3 showed a significant improvement in visual function by reducing retinal inflammation and amyloid-b accumulation (Lee,2012).

4.2 Altered Adipose Tissue Gene Expression:

Vitamin D and its receptor VDR have been implicated in the modulation of preadipocyte differentiation into adipocytes adipogenesis (Blumberg et al.,2006), The differentiation of 3T3-L1, preadipocytes is a highly controlled process through sequential induction of transcription factors that regulate the expression of adipocyte-specific markers. During adipogenesis, a series of cellular events begins with the rapid expression of CCAAT/enhancer-binding protein b (C/EBPb), followed by the expression of C/EBPa, PPARg and sterol regulatory element-binding protein 1 (SREBP1) (Mandrup & Lane.,1997), As a result, there is increased expression of genes that produce the adipocyte phenotype, such as lipoprotein lipase, and adipocyte lipid-binding protein 2, which serves as a late marker of adipogenesis (Christy et al.,1989).

During differentiation, the expression of genes encoding lipogenic enzymes such as fatty acid synthase is highly induced and de novo fatty acid synthesis increases enormously (Madsen et al.,2005), There is some evidence that 1,25(OH)2D3 inhibits 3T3-L1 preadipocyte differentiation in a dose-dependent manner, and this is in line with its inhibitory effect on the expression of adipogenic transcription factor (C/EBPb, PPARg and SREBP1) genes and of the downstream adipocyte markers lipoprotein lipase, adipocyte lipid-binding protein 2 and fatty acid synthase, although 1,25(OH)2D3

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does not block the induction of C/EBP, The linkage between 1,25(OH)2D3 and adipocyte lipogenesis has also been supported by a study which demonstrated that the hormone strongly increased mRNA levels of insulin-induced gene-2 (Insig-2), a factor which blocks fatty acid synthesis in mature 3T3-L1 adipocytes and inhibits preadipocyte differentiation (Lee et al.,2005).

During the differentiation of human mammary preadipocytes, exposure to 25(OH)D3 or 1,25(OH)2D3 led to a significant reduction in lipid accumulation at day 7 but not at day 14, suggesting that vitamin D metabolites may inhibit the initiation of human preadipocyte differentiation Furthermore, in addition to reducing protein expression of C/EBPa, PPARg and adipocyte lipid-binding protein 2 by 1,25(OH)2D3 alone, the combination of 1,25(OH)2D3 with genistein enhanced suppression of adipocyte lipid-binding protein 2 expression and lipid accumulation in 3T3-L1 adipocytes, The effects of 1,25(OH)2D3 metabolites on adipogenesis may involve VDR, as 1,25(OH)2D3 combined with genistein significantly increased VDR protein expression (Lai et al.,2011).

In addition, 1,25(OH)2D3 induces the up-regulation of C/ EBPb core-repressor, eight twenty-one (ETO), which would further restrain the activity of remaining C/EBPb, A recent study has shown a positive association between VDR polymorphisms and the parameters of adiposity VDR gene variants with polymorphisms on the 30 UTR site, which affect the expression of VDR, are postulated to suppress the anti-adipogenic effect of vitamin D (Ochs-Balcom et al.,2011). Interestingly, a role for unligand VDR in adipogenesis has been proposed, as VDR overexpression suppresses 3T3-L1 preadipocyte differentiation in the absence of 1,25(OH)2D3. In contrast, the data from another study suggest that the unligand VDR is required for lipid accumulation, as VDR knockdown with siRNA delays and prevents this process (Blumberg et al.,2006). However, in vivo studies on VDR function suggest that VDR could promote adipogenesis. Mice with a global VDR knockout had little fat mass and higher rates of b-oxidation in adipose tissue in comparison with wild-type controls, additional studies, including adipose tissue-specific knockout models, are required to clarify the function of VDR in adipogenesis (Wong et al.,2009)

4.3 Links to Maternal Obesity and Offspring Outcomes:

An inverse relationship between vitamin D nutritional status, as measured by serum 25-hydroxyvitamin D (25-OH D), and increased adiposity has been established in children, adolescents, and adults (Arunabh et al.,2003; Rajakumar et al.,2011). The mechanism whereby increasing adiposity reduces vitamin D sufficiency is thought to be related to sequestering of vitamin D in adipose tissue, thereby producing a reduction in its bioavailability of the parent compound for subsequent metabolic activation (Wortsman et al.,2000). Maternal obesity is associated with increased offspring birth weight (Ehrenberg et al.,2004) and increased neonatal adiposity, both of which are associated with increased risk of obesity in offspring (Oken et al.,2009).

However, the associations between obesity in pregnancy, vitamin D status, and newborn vitamin D levels have not been studied extensively. One study reported prepregnancy obesity to be associated with midpregnancy and subsequent neonatal vitamin D deficiency despite the use of prenatal vitamins, in that study, neonates born to obese women had significantly lower cord blood 25-OH D levels compared with neonates born to lean women (Bodnar et al.,2007), but data on newborn size was not reported. Because reduced levels of serum 25-OH D have been shown to be related to increased adiposity later in life, it is of great interest to understand the maternal-newborn relationships of vitamin D and this relationship to newborn adiposity itself. Reported associations between maternal obesity and increased birth weight and adiposity are confounded by the presence of gestational diabetes mellitus (GDM). GDM leads to excessive fetal insulin production, insulin acts as a growth factor causing increased fetal size and relative amount of fat mass, The obese perinatal

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environment, even in women without GDM, has been shown to induce fetal insulin resistance (Catalano et al.,2009).

In adults and children, insulin resistance has been shown to be related to lower 25-OH D levels (Roth et al.,2011). However, the mechanism underlying this relationship and whether it is causal or an association has not been determined. Therefore, to study the relationship between maternal vitamin D status and newborn adiposity, it is important to remove the possible confounding effects of GDM. Separately, both vitamin D deficiency and obesity in pregnancy are common (Chu et al.,2009). Because obesity is associated with vitamin D deficiency, we would expect obese pregnant women to have lower levels of 25-OH D, that obese pregnant women transfer less 25-OH D to their offspring compared with normal-weight women due to the reduced bioavailability and sequestering of 25-OH D in adipose tissue.

5. Interventions and Future Directions:

5.1 Vitamin D Supplementation Trials:

Women of reproductive age are assumed to be able to obtain the recommended intake for almost all vitamins without the use of supplements, and no national organization recommends routine vitamin D supplementation during pregnancy unless a woman is at nutritional risk (Kaushal & Magon.,2013).

Vitamin D is lipophilic and early studies used radioactive isotopes to demonstrate its accumulation in adipose tissue ,Supplementing with 20 000 international units(IU) of vitamin D3 per week for 3–5 years leads to a substantial increase in vitamin D3 content in subcutaneous abdominal adipose tissue, approximately sixfold greater than placebo, The amount of 25(OH)D present in adipose explants remained correlated with serum 25(OH)D concentrations 1 year after supplementation had ceased (Hengist et al.,2019).

The importance of maternal nutrition concerning pregnancy health and intrauterine fetal growth and beyond is widely recognized. However, there is a great deal of variation in policies and practices within and among countries concerning nutritional assessment and related care of women during the perinatal period. Several initiatives and organizations across the globe have attempted to address the growing nutritional challenges among maternity populations, including the National Academy of Medicine (formerly the IOM), NICE, and Think Nutrition First. Furthermore, there are initiatives, such as those in the United Kingdom Every Contact Counts, with the aim of promoting a healthy lifestyle at every opportunity in which patients and mothers attend clinics or visit healthcare providers, However, there are evident inconsistencies in recommendations and practices that are counterproductive in achieving optimum lifestyle and nutritional health during the reproductive period. A lack of sufficient evidence in clinically meaningful and/or locally sensitive and effective gestational weight management approaches has been cited as the main reason for variation in current nutritional assessment and relevant care and management. Providing nutritional education and introducing interventions before pregnancy particularly from adolescent stages through pregnancy and using digital sources for wider engagements are suggested (Marshall et al.,2022).

5.2 Potential Therapeutic Strategies:

ViD supplementation reduces the risk of preeclampsia. Studies in women with preeclampsia have shown low urinary excretion of calcium, low ionized calcium levels, high levels of PTH and low levels of 1.25(OH)2D. An association between maternal VDD (<50nmol/L) and increased risk of gestational diabetes (OR:2.66, 95% CI: 1.01 to 7.02), as well as the fact that VDD is an independent risk factor for bacterial vaginosis in pregnancy have also been documented. A recent randomized and controlled study showed that supplementation with 4,000IU/d during pregnancy was associated with reduced risk of combined morbidities, such as maternal infections, cesarean section and preterm delivery (Urrutia et al.,2015)

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A meta-analysis of studies carried out in adults on ViD supplementation (2,000IU/d) and bone health showed that for each 1IU of vitamin D3 ingested, there is a corresponding increase of 0.016nmol/L in serum levels of 25(OH)D.

Despite the limited evidence on the effects of ViD supplementation in pregnancy and the outcomes in the mother's health and perinatal and early childhood effects, ViD supplementation (800-1,000IU/d) was accompanied by a protective effect in newborns with low birth weight (Cunningham& Cameron.,2003).

Studies have shown that maternal exposure during pregnancy to serum levels of 25(OH)D superior to 75nmol/L had no effect on the intelligence and psychological health of the children or on their cardiovascular system, but it could increase the risk of atopic diseases, The Canadian Academy of Pediatrics (CAP) recommends supplementation with 2.000IU/d during pregnancy and lactation. According to the American College of Obstetricians and Gynecologists, in the presence of VDD diagnosed during pregnancy, there should be supplementation with 1.000-2.000IU/day of ViD (Gale et al.,2008).

6. Conclusion:

In summary, vitamin D3 deficiency during pregnancy appears to have significant implications for both liver and adipose tissue function in mice. The altered molecular and cellular changes observed in these tissues can potentially contribute to maternal health complications and impact fetal development. Further research is warranted to comprehensively understand the mechanisms underlying these effects and to develop targeted interventions that promote optimal maternal and offspring outcomes.

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تأثير نقص فيتامين دي3 على الكبد والأنسجة الدهنية في الفئران الحوامل

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المستخلص:

فيتامين د هو عنصر غذائي مهم ومتكامل لمختلف العمليات الفسيولوجية مثل صحة العظام، ووظيفة المناعة، وتنظيم الجينات. ويرتبط نقصه بمجموعة من المضاعفات الصحية، مما يؤكد الحاجة إلى فهم آثاره على الأفراد الحوامل ونمو الجنين.

تركز هذه المقالة المراجعة على عواقب نقص فيتامين د3، وخاصة على الكبد والأنسجة الدهنية في الفئران الحوامل. تهدف الدراسة إلى الكشف عن التغيرات الجزيئية والخلوية والفسيولوجية التي تحدث في هذه الأنسجة بسبب نقص فيتامين د3.

الكلمات المفتاحية: الأنسجة الدهنية، نمو الجنين، صحة الكبد، صحة الأم، الحمل، نقص فيتامين د3