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Correlation between anthropometric and biological parameters of the offspring and parental plasma 25-hydroxyvitamin D levels: a cross-sectional study conducted at Oran, Algeria

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Abstract

Background Vitamin D is critical in overall health, particularly during pregnancy, as it supports a healthy pregnancy and promotes proper fetal development. This study examined the link between parental 25-hydroxyvitamin D (25(OH)D) deficiency and their offspring's anthropometric and biological parameters.

Methods A cross-sectional study was conducted involving 50 Algerian families, which included 50 pregnant women in their third trimester, 50 fathers, and 50 newborns. Blood samples were collected from both parents and the umbilical cord of the newborns. Serum 25(OH)D concentrations were measured, and demographic and health-related information was gathered from the participants. The anthropometric parameters of the newborns were recorded at birth.

Results In our study, 16% of women were insufficient in 25(OH)D, 54% were deficient, and the remaining 30% exhibited severe deficiency, with mean 25(OH)D levels of 24.53 ng/ml, 14.23 ng/ml, and 7.69 ng/ml, respectively. Among males, 40% were insufficient, 42% were deficient, and 18% had severe deficiency, with mean 25(OH)D levels of 25 ng/ml, 15.78 ng/ml, and 8.53 ng/ml, respectively. Furthermore, 24% of newborns were insufficient, 52% were deficient, and 24% had severe deficiency, with mean 25(OH)D levels of 23.53 ng/ml, 13.46 ng/ml, and 7.53 ng/ml, respectively. Maternal 25(OH)D levels were positively correlated with the anthropometric parameters of newborns (height, femur length, weight, and Apgar scores at 1 and 5 min after birth). Conversely, paternal deficiency showed no correlation with these parameters.

Conclusion 25(OH)D deficiency significantly impacts newborns and represents a significant risk to their development, whereas paternal deficiency has no impact on the measured anthropometric parameters of newborns.

Keywords 25-Hydroxyvitamin D, Pregnant women, Deficiency, Parents, Offspring, Anthropometric parameters

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Introduction

Vitamin D is a prohormone [1] primarily recognized for regulating calcium homeostasis and bone metabolism [2]. The circulating 25(OH)D concentration is widely accepted as the individual vitamin D status marker. Many agencies use it to establish dietary requirements for vitamin D and monitor the population for deficiency or insufficiency [3]. Hypovitaminosis D poses a significant public health issue among the general population [4]. In Africa, data from 119 studies, including meta-analyses, estimated prevalence rates of 18.5% for serum 25(OH)D levels below 30 nmol/L and 34.2% for levels below 50 nmol/L. The analysis also indicated that most studies reporting low 25(OH)D concentrations originated from North and South African countries, compared to Sub-Saharan Africa. In Africa, urban populations exhibited lower 25(OH)D levels than rural areas. A guest commentary on the systematic review highlighted that, despite the long-held belief that Africa was spared mainly from severe vitamin D deficiency issues due to abundant sunlight across much of the continent, the findings of the systematic survey suggest a potentially higher prevalence of 25(OH)D levels below 30 ng/L compared to Europe (18.5% vs. 13%, respectively) [5]. Numerous studies underscore the role of vitamin D in the development of pathologies during pregnancy [6]. Although several studies have emphasized the beneficial effects of vitamin D supplementation on maternal and neonatal health during pregnancy and recommend daily supplementation during this critical period [7], adherence to these recommendations remains low.

Maternal vitamin D levels are influenced by maternal age, sample collection season, pre-pregnancy body mass index (BMI), ethnicity, and study site latitude [8]. Since the fetus's vitamin D supply is also ensured by transfer from the maternal placenta [9], researchers have hypothesized that these factors above have long been involved in lasting changes in the offspring's body composition, physiology, and metabolism. Maternal vitamin D deficiency during pregnancy has several adverse effects on neonatal and maternal health [10]. Recently, vitamin D nuclear receptors (VDR) have been identified in various tissues, including organs involved in reproduction and infant growth, such as ovarian cells [11], where calcitriol plays a significant role in placental physiology. It stimulates endometrial decidualization, estradiol, and progesterone synthesis, and regulates the expression of human chorionic gonadotropin (hCG) and human placental lactogen (hPL) [12]. This receptor is also expressed in testicular cells, where vitamin D influences male fertility, particularly sperm motility [13]. Therefore, vitamin D deficiency in both parents may impact the health of the offspring [14], as demonstrated in a previous study that vitamin D deficiency in parents is linked to epigenetic alterations and higher blood pressure levels in their offspring [15]. In Algeria, the impact of maternal status on 25(OH)D on newborns' health is poorly studied.

No studies have been conducted on the impact of parental 25(OH)D deficiency on newborns' phenotypes. Therefore, our study aims to determine whether the level of parental 25(OH)D deficiency affects the offspring's phenotype.

Materials and methods

Study sample

This study was a cross-sectional examination of Algerian families aimed at investigating the correlation between parental 25(OH)D levels during pregnancy and the anthropometric and biological parameters of newborns. Conducted over two years at the Department of Gynecology and Obstetrics at Oran University Hospital, the research involved 50 Algerian families, including 50 pregnant women in their third trimester, 50 males, and 50 newborns. The study received approval from the Medical Ethics Committee of Oran University Hospital under N°83/2021/DAPM.

Inclusion criteria

The participants included parents and their newborns with 25(OH)D levels below 30 ng/ml, aged between 20 and 45 for women and 25 to 45 for men, with the newborns being full-term singleton infants. According to the WHO, the parents had a normal BMI ranging from 18.5 to 24.9 kg/m². The sample selection was purposive, meaning participants were chosen to fulfill the study's objectives best.

Exclusion criteria

Participants with chronic diseases that directly or indirectly affect vitamin D metabolism, such as thyroid and parathyroid disorders, chronic liver diseases, renal impairment, and chronic inflammatory bowel diseases, as well as individuals taking vitamin D supplements or anticonvulsants, and those with a family history of rickets, were excluded from the study. Women with conditions such as preeclampsia, autoimmune diseases, antiphospholipid antibody syndrome, lupus, and abnormal placental locations (including placenta previa and accreta) were also excluded, along with newborns who had conditions like arteriovenous malformation, a single umbilical artery (due to velamentous insertion of the umbilical cord), fetal distress (from umbilical cord torsion), hemorrhages (such as feto-maternal transfusion), retroplacental hematoma, and prematurity.

Data collection

After obtaining signed consent, a recruitment questionnaire (Supplemental data) was administered through face-to-face interviews with the couples, which included the following anthropometric data: participant serial number, age of parents, parity, mode of delivery, parental illness, vitamin intake during pregnancy, and the presence of a family history of vitamin D deficiency. Weight was measured while height and waist circumference were measured using a graduated tape measure in centimeters. Body Mass Index (BMI) was then calculated by dividing weight (kg) by the square of height (m^2). The questionnaire also included information on occupation, educational level, and habitat type. Regarding the newborn, their gender, birth weight, height, and femur length were extracted from the maternal delivery records. The midwife assigned the Apgar score 1 and 5 min after birth. If respiratory support or other assistance was required, a pediatrician was immediately summoned to the delivery room to assign the score. This score was based on five objective criteria: appearance, pulse, grimace, activity, and respiration, each scored from 0 to 2. Apgar scores above 7 were considered "reassuring," those between 4 and 6 were regarded as "below normal," and those between 1 and 3 were classified as "critical," typically requiring urgent clinical intervention. The neonatal 25(OH)D level and any congenital abnormalities or signs of umbilical cord infection were recorded. All newborns were examined for these parameters after resuscitation [16].

Blood sample collection

25(OH)D concentrations were measured from fasting blood samples taken from parents and the umbilical cord of newborns at birth in heparin-lithium tubes. The blood was then centrifuged at 3000 rpm for 15 min at 4 °C. Immediately afterward, the serum samples were stored in aliquots at -80 °C until analysis. The samples were analyzed in the Duval El-Biar clinic laboratory in Algiers using the Atellica® system (Siemens Healthcare Diagnostics Inc., Tarrytown, NY, USA), which integrates modules for clinical biochemistry analysis and flexible immunoassays. The thresholds for determining 25(OH)D status are < 20 ng/ml for deficiency and 20 to 29.9 ng/ml for insufficiency, following guidelines from the Endocrine Society.

Statistical analysis

The first part of the analysis used GraphPad Prism software, while the second part used IBM SPSS Statistics Version 26.

To assess the normality of our data, we performed the Kolmogorov-Smirnov test for each group (mothers, fathers, newborns). The results showed that all p-values were greater than 0.05, indicating that the data from each group followed a normal distribution. Therefore, we could employ parametric tests for the subsequent statistical analyses.

Continuous quantitative data were reported as means ± standard deviations, while qualitative data were shown as percentages. Comparisons were conducted using the Student's t-test for qualitative variables with two categories and one-way ANOVA for those with three or more categories, followed by Tukey's post hoc test when significant differences were detected. We employed Pearson's correlation to analyze the relationships between two quantitative variables.

A multiple linear regression was performed to examine the simultaneous effect of several independent variables on a single continuous quantitative dependent variable.

After multiple comparisons, the Bonferroni adjustment was applied to correct the significance threshold, maintaining strict control over the overall Type I error rate.

ROC analysis was performed to evaluate the predictive ability of parental 25(OH)D levels for a lower Apgar score in newborns of mothers with suboptimal vitamin D status. The area under the curve (AUC) was calculated to assess the overall accuracy of the prediction. Differences were considered significant if $p < 0.05$.

Results

Sociodemographic characteristics of the parents

The present study included fifty Algerian families residing in Oran, comprising 50 males and 50 pregnant women who gave birth to 50 newborns. Parental characteristics are detailed in Table 1. The median age of the women was 30 years, and most were stay-at-home mothers, with 18% having only a primary education, the majority (60%) possessing an intermediate level of education, and the remaining 11% having attained higher education. 60% of the blood samples were collected during the winter season. A significant majority of the women (90%) gave birth vaginally. It was noted that 26% of the women had a history of COVID-19. Additionally, 60% of the women had dark skin, and 84% experienced insufficient sun exposure (less than 30 min per day). Concerning anemia, it was present in all the pregnant women, but its severity varied, with 62% of the women exhibiting severe anemia.

The median age of the males participating in the study was 36 years, with most having a moderate level of education (64%) and 22% having completed primary education. In terms of occupational income, 78% reported moderate income. Among these families, 64% lived in free housing, while 26% were homeowners. Half of the males had dark skin, but the difference lay in the duration of sun exposure, as 40 out of 50 males had insufficient exposure to sunlight. Additionally, 68% of them were smokers.

Among women, specific characteristics significantly increase the risk of developing 25(OH)D insufficiency, particularly a history of COVID-19, dark skin, anemia, and insufficient sun exposure (Table 1). In contrast, among men, two factors appeared to significantly affect

Table 1 Sociodemographic characteristics in parents and their impact on 25(OH)D levels

Maternal description	N	Mean(SD)	p-value	Paternal description	N	Mean(SD)	p-value[1]
Age				Age			
20 years – 26 years	18	14.92 (6.486)	0.180	20 years – 26 years	1	26,41 (/)	0.310
27 years – 35 years	22	14.57 (5.846)		27 years – 35 years	23	18.37 (6.142)	
36 years – 45 years	10	10.90 (3.814)		36 years – 45 years	27	17.97 (7.308)	
Blood sample Collection Season				Blood sample Collection Season			
Winter	30	14.95 (6.298)	0.344	Winter	30	18.70 (6.933)	0.556
Spring	8	12.79 (5.944)		Spring	8	15.780 (5.847)	
Autumn	12	12.27 (4.369)		Autumn	12	18.34 (6.954)	
Education level				Education level			
Never attendedschool	/	/	0.459	Never attendedschool	1	25.64 (/)	0.015*
Primaryeducation	9	12.63 (4.505)		Primaryeducation	11	16.30 (5.458)	
Middle schooleducation	30	14.82 (6.665)		Middle schooleducation	32	17.17 (6.751)	
Highereducation	11	12.72 (4.202)		Highereducation	6	25.49 (3.516)	
Occupation type				Occupation type			
Low income	10	9.79 (3.67)	0.073	Low income	10	14.30 (5.717)	0.052
Moderateincome	39	14.74 (5.69)		Moderateincome	39	18.89 (6.617)	
High income	1	25.52 (0)		High income	1	27.76 (/)	
Housing occupation status				Housing occupation status			
Housingprovided for free.	33	13,17(5,35)	0.276	Housingprovided for free.	33	16.15 (6.255)	0.006**
Own a detached house.	13	15,29(6,61)		Own a detached house.	13	21.14 (6.593)	
Renting an empty residence	4	16,24(7,61)		Renting an empty rresidence	4	24.92 (2.234)	
COVID-19				COVID-19			
Yes	13	7.47 (1.024)	0.000***	Yes	/	/	/
No	37	16.24 (5.083)		No	50	18,21(6,785)	
Skin color				Skin color			
Light	20	16.69 (6.78)	0.006**	Light	25	22.12 (5.42)	< 0.0001***
Dark	30	12.15 (4.40)		Dark	25	14.18 (5.51)	
Sun exposure				Sun exposure			
Insufficient < 30 min/day	42	12.64 (4.96)	< 0.0001***	Insufficient < 30 min/day	40	44 (6.34)	0.0002***
Sufficient ≥ 30 min/day	8	20.95 (5.47)		Sufficient ≥ 30 min/day	10	24.79 (2.79)	
Smoking				Smoking			
Yes	/	/	/	Yes	34	17.50 (6.85)	0.324
No	50	13,96(5,800)		No	16	19.53 (6.46)	
Anemia							
Low	19	19.66 (4.68)	< 0.0001***				
High	31	10.48 (3.15)					
Type of delivery							
Vaginal	45	14.22 (6.024)	0.322				
Cesarean	5	11.47 (3.569)					

Significant differences between groups (Student' test or ANOVA tests; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$)

this deficiency: skin color and insufficient sun exposure (Table 1). Other characteristics were examined, but they did not significantly influence the deficiency observed in the parents (Table 1).

A multiple linear regression was conducted to examine the relationship between parental 25(OH)D status and sociodemographic characteristics. No significant relationship was observed between maternal 25(OH)D level and age (-0.82, CI 95% -0.56 to -0.60; p-value = 0.413), education level (-0.46, CI 95% -0.26 to -0.03; p-value = 0.646), occupation type (-0.25, CI 95% -0.25 to -0.02; p-value = 0.804), housing occupation status (-0.41, CI 95% -0.30 to -0.03; p-value = 0.681), type of delivery (-0.17, CI 95% -0.28 to -0.01; p-value = 0.859) or skin color (1.18, CI 95% 1.25 to 0.10; p-value = 0.243). However, a significant relationship and weak association were noted between maternal 25(OH)D levels and blood sample collection season (-2.02, CI 95% -1.23 to -0.16; p-value = 0.049). A highly significant relationship and a moderate association with anemia (-2.76, CI 95% -9.26 to -0.22; p-value = 0.009) and strong association with very highly significant relationship was noted with COVID-19 (-5.68, CI 95% -6.34 to -0.48; p-value = 0.000) and sun exposure (5.71, CI 95% 0.80 to 0.49; p-value = 0.000).

(Fig. 1A). After applying the Bonferroni correction for multiple comparisons (adjusted significance threshold: p-value < 0.005), only two associations -those with COVID-19 status and sun exposure- remained statistically significant, suggesting a robust and reliable relationship. In contrast, the associations with anemia and the season of blood sample collection no longer reached statistical significance.

The relationship was highly significant for males, showing a strong association between 25(OH)D levels and skin color (3.66, CI 95%, 6.61 to 0.49; p-value = 0.001). A significant, moderate association was observed with housing occupation status (2.08, CI 95% 2.92 to 0.27; p-value = 0.043). There was no statistically significant difference found among the remaining sociodemographic characteristics (age, blood sample collection season, education level, occupation type, sun exposure, smoking) (-0.01, CI 95% -0.03 to -0.002; p-value = 0.985), (-0.96, CI 95% -0.99 to -0.11; p-value = 0.341),(1.26, CI 95% 1.47 to 0.16; p-value = 0.215), (-0.44, CI 95% -0.76 to -0.05; p-value = 0.658), (1.12, CI 95% 0.04 to 0.13; p-value = 0.269), (1.63, CI 95% 2.98 to 0.20; p-value = 0.109) respectively (Fig. 1B).

Only skin color remained statistically significant after applying Bonferroni correction for multiple testing (adjusted significance threshold: p-value < 0.0062).

Biological characteristics of parents

After measuring 25(OH)D levels in parents, it was observed that the majority of parents were deficient in 25(OH)D, with 54% of women having an average of 14.23 ng/ml and 42% of men averaging 15.78 ng/ml. 16% of pregnant women studied were insufficient (with levels between 20 and 29.9 ng/ml), averaging 24.53 ng/ml, and 40% of men fall into this category. A severe deficiency was present in 30% of women, with an average of 7.69 ng/ml, and in 18% of men, with an average of 8.53 ng/ml.

The averages also seem to be significantly lower in women compared to males overall (13.96 ng/ml vs. 18.15 ng/ml, respectively), as well as in each category (insufficient and deficient).

Biological and anthropometric parameters of newborns

Newborns with parents exhibiting insufficiency (25(OH)D levels between 20 and 29.9 ng/ml) or deficiency (25(OH)D levels < 20 ng/ml) showed suboptimal 25(OH)D concentrations. Among these newborns, 52% of girls and 28% of boys were deficient, yielding average levels of 14.16 ng/ml and 12.77 ng/ml, respectively. Additionally, 25(OH)D insufficiency was noted in 24% of girls and 20% of boys, with average levels of 24.27 ng/ml and 22.79 ng/ml, respectively. Furthermore, 24% of girls and 52% of boys exhibited severe deficiency, with average levels of 7.26 ng/ml and 7.81 ng/ml, accordingly. However, no significant association was identified between 25(OH)D status and the newborn's sex (p-value = 0.13).

Various anthropometric parameters were studied in newborns, including height, femur length, weight, and Apgar scores at one minute (Apgar1) and at five minutes (Apgar5) after birth. All newborns with suboptimal 25(OH)D levels exhibited anthropometric parameters that measured below the norm (Table 2), showing a strong and highly significant correlation (p-value = 0.0001 for all anthropometric parameters). The normal values for these parameters were as follows: height > 47 cm, weight > 2500 g, femur length = 69–73 cm, Apgar score at 1st minute ≥ 7/10, and Apgar score at 5th minute ≥ 7/10. No differences were observed between boys and girls for any of the physiological characteristics studied (p-value > 0.05) (Table 2).

Correlation between parental 25(OH)D levels and anthropometric parameters of newborns

Maternal 25(OH)D levels were positively correlated with newborn parameters: height, femur length, weight, and Apgar score at 1 and 5 min, demonstrating a strong correlation (p-value = 0.0009, 0.004, 0.023, 0.0007, 0.0042, respectively) (Fig. 2A, B, C, D, E).

No significant correlation was observed between paternal 25(OH)D levels and the anthropometric parameters of the offspring, including height, femur length, weight, and Apgar scores at 1 and 5 min for the newborns (p-value = 0.19, 0.37, 0.45, 0.53, and 0.58, respectively) (Fig. 3A, B, C, D, E).

Two distinct ROC analyses were performed to assess the performance of maternal 25(OH)D concentration in predicting an Apgar score < 7 at the 1st and 5th minutes of life. For the score at the 1st minute, the area under the curve (AUC) was 0.785 (95% CI: 0.652–0.918), indicating good discriminative ability. The optimal cut-off identified using the Youden index was 12.58 ng/mL, with a sensitivity of 75% and specificity of 76%. (Fig. 4.A). For the score at the 5th minute, the obtained AUC was 0.652 (95% CI: 0.444–0.871), reflecting moderate discriminative ability. The optimal cut-off determined was 12.49 ng/mL, with a sensitivity of 75% and specificity of 64%. (Fig. 4.B)

This indicates that Maternal 25(OH)D levels below 12.58 ng/mL and 12.49 ng/mL were associated with a higher risk of an Apgar score < 7 at the 1st and 5th minutes, respectively.

Correlation between parental and umbilical cord serum 25(OH) D levels

A positive and moderate correlation was observed between the 25(OH)D levels in newborns and those in their mothers. In other words, the 25(OH)D levels of newborns were significantly correlated with those of their mothers (r = 0.419; p-value = 0.002) (Fig. 5A). In contrast,

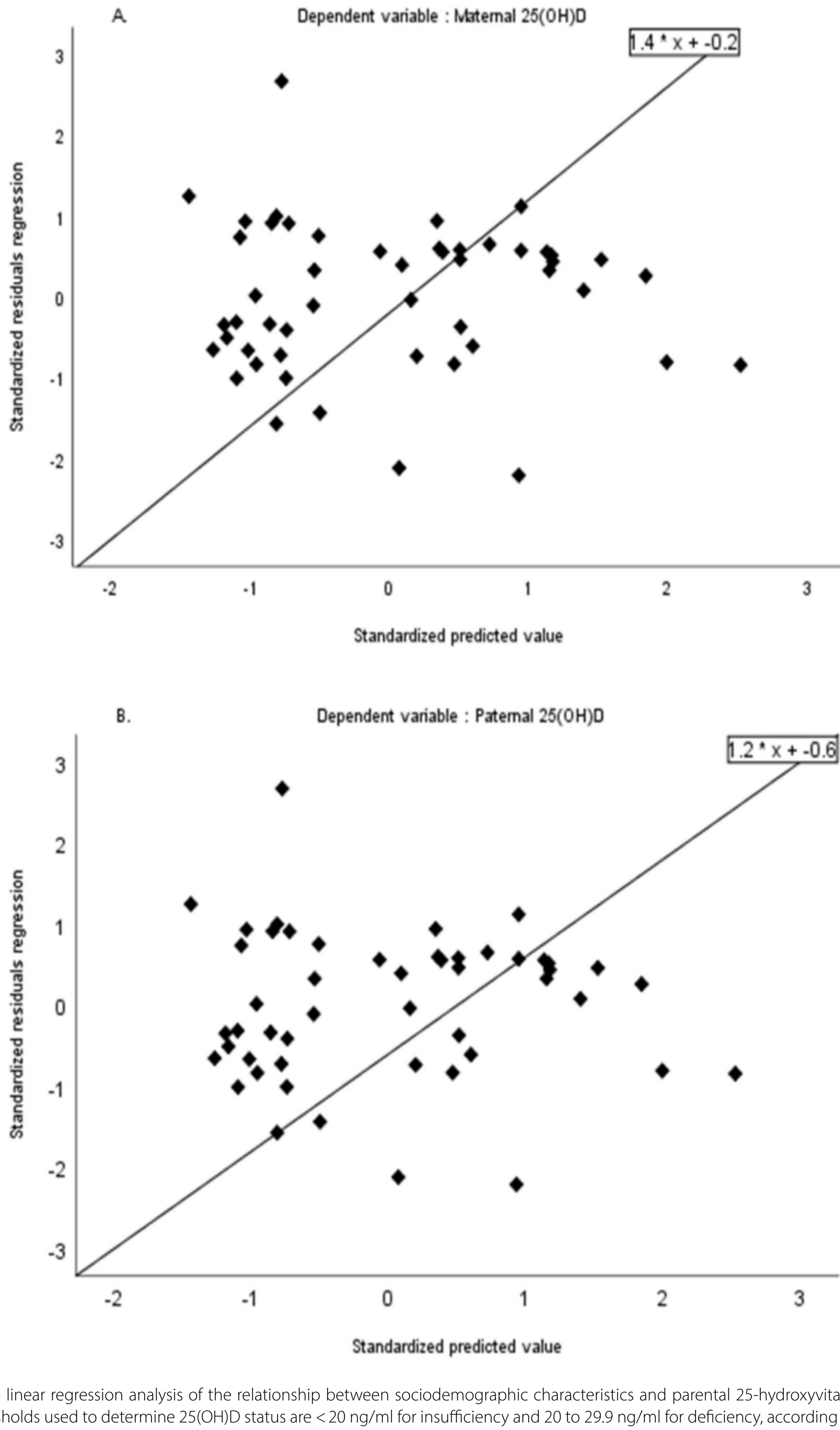

Fig. 1 Multiple linear regression analysis of the relationship between sociodemographic characteristics and parental 25-hydroxyvitamin D (25(OH)D) levels. The thresholds used to determine 25(OH)D status are < 20 ng/ml for insufficiency and 20 to 29.9 ng/ml for deficiency, according to the guidelines from the Endocrine Society. (**A**) Relationship with maternal 25(OH)D levels. (**B**) The relationship between sociodemographic characteristics and paternal 25(OH)D levels

Table 2 Normal and recorded values of anthropometric parameters in newborns

Anthropometric parameters	Normal Values	Recorded Values			*p*-value
		Total ($n=50$) Mean(SD)	Girls ($n=25$) Mean(SD)	Boys ($n=25$ Mean(SD)	
Height(cm)	> 47	45.80 (2.86)	46.28 (2.85)	45.32 (2.85)	0.24
Weight(g)	> 2500	2420 (0.28)	2470 (0.32)	2370 (0.23)	0.17
Femur length(cm)	69–73	68.16 (2.37)	68.60 (2.57)	67.72 (2.11)	0.19
Apgar score at 1st min	≥ 7/10	6.7 (1.6)	7 (1.6)	6.3 (1.7)	0.14
Apgar score at 5th min	≥ 7/10	8.2 (1.4)	8.4 (1.3)	8 (1.5)	0.24

Significant differences between groups (ANOVA tests)

no correlation was found between paternal 25(OH)D levels and those of their newborns (*p*-value = 0.34) (Fig. 5B).

Discussion

According to the Endocrine Society's guidelines, the thresholds for determining 25(OH)D status are < 20 ng/ml for deficiency and 20 to 29.9 ng/ml for insufficiency [17]. We observed a marked deficiency of 25(OH)D in pregnant women toward the end of their pregnancies, which was significantly correlated with insufficient sun exposure duration. In our sample, 42 out of 50 women did not receive adequate sun exposure (< 30 min/day) (*p*-value < 0.0001). This result is supported by multivariate analysis, which identified sun exposure as the most impactful factor on maternal 25(OH)D status (p-value = 0.000). Some studies indicate that girls are more likely to experience vitamin D insufficiency due to less time outdoors and wearing clothing that reduces sunlight exposure [18]. It is widely accepted in the literature that when sun exposure falls below 30 min per day, even with substantial skin area exposed, the risk of vitamin D deficiency becomes significant [19]. Although the study region enjoys abundant sunlight, hypovitaminosis D remains prevalent in several countries with similar climates, such as Morocco [20] and Tunisia [21]. Additionally, darker skin color appears to predict this deficiency, significantly associated with varying 25(OH)D levels among pregnant women and males (*p*-value = 0.006 and *p*-value < 0.0001, respectively). In the multivariate analysis, skin color lost its influence on maternal 25(OH)D status in the presence of other sociodemographic factors (*p*-value = 0.24), while paternal 25(OH)D deficiency is more influenced by skin color (*p*-value = 0.001).

In line with the literature [22], we observed a consistent positive relationship between low socioeconomic status- including educational level and housing occupation status- and various levels of decreased 25(OH)D (*p*-values = 0.015 and 0.006, respectively). When accounting for other confounding factors, housing occupation status significantly impacts paternal 25(OH)D (*p*-value = 0.004). This finding may relate to poor nutrition in many households or the substantial amounts spent on rent, which ultimately reduce purchasing power.

This multivariate analysis also allowed us to determine the impact of blood sampling season on maternal 25(OH)D status. In the univariate analysis, this relationship was negative (*p*-value = 0.34), but it became significantly positive (*p*-value = 0.02) in the presence of several other confounding factors. This result is inconsistent with the findings of an Algerian study conducted in the Tlemcen region, which indicated a positive relationship between these two variables [23]. Our results also showed the negative effect of smoking on 25(OH)D levels in males, a finding that has already been reported in a study investigating the prevalence and factors associated with vitamin D deficiency in Hashimoto's thyroiditis [24].

Furthermore, pregnant women who are deficient in 25(OH)D are more likely to contract COVID-19 (*p*-value = 0.000), and all of them exhibited anemia of varying severity. In pregnant women, anemia is defined as having a hemoglobin level below 110 g/L, with severe anemia characterized by levels below 70 g/L [25]. 80% of the women had severe anemia, and this severity was positively correlated with decreased 25(OH)D levels in both univariate and multivariate studies (*p*-value < 0.0001 and 0.009, respectively) compared to males. Our observation that 25(OH)D insufficiency during the third trimester of pregnancy was associated with a lower rate of gestational anemia aligns with several previous studies, suggesting that maternal vitamin D deficiency during pregnancy may contribute to gestational anemia. Several mechanisms explain the relationship between vitamin D deficiency and anemia. According to Young et al., vitamin D deficiency may positively regulate hepcidin, a peptide hormone that controls iron metabolism, which decreases hemoglobin concentrations and could therefore contribute to anemia [25]. A more recent study by Stallhofer et al. confirmed this association between vitamin D and anemia, demonstrating that vitamin D can improve iron deficiency, potentially by downregulating hepcidin and upregulating ceruloplasmin, thus enhancing intestinal iron absorption [26]. The Bonferroni adjustment resulted in the loss of statistical significance for certain sociodemographic variables. While this correction enhances statistical rigor by limiting false positives, it may also lead to type II errors. Therefore, some of these variables may

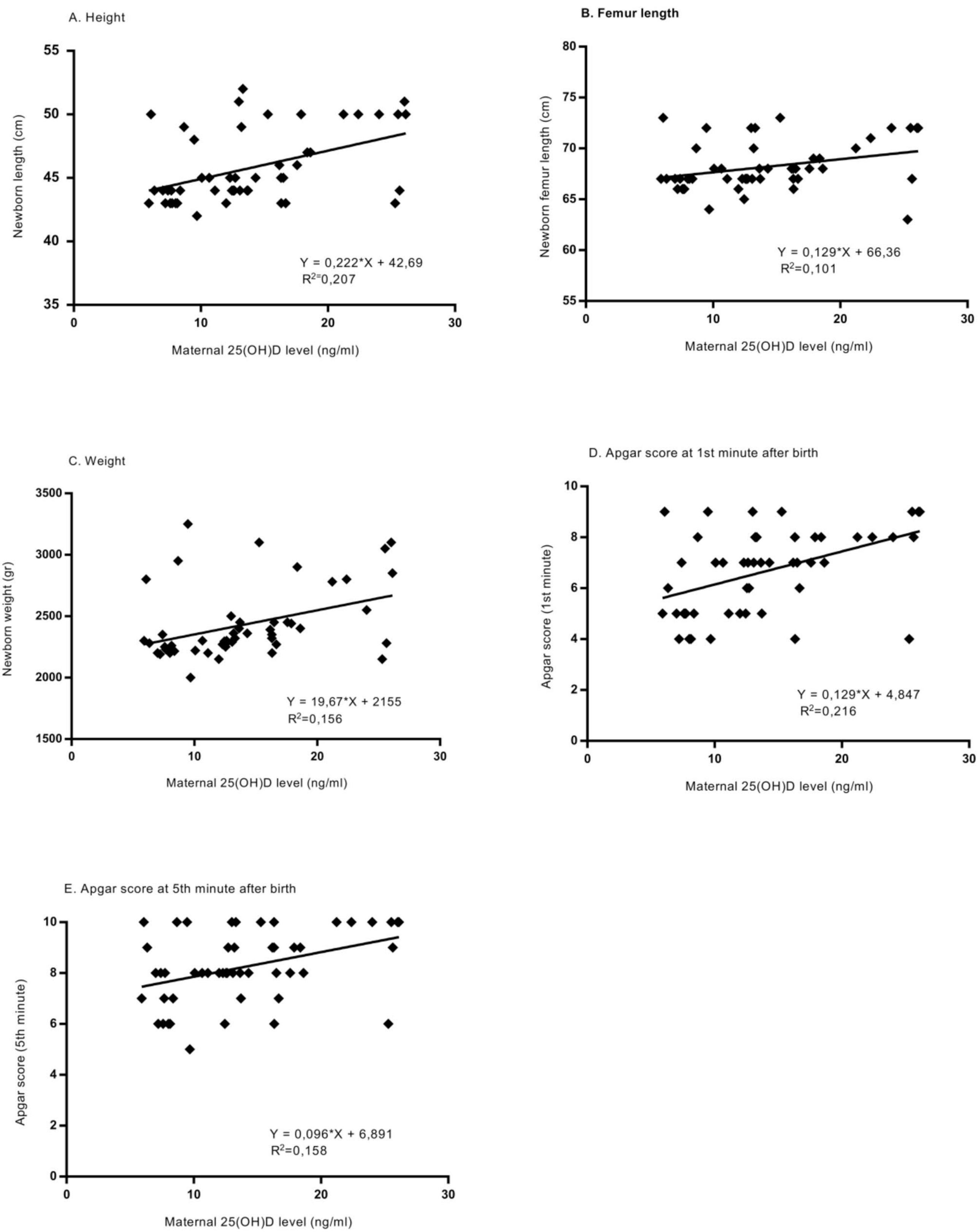

Fig. 2 Correlation between maternal 25(OH)D levels and the anthropometric parameters of newborns. (**A**) Correlation between maternal 25(OH)D levels and newborn height. (**B**) Correlation between maternal 25(OH)D levels and newborn femur length. (**C**) Correlation between maternal 25(OH)D levels and newborn weight. (**D**) Correlation between maternal 25(OH)D levels and the Apgar score of newborns at the 1st minute. (**E**) Correlation between maternal 25(OH)D levels and the Apgar score of newborns at the 5th minute

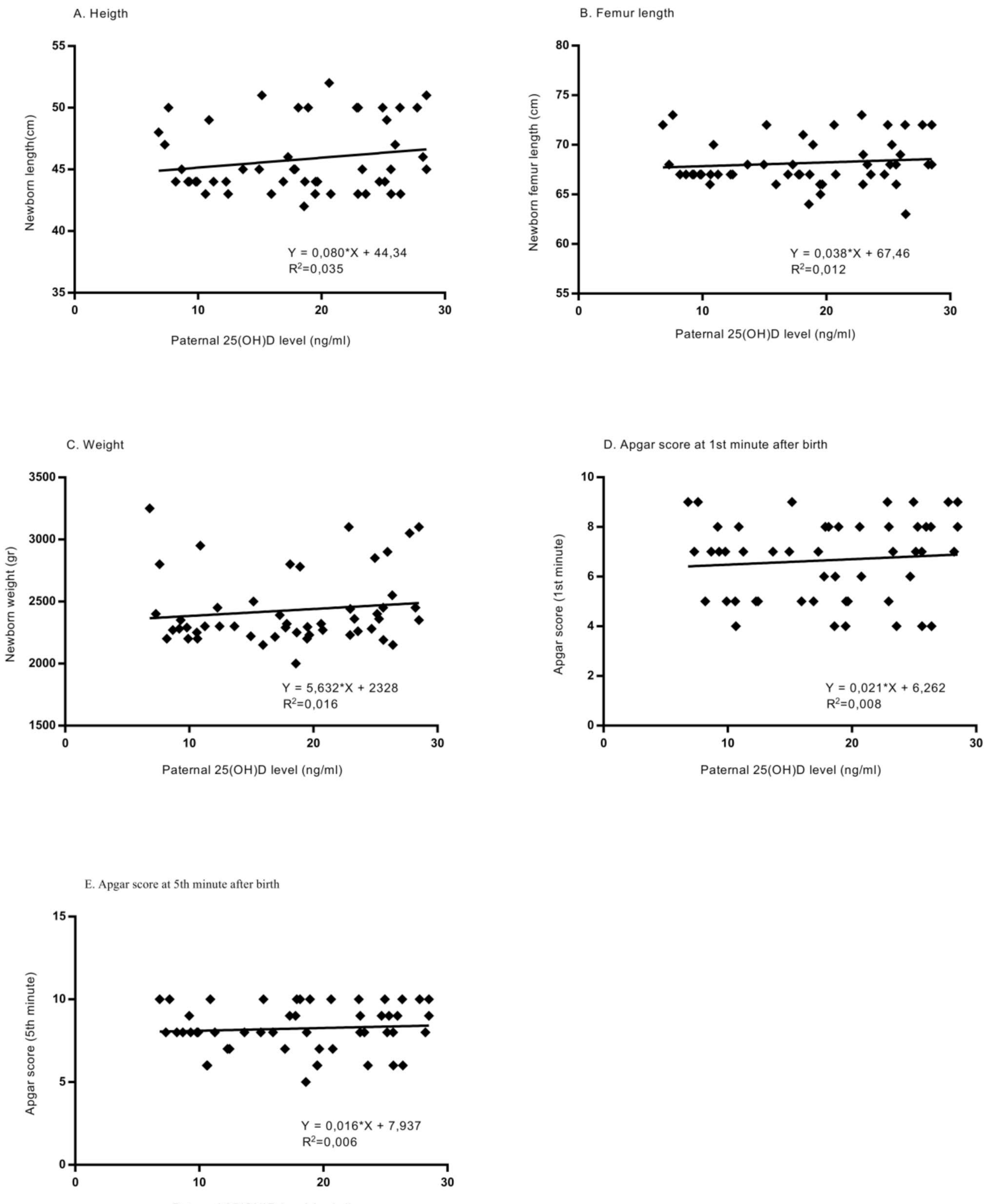

Fig. 3 Correlation between paternal 25(OH)D levels and the anthropometric parameters of newborns. (**A**) Correlation between paternal 25(OH)D levels and newborn height. (**B**) Correlation between paternal 25(OH)D levels and newborn femur length. (**C**) Correlation between paternal 25(OH)D levels and newborn weight. (**D**) Correlation between paternal 25(OH)D levels and the Apgar score of newborns at 1 min. (**E**) Correlation between paternal 25(OH)D levels and the Apgar score of newborns at 5 min

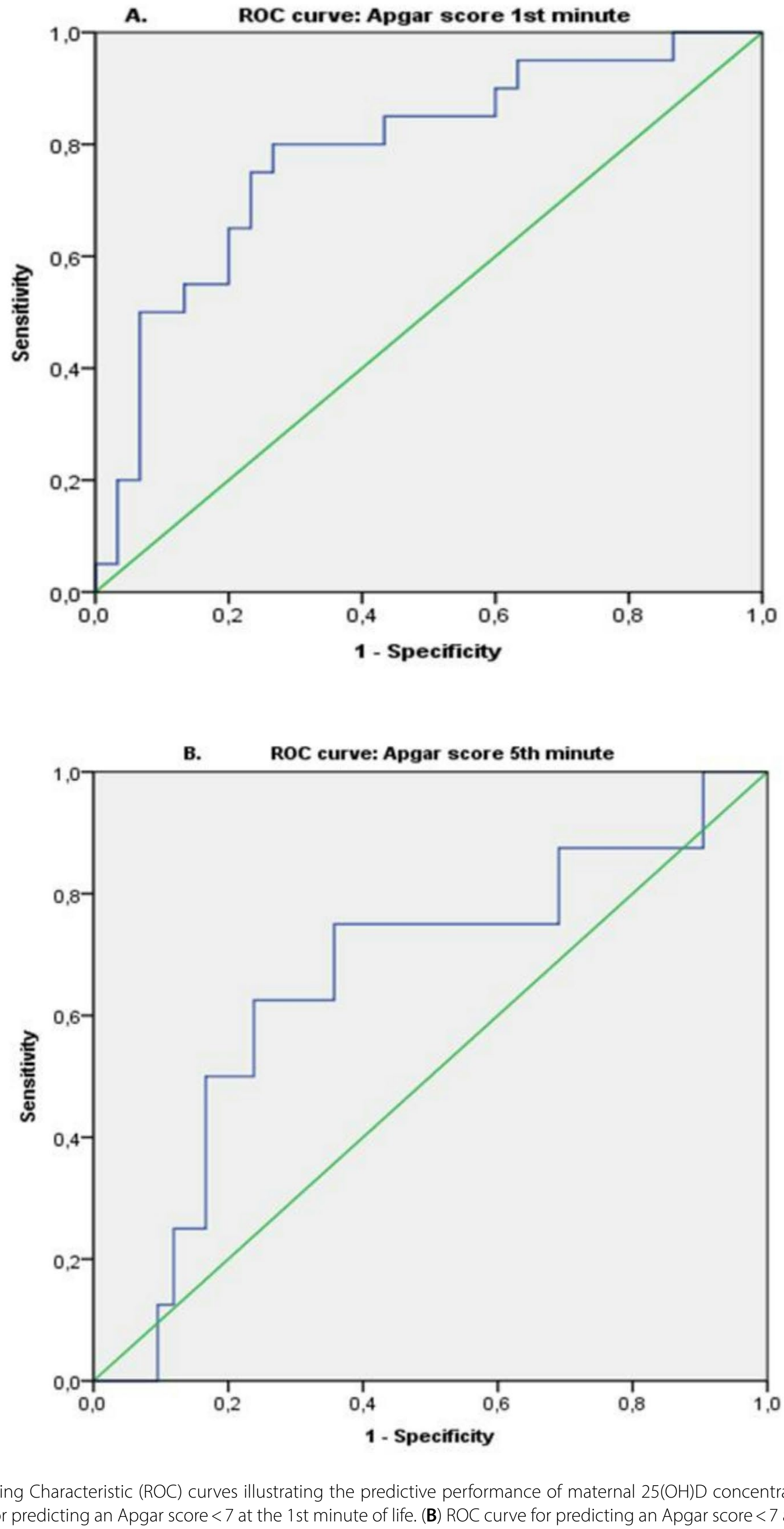

Fig. 4 Receiver Operating Characteristic (ROC) curves illustrating the predictive performance of maternal 25(OH)D concentration for neonatal Apgar scores. (**A**) ROC curve for predicting an Apgar score < 7 at the 1st minute of life. (**B**) ROC curve for predicting an Apgar score < 7 at the 5th minute of life

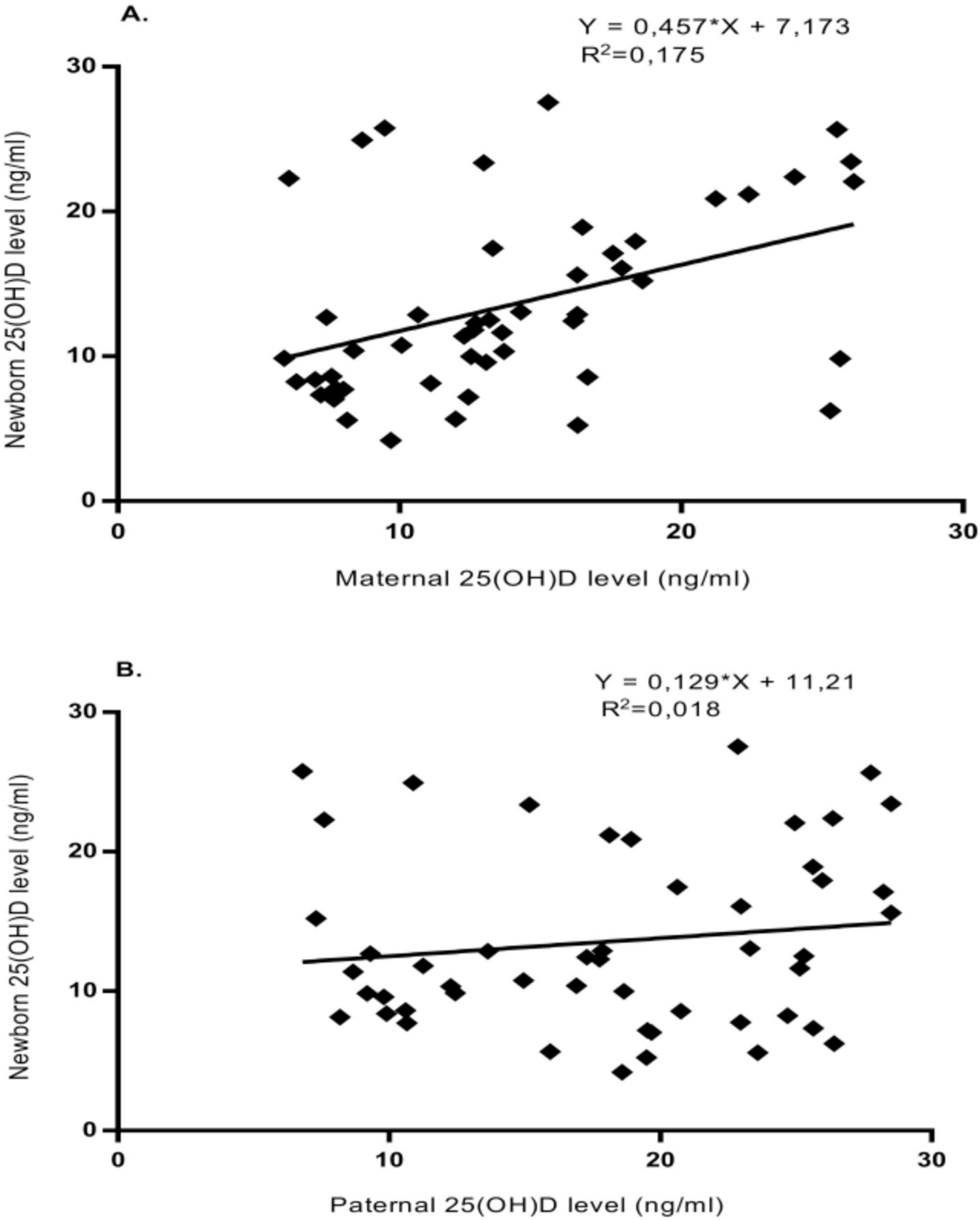

Fig. 5 Correlation between parental and newborn 25(OH) D levels. (**A**) Correlation between maternal and newborn 25(OH) D levels and in the second graph. (**B**) Correlation is between paternal and newborn 25(OH) D levels

still hold biological or social relevance despite the lack of statistically significant correction.

In the present study, a significant difference in 25(OH)D levels was observed between pregnant women and men (p-value = 0.001). Maternal 25(OH)D deficiency was identified in 27 out of 50 women, with an average level of 14.23 ng/ml, while severe deficiency was noted in 15 women, who had an average level of 7.69 ng/ml. These findings align with previous studies demonstrating the prevalence of 25(OH)D deficiency during pregnancy [27], with rates ranging from 8 to 70%, depending on skin pigmentation; darker skin is associated with a higher risk of vitamin D deficiency and longer duration of sun exposure [28]. Additionally, it is crucial to consider other factors that affect vitamin D levels, such as poor nutrition stemming from low socioeconomic status, as diet contributes only a small amount of vitamin D. Furthermore, these women did not receive vitamin D supplementation. Similarly, these factors also influenced the 25(OH)D levels in men, with 21 out of 50 being deficient, 20 classified as insufficient, and the remaining 9 exhibiting severe deficiency.

No significant difference was observed between the 25(OH)D levels of boys and girls (p-value = 0.13). However, 40% of the newborns were deficient, 22% were insufficient, and 38% had severe deficiency. Additionally, our results indicate that 25(OH)D levels in offspring, regardless of gender, were positively correlated with their mothers' levels. These findings support a meta-analysis that provides evidence of an association between maternal blood 25(OH)D concentrations during pregnancy and umbilical cord blood 25(OH)D concentrations at birth. Overall, maternal 25(OH)D concentrations throughout all trimesters of pregnancy, especially during the third trimester, significantly influence umbilical cord blood 25(OH)D concentrations [29]. During pregnancy, 25(OH)D crosses the placenta from the mother to the fetus, and the level measured in umbilical cord blood at birth depends on maternal status, which is, on average, 80% of the woman's blood value. Therefore, if the mother is deficient, the fetus will likely experience the same deficiency [30]. In contrast, no significant difference was found between males and their newborns, and no studies have investigated this relationship, paving the way for potential future research.

Examining the parent-offspring relationship further, a question arises: Is there a link between parental 25(OH)D levels and the anthropometric parameters of newborns? The results revealed a positive correlation between maternal 25(OH)D deficiency and reduced birth size, shorter femur length, and lower birth weight (p-values = 0.0009, 0.023, 0.004, respectively). In this context, maternal vitamin D directly impacts neonatal anthropometric parameters, and deficiency in the last trimester of pregnancy poses a significant risk for both mothers and newborns. Several previous studies support this, linking maternal vitamin D deficiency to various health issues in both pregnant women and newborns, including bone problems for women, infertility, endometriosis, polycystic ovary syndrome, and adverse pregnancy outcomes such as miscarriages, gestational diabetes, bacterial infections, infectious diseases, premature birth, bacterial vaginosis, and preeclampsia [31]. Additionally, problems such as neonatal hypocalcemia, prematurity, growth disorders, and low birth weight in newborns have also been noted [32]. Zhang et al. explained in a study that placental VDR plays a crucial role in pregnancy, and maternal VDR gene polymorphism may affect birth weight. Maternal vitamin D status during pregnancy may also significantly determine offspring telomere length, which is positively correlated with birth weight [33].

In our study, we also noted a highly significant relationship between maternal deficiency in 25(OH)D and the Apgar score at the first and fifth minutes after birth (p-values = 0.0007, 0.0042, respectively). The Apgar score is the most commonly used measure for assessing the health status of newborns, and non-malformed term infants with lower Apgar scores within the normal range face an increased risk of adverse long-term outcomes, such as epilepsy, cerebral palsy, and the need for additional care [34]. To further explore the relationship between maternal deficiency in 25(OH)D and the Apgar score, we conducted a ROC curve analysis, which revealed that maternal 25(OH)D concentration has a meaningful predictive value for neonatal vitality, particularly in the immediate minutes following birth. At the 1st minute, the area under the curve (AUC) reached 0.785 (95% CI: 0.652–0.918), indicating a good discriminative capacity. The optimal cut-off point determined by the Youden index was 12.58 ng/mL, with a sensitivity of 75% and a specificity of 76%. This suggests that maternal vitamin D status plays a significant role in the newborn's initial adaptation to extrauterine life, and that a 25(OH)D concentration below this threshold is associated with an increased risk of compromised neonatal condition, as reflected by an Apgar score < 7. At the 5th minute, although the discriminative power decreased (AUC = 0.652, 95% CI: 0.444–0.871), the analysis still indicated a moderate predictive ability. The optimal cut-off was 12.49 ng/mL, with the same sensitivity of 75%, but a slightly lower specificity of 64%. This relative decline in specificity may reflect the growing influence of postnatal interventions or other perinatal factors on the Apgar score as time progresses. Nevertheless, the persistence of high sensitivity supports the idea that maternal 25(OH)D deficiency continues to exert an influence on neonatal adaptation even several minutes after birth.

The relationship between vitamin D and the Apgar score has been confirmed by several studies, which found that women with vitamin D deficiency had a significantly higher proportion of infants born with a low Apgar score [35–37].Augustin et al. suggested that poor vitamin D status disrupts myometrial function through several mechanisms, including impaired regulation of intracellular calcium concentration, diminished binding to the vitamin D receptor in the uterine endometrium and myometrium, and increased levels of inflammation-induced cytokines and factors associated with contraction in myometrial smooth muscle cells [38].

Conversely, our results did not show any significant relationship between various paternal 25(OH)D levels and neonatal anthropometric parameters (height, femur length, weight, Apgar scores at the 1st and 5th minutes, with *p*-values of 0.19, 0.37, 0.45, 0.53, and 0.58, respectively). These findings indicate that neonatal anthropometric parameters are positively associated with maternal 25(OH)D levels rather than paternal levels. Similarly, maternal 25(OH)D deficiency directly affects neonatal 25(OH)D levels, while paternal 25(OH)D levels do not influence those of the newborns.

However, this study has limitations, such as the relatively small sample size due to limited available resources. This constraint may have affected the statistical power of certain comparisons, increasing the risk of Type II error, meaning the possibility of missing weak but clinically relevant associations between vitamin D levels and the studied parameters. Moreover, although the sample is representative of the local population (Oran, Algeria), the generalizability of the results to other geographic or demographic contexts remains limited. Future studies involving larger and more diverse samples will be necessary to confirm our findings and assess their external validity.

Furthermore, the presence of a non-deficient couple group will be necessary for such a study, allowing for comparison with the deficient group. Additionally, the lack of a couple group where mothers are non-deficient and fathers are deficient has limited our ability to conclude the paternal-neonatal relationship.

To conclude, this study revealed that 25(OH)D deficiency and insufficiency are highly prevalent among both Algerian women and men. Decreased 25(OH)D levels in late pregnancy significantly correlate with a higher risk of neonatal 25(OH)D deficiency, growth delays, and, most importantly, an Apgar score below 7 at the first and fifth minutes after birth. Paternal deficiency did not impact offspring outcomes. Individualized vitamin D supplementation at the end of pregnancy should be considered to minimize this risk. Administering vitamin D throughout pregnancy is essential to protect infants from adverse effects on neonatal health. Furthermore, fortifying food with vitamin D could be an effective preventive measure, especially in countries like Algeria, where specific groups (pregnant women, infants, and the elderly) are at a heightened risk of deficiency. Enhancing commonly consumed foods such as dairy products, flour, and other staples could help improve vitamin D coverage. Numerous studies conducted in other countries have demonstrated that this approach can reduce vitamin D deficiencies at the population level and enhance the health of at-risk groups. Therefore, we recommend that further studies be conducted to explore these fortification strategies in Algeria, particularly aimed at the most vulnerable groups, to mitigate the risks associated with vitamin D deficiency and improve public health in the country.

Supplementary Information

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Supplementary Material 1

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Author contributions

Sara Mama Abadi, Habib Hammou, Lidia Saidi, Fenni Soumia, and Tawfik Addi conducted the research and analyzed the data. Ilies Megueni provided essential tools for the study. Seyf El Islem Negadi assisted in the recruitment. Sahra Meziane, Farid Boubred contributed critical interpretation, revision, and input to the article. Sara Mama Abadi and Jean-Francois Landrier designed the experiment, interpreted the results, and wrote the paper.

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Data availability

Data is provided within the manuscript.

Declarations

Ethics approval and consent to participate

This study was approved by the Medical Ethics Committee of Oran University Hospital N°83/2021/DAPM. The study was conducted according to the guidelines laid down in the Declaration of Helsinki of 1975 as revised in 1983 and to the guidelines for Good Clinical Practice of ICH. All persons gave their informed consent before their inclusion in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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