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Association between Vitamin D Status and Health Status of Adults in Western Libya

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Abstract: Vitamin D (VitD) is essential for health and preventing diseases. This study aimed to investigate the possible association between VitD status and health status in 306 Libyan male and female young adults (18–25 Y) and adults (26–65 Y). There were 89.54% of subjects that had VitD levels below normal (<30 ng/mL), of which 45.42% were VitD deficient (<10 ng/mL) and 44.12% were VitD insufficient (10–29.9 ng/mL). VitD deficiency was associated with higher fasting blood sugar (FBS), low-density lipoprotein (LDL), and triacylglycerol (TAG) levels. Young adults had lower VitD levels than adults, which was associated with some health conditions. VitD insufficiency was associated with higher body mass index (BMI) values in adults, especially females, with higher FBS levels in adult males and higher hemoglobin A1c (HbA1c) levels in adult females. VitD deficiency in young adults was associated with higher TAG levels (more likely in adults) and lower high-density lipoprotein (HDL) values. Furthermore, VitD deficient adult females appeared to have a higher risk of sleeping problems, psychological disorders, headache, and osteoporosis, whereas their male counterparts appeared to be at a higher risk of developing obesity and diabetes mellitus (DM). Findings showed a serious prevalence of VitD inadequacy in the Libyan population, which appears to negatively affect health status and be associated with some disease conditions.

Keywords: Vitamin D; health status; young adult; adult; deficiency; insufficiency; Western Libya; epidemiological study; malnutrition

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1. Introduction

Vitamin D (VitD) plays an essential role in health and diseases [1]. It plays a key role in maintaining calcium and phosphate homeostasis and promoting the proliferation and differentiation of bone-forming osteoblasts [1]. Moreover, VitD can play key "non-classical" roles in many diseases. VitD deficiency is an increasingly prevalent public health concern in many countries [2]. VitD status is commonly assessed based on a single measurement of the serum concentration of 25-hydroxyvitamin D [25(OH)D], the precursor of the metabolically active VitD [1,25(OH)2D] that binds to the ubiquitously expressed VitD receptor. VitD deficiency can affect immunity and inflammatory responses to infections, especially in granulomatous diseases, such as tuberculosis, inflammatory bowel disease, and multiple

sclerosis, and it is associated with an increase in the incidence of cancer and an acceleration of cognitive decline [2]. VitD deficiency leads to skeletal conditions such as rickets in children and osteomalacia in adults [1]. It is also crucial in diabetes mellitus (DM) and cardiovascular diseases (CVDs) [3].

VitD deficiency is more prevalent in diabetic patients; it reduces pancreatic islet cell destruction via suppression of pro-inflammatory cytokines, such as tumor necrosis factor-α (TNFα), IL-1b, and IL-6, thereby reducing the incidence of type-I DM [4]. VitD replacement can modulate glucose homeostasis in type-II DM [3]. Evidence suggests a possible role of vitamin D in the improvement of insulin secretion and sensitivity [3]. VitD replacement in VitD deficient subjects enhances glycemic control in type-II DM, although this evidence has not been substantiated in a systematic review of interventional studies [5]. Maternal VitD deficiency is correlated with an increased risk of pre-eclampsia, preterm birth, low birth weight, impaired postnatal growth, and increased gestational DM risk [3,6].

Obesity is a global epidemic that results in major morbidity and premature death, particularly in developed nations [2]. It is associated with VitD deficiency [2] and both are current public health concerns. Many reasons have been proposed to explain the reduced levels of VitD in obesity [7]. Perhaps the most significant is that the serum level of VitD is reduced because VitD enters the large fat deposits of adipose tissue. Obese individuals have an increased risk of VitD deficiency; however, the underlying mechanisms are unclear [8]. 1,25(OH)2D may influence the mobilization of free fatty acids from adipose tissue. In vitro experiments in rats have also shown that large doses of vitamin D2 lead to an increased energy expenditure due to the uncoupling of oxidative phosphorylation in adipose tissues [9]. However, VitD is stored in adipose tissue and, hence, perhaps the most likely explanation for this association is that the larger storage capacity for VitD in obese individuals leads to a lower circulating 25(OH)D concentration, which is a nutritional status marker [6]. Obesity and low VitD concentrations influence the risk of death [10]. However, they may not be causal factors in mortality and could be markers of poor health status preceding death [10].

There is growing concern about the health consequences of the high prevalence of VitD deficiency worldwide. The increased mortality in subjects with a low serum 25(OH)D concentration appears to be particularly related to CVDs [11], which could be explained by the well-documented association between low serum 25(OH)D concentrations and increased blood pressure [11], blood glucose, and body mass index (BMI) [12]. However, the relationship between serum 25(OH)D and serum lipid levels, which are among the major risk factors for CVDs, is less clear [13].

In Libya, there are currently few epidemiological studies on VitD. Therefore, we examined the VitD status and its relationship with some health indicators in a large (306) population of healthy subjects from West Libya (young adults and adults). The associations between VitD status and the clinical characteristics of patients with cardiometabolic disorders were examined. To assess the study objectives, we used the VitD status, Ca^{2+}, lipid profile status, fasting blood sugar (FBS), and hemoglobin A1c (HbA1c) data of the study participants.

2. Materials and Methods

2.1. Ethical Statement

This study was conducted according to the guidelines laid down in the Declaration of Helsinki [14] and all procedures involving human subjects were approved by the Research Ethics Committee of the Biotechnology Research Center in Tripoli, Libya, with an approval number of BEC-BTRC 22-2020. All study subjects provided their written consent.

2.2. Study Participants and Design

This cross-sectional study was conducted between April 2019 and March 2020 to investigate the possible association between the Vitamin D status and health status of adults in Western Libya. Data on VitD status were analyzed from available samples for

306 male and female Libyans aged 18–65 years, in groups of young adults (18–25 Y) and adults (26–65 Y). The participants of this study comprised all the attendees of different hospitals and clinics (e.g., Tripoli University Hospital), which covers most of Western Libya, including the capital, Tripoli.

2.3. Data Collection

All participants were asked to complete a predesigned face-to-face questionnaire that included information about their demographic characteristics, socioeconomic status, sociodemographic, lifestyle choices, and health-related, cognitive performance, and functional status. The levels of VitD, Ca^{2+}, total cholesterol, high-density lipoprotein (HDL), low-density lipoprotein (LDL), triacylglycerol (TAG), FBS, and HbA1c were also included. VitD status and blood samples, including serum, were assessed in a subsample of randomly selected participants (51) from this study group.

2.4. Measurement of VitD Status

Blood samples were collected from 51 randomly selected participants who participated in this study. Serum VitD analysis was performed by electrochemiluminescence protein binding assay (ECLIA) using Roche Diagnostics, Cobas e411 analyzer [15]. The VitD status was analyzed based on cut-off values proposed by the Institute of Medicine (IOM) in 2011 [16]. VitD sufficiency, insufficiency, and deficiency were defined as a serum concentration of $\geq$30, 10.1–29.9, and $\leq$10 ng/dL, respectively.

2.5. Anthropometry

Measurements of anthropometrics were done without shoes and jackets. Height was measured to the nearest 0.1 cm (Perspective Enterprises, Kalamazoo, MI, USA) and weight to the nearest 0.5 kg using a calibrated weight scale. Waist circumference (WC) was measured to the nearest 0.1 cm using soft tape. Anthropometric status was analyzed using classification according to body mass index (BMI; <18.5: underweight, 18.5–24.9: normal weight, 25.0–29.9: overweight, $\geq$30: obese) [17].

2.6. Statistics

Data were analyzed using Statistical Package for Social Science (SPSS) software (version 20.0; IBM Corp., Armonk, NY, USA) and are presented as means $\pm$ SEM (standard error of the mean) [18]. Data were tested for normality using the Kolmogorov–Smirnov test (with Lilliefors correlation). Statistical analyses of non-parametrical data of multiple experimental groups were analyzed using either a one-tailed Mann–Whitney U rank sum *t*-test or Kruskal–Wallis test, as appropriate. However, the statistical analysis of non-parametrical data of multiple experimental groups was analyzed using either two-way analysis of variance (two-way ANOVA) or Student's *t* test, as appropriate. Dunnett's test was used to determine the statistical significance between the studied groups. Statistical significance was set at $p \leq 0.05$.

3. Results

3.1. General Characteristics of the Participants

The total study population comprised 306 Libyan adult subjects aged 18–65 years (27.45% (N = 84) were male and 72.55% (N = 222) were female) (Figure 1). The general mean age of the participants was 38.67 $\pm$ 14.75 years (Figure 1). The mean ages of males and females were 39.29 $\pm$ 15.93 and 38.44 $\pm$ 14.32 years, respectively (Figure 1). The mean VitD level in male subjects was 16.59 $\pm$ 9.84 ng/dL and 13.59 $\pm$ 11.28 ng/dL in female subjects (Figure 1). Compared to males, female subjects had significantly more inadequate VitD levels (p = 0.033), which means that females are more prone to VitD deficiency than males (Figure 1). A significantly higher level of FBS was found in males than in females (p = 0.022) (Figure 1). Conversely, the other studied health indicators appeared to be unrelated to sex (Figure 1).

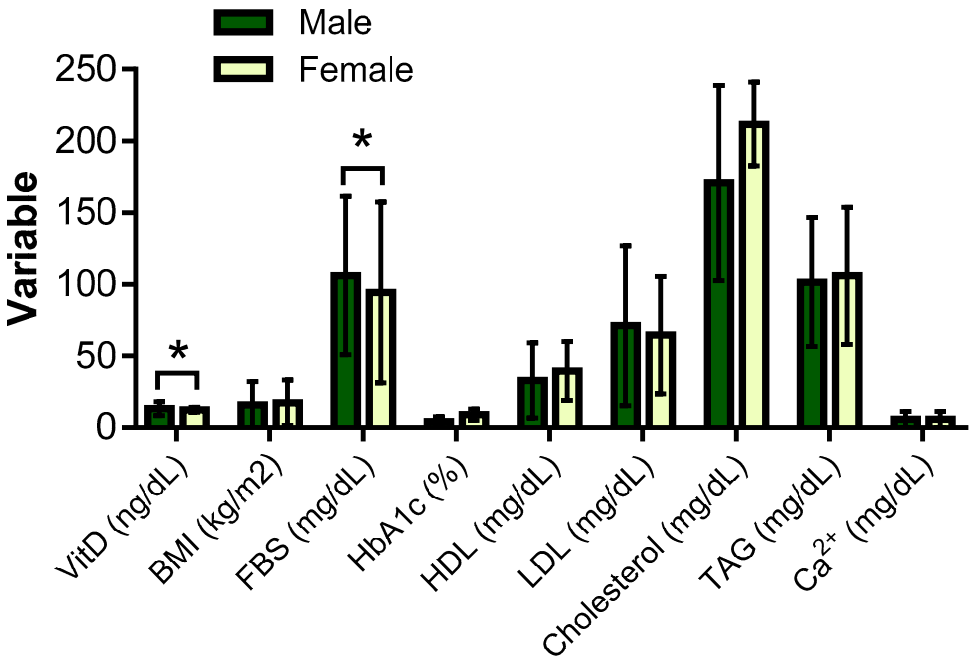

Figure 1. VitD status and other health indicators in Libyan adults according to sex. N = number; % = percentage within population; BMI = body mass index; FBS = fasting blood sugar; HbA1c = glycosylated hemoglobin; HDL = high-density lipoproteins; DL = low-density lipoproteins; TAG = triglycerides; Ca^{2+} = calcium; VitD = vitamin D. (*) indicates $p < 0.05$.

3.2. VitD Level in Libyan Adults

When assessing VitD status, three cut-off groups were defined, according to the World Health Organization classification for categorizing the subjects: VitD deficient (VitD level $\leq$ 10 ng/dL), VitD insufficient (VitD level of 10.1–29.9 ng/dL), and VitD sufficient or normal (VitD level $\geq$ 30 ng/dL). Accordingly, 45.42% (N = 139) of participants were VitD deficient, 44.12% (N = 135) were VitD insufficient (Table 1), and only 10.46% (N = 32) had sufficient/normal VitD levels (Table 1).

Table 1. VitD status and other health indicators in Libyan young adults (18–25 years) according to the VitD cut-off groups and sex.

	VitD Deficient (≤10 ng/dL)					**VitD Insufficient (10.1–29.9 ng/dL)**					**VitD Sufficient (≥30 ng/dL)**				
	Males		**Females**		***p*-Value**	**Males**		**Females**		***p*-Value**	**Males**		**Females**		***p*-Value**
	N	**%**	**N**	**%**		**N**	**%**	**N**	**%**		**N**	**%**	**N**	**%**	
	29	**34.52**	**110**	**49.54**		**46**	**54.76**	**89**	**40.09**		**9**	**10.71**	**23**	**10.36**	
VitD (ng/dL)	6.33 ± 2.65		5.2 ± 2.31		0.043	19.61 ± 4.20		17.63 ± 5.24		0.019	34.22 ± 9.82		38.09 ± 9.82		0.324
BMI (kg/m^2)	27.66 ± 4.70		28.20 ± 6.28		0.663	26.98 ± 4.47		29.10 ± 5.83		0.033	28.78 ± 2.53		27.45 ± 6.58		0.562
FBS (mg/dL)	180.55 ± 75.67		143.87 ± 47.87		0.018	140.59 ± 59.32		135.99 ± 51.30		0.641	148.00 ± 55.93		126.91 ± 50.98		0.314
HbA1c (%)	6.68 ± 1.80		6.21 ± 1.72		0.199	6.30 ± 1.74		6.12 ± 1.73		0.554	6.60 ± 1.39		5.84 ± 1.76		0.258
HDL (mg/dL)	48.41 ± 13.29		49.95 ± 12.76		0.567	53.35 ± 15.29		59.61 ± 35.57		0.257	51.89 ± 12.03		53.04 ± 13.57		0.825
LDL (mg/dL)	106.61 ± 39.13		101.95 ± 34.67		0.532	109.80 ± 33.01		103.64 ± 35.37		0.328	127.22 ± 45.56		110.91 ± 41.14		0.335
Cholesterol (mg/dL)	226.13 ± 76.99		254.00 ± 123.68		0.137	204.65 ± 87.95		239.89 ± 131.74		0.067	268.66 ± 143.86		196.60 ± 94.78		0.106
TAG (mg/dL)	145.82 ± 47.98		143.75 ± 44.54		0.827	127.82 ± 34.10		136.45 ± 38.76		0.205	121.66 ± 30.36		133.68 ± 43.42		0.455
Ca2+ (mg/dL)	9.80 ± 1.83		9.53 ± 1.92		0.511	9.46 ± 1.87		9.88 ± 1.80		0.207	10.52 ± 1.44		9.91 ± 0.86		0.153

N = number; % = percentage within sex; BMI = body mass index; FBS = fasting blood sugar; HbA1c = glycosylated hemoglobin; HDL = high-density lipoproteins; LDL = low-density lipoproteins; TAG = triglycerides; Ca^{2+} = calcium; VitD = vitamin D.

Based on these findings, the VitD status (deficient, insufficient, or sufficient) of participants of the same sex was analyzed. The results showed that 34.52% (N = 29) of males had

VitD deficiency, 54.76% (N = 46) had VitD insufficiency, and 10.71% (N = 9) had normal VitD levels (Table 2). Among women, 49.54% (N = 110) had VitD deficiency, 40.09% (N = 89) had VitD insufficiency, and 10.36% (N = 23) had normal VitD levels (Table 1).

Table 2. VitD status and other health indicators in Libyan young adults (18–25 years) according to the VitD cut-off groups and sex.

	Young Adults (18–25 years)														
	VitD Deficient (≤10 ng/dL)					**VitD Insufficient (10.1–29.9 ng/dL)**					**VitD Sufficient (≥30 ng/dL)**				
	Males		**Females**		***p*-Value**	**Males**		**Females**		***p*-Value**	**Males**		**Females**		***p*-Value**
	N	**%**	**N**	**%**		**N**	**%**	**N**	**%**		**N**	**%**	**N**	**%**	
	9	**13.84**	**30**	**46.16**		**12**	**18.46**	**10**	**15.39**		**1**	**1.53**	**3**	**4.62**	
VitD (ng/dL)	3.73 ± 1.61		4.94 ± 2.22		0.089	20.22 ± 3.60		18.17 ± 4.88		0.270	30.00		39.33 ± 16.16		0.667
BMI (kg/m^2)	25.25 ± 4.53		24.10 ± 5.11		0.548	25.26 ± 4.57		23.06 ± 2.29		0.162	26.99		21.51 ± 7.93		0.611
FBS (mg/dL)	131.22 ± 37.09		128.47 ± 41.56		0.859	129.50 ± 52.18		132.30 ± 75.37		0.919	77.00		119.33 ± 51.67		0.552
HbA1c (%)	5.80 ± 1.28		5.59 ± 1.44		0.697	5.94 ± 1.77		5.73 ± 1.39		0.771	5.70		6.12 ± 1.35		0.811
HDL (mg/dL)	46.33 ± 11.24		50.37 ± 13.75		0.428	51.50 ± 14.35		58.60 ± 14.50		0.264	60.00		53.33 ± 13.31		0.707
LDL (mg/dL)	93.88 ± 20.82		95.05 ± 20.08		0.881	109.66 ± 47.86		101.09 ± 50.45		0.687	90.00		110.33 ± 26.08		0.569
Cholesterol (mg/dL)	245.00 ± 71.13		274.36 ± 147.94		0.421	184.16 ± 72.87		206.40 ± 128.39		0.615	180.00		116.66 ± 45.09		0.348
TAG (mg/dL)	137.11 ± 29.61		137.34 ± 30.16		0.984	129.08 ± 25.76		116.20 ± 33.64		0.321	110.00		109.56 ± 36.77		0.993
Ca^{2+} (mg/dL)	9.78 ± 2.13		9.42 ± 2.05		0.649	9.68 ± 1.73		9.53 ± 1.68		0.837	11.00		10.20 ± 0.34		0.184

N = number; % = percentage within age group; BMI = body mass index; FBS = fasting blood sugar; HbA1c = glycosylated hemoglobin; HDL = high-density lipoproteins; LDL = low-density lipoproteins; TAG = triglycerides; Ca^{2+} = calcium; VitD = vitamin D.

Regarding the VitD level cut-off, female participants had significantly lower levels of VitD than males in both the VitD deficient and insufficient groups ($p = 0.043$ and $p = 0.019$, respectively; Table 1). The mean VitD levels in these groups were 6.33 ± 2.65 and 19.61 ± 4.20 ng/dL in males and 5.2 ± 2.31 and 17.63 ± 5.24 ng/dL in females, respectively (Table 1). In the group with sufficient/normal VitD levels, the mean VitD levels were 34.22 ± 9.82 and 38.09 ± 9.82 ng/dL in male and female subjects, respectively, without any significant differences (Table 1).

BMI was significantly higher in women than in men ($p = 0.033$), whereas the FBS was significantly higher in men than in women ($p = 0.018$), within the VitD insufficient group (Table 1). Moreover, the cholesterol levels were higher in women than in men ($p = 0.067$) within the VitD insufficient group (Table 1). The other health indicators appeared to be sex-unrelated within the same VitD status group (Table 1). VitD deficient females appeared to have a higher risk of headache ($p = 0.003$) and osteoporosis ($p = 0.026$).

The mean ages of the VitD deficient, VitD insufficient, and VitD groups were 36.6 ± 13.77, 40.28 ± 15.14, and 40.84 ± 16.46 years, respectively (Table 1). There were no significant VitD level differences between the age groups (Table 1).

The analysis of health indicators revealed that VitD deficiency was related to high FBS ($p = 0.058$) and TAG ($p = 0.056$) levels and significantly low HDL levels ($p = 0.015$) (Table 1). Conversely, other health indicators, such as BMI, HbA1c, LDL, cholesterol, and Ca^{2+} levels appeared to be unrelated to the VitD status in those groups (Table 1).

3.3. VitD Level Is Significantly Lower in Libyan Young Adults than in Adults

To investigate the relationship between the VitD status and age, Libyan adults were first divided into two age groups: young adults (18–25 years) and adults (≥26 years). Accordingly, the results revealed that 21.24% (N = 65) participants were young adults and 78.76% (N = 241) were adults (Figure 2). The mean VitD level among young adults was 11.60 ± 10.38 ng/dL, whereas among adults it was 15.17 ± 11.02 ng/dL. Furthermore, the VitD levels were significantly lower in young adults than in adults ($p = 0.020$; Figure 2). Compared to adults, young adults had a significantly lower BMI ($p = 0.0001$), lower

FBS level (p = 0.008), lower HbA1c percentage (p = 0.003), and likely a lower TAG level (p = 0.055; Figure 2).

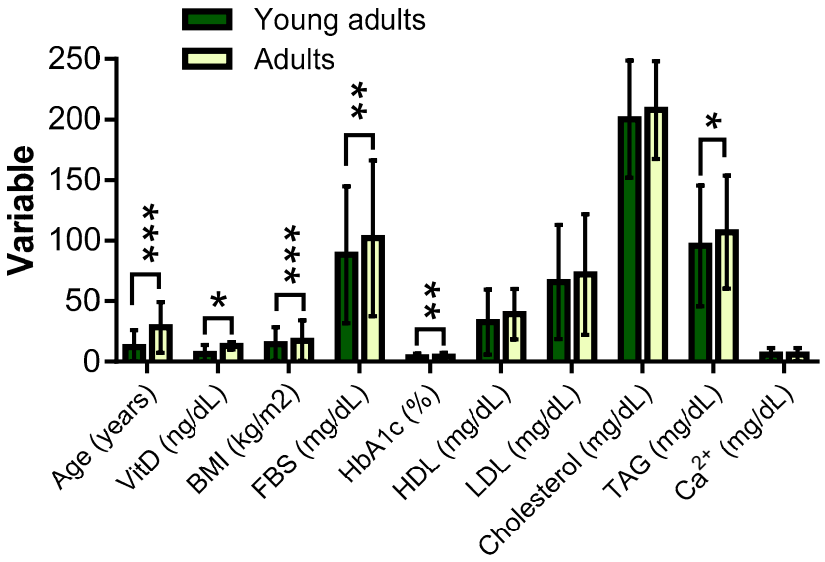

Figure 2. Mean age, VitD status and other health indicators in Libyan young adults and adults. N = number; % = percentage within population; BMI = body mass index; FBS = fasting blood sugar; HbA1c = glycosylated hemoglobin; HDL = high-density lipoproteins; LDL = low-density lipoproteins; TAG = triglycerides; Ca^{2+} =calcium; VitD = vitamin D. (*) indicates $p < 0.05$, (**) indicates $p < 0.01$, and (***) indicates $p < 0.001$.

3.4. VitD Level Is Significantly Lower in Libyan Female Adults than Male Adults

Next, to study the relationship between VitD status and other health indicators in Libyan young adults and adults according to their sex, the two age groups were divided into males and females. The results showed that approximately 33.85% (N = 22) of young adults were male and 66.15% (N = 43) were female. Conversely, approximately 25.73% (N = 62) of the adults were males and 74.27% (N = 179) were females (Figure 3).

The results showed that the mean VitD levels were 13.92 ± 9.34 and 10.42 ± 10.78 ng/dL in young adult males and females, respectively, without a significant difference (p = 0.201) (Figure 3). Conversely, VitD levels were significantly lower in adult females (mean: 14.35 ± 11.29 ng/dL) than in adult males (mean: 17.54 ± 9.90 ng/dL) (p = 0.050; Figure 3).

The FBS levels were significantly higher in men than in women (p = 0.018) (Figure 3) and the BMI was higher in female adults than in males (p = 0.066), whereas the rest of the studied health indicators were sex-unrelated (Figure 3).

3.5. VitD Deficiency Is More Health-Related in Libyan Adults than in Young Adults

To study the relationship between VitD status, age, and other health indicators in Libyan young adults and adults, the two age groups were analyzed for their VitD status, according to the VitD cut-off groups, and according to their sex. Among the Libyan young adults, the VitD deficient group comprised 13.84% (N = 9) males (mean level: 3.73 ± 1.61 ng/dL) and 46.16% (N = 30) females (mean level: 4.94 ± 2.22 ng/dL); the VitD insufficient group had 18.46% (N = 12) males (mean level: 20.22 ± 3.60 ng/dL) and 15.39% (N = 10) females (mean level: 18.17 ± 4.88 ng/dL); and the VitD sufficient group had 1.53% (N = 1) males (mean level: 30.00 ng/dL) and 4.62% (N = 3) females (mean level: 39.33 ± 16.16 ng/dL) (Table 2). There were no significant differences in VitD levels between the sexes among the three groups (Table 2).

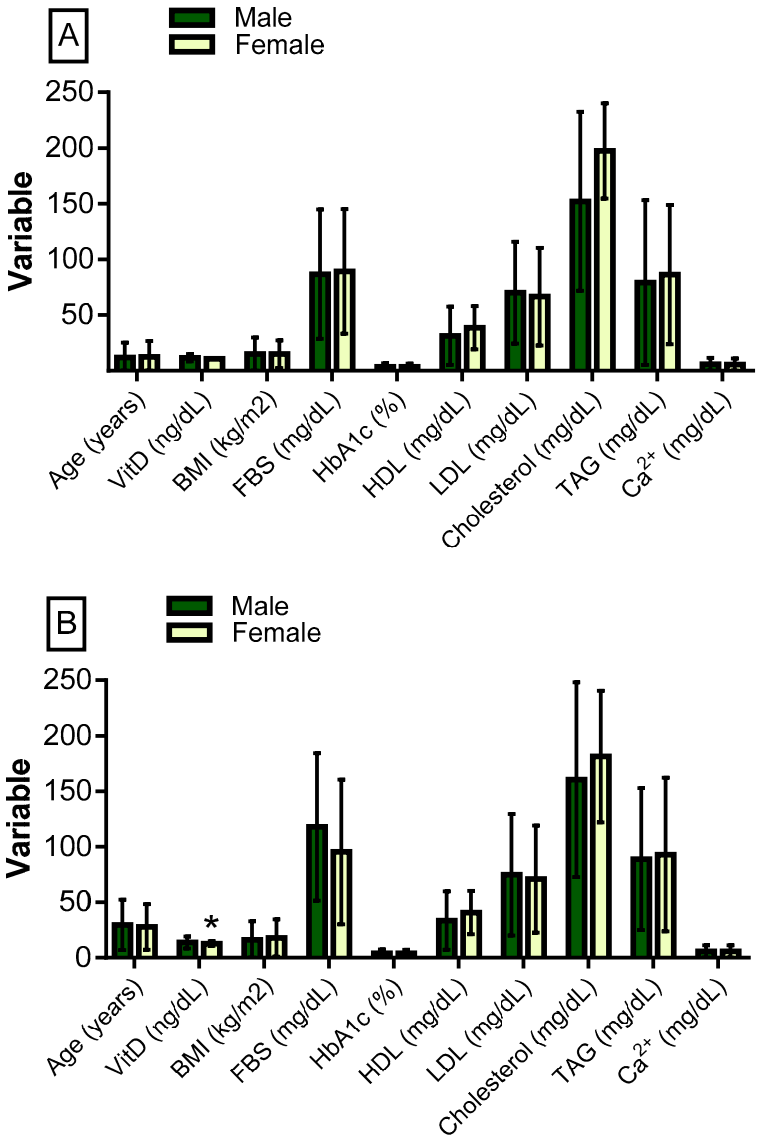

Figure 3. Mean age, VitD status, and other health indicators in Libyans according to the sex within the two age groups (**A**) young adults and (**B**) adults. N = number; % = percentage within age group; BMI = body mass index; FBS = fasting blood sugar; HbA1c = glycosylated hemoglobin; HDL = high-density lipoproteins; LDL = low-density lipoproteins; TAG = triglycerides; Ca^{2+} = calcium; VitD = vitamin D. (*) indicates $p < 0.05$.

The other studied health indicators appeared to be unrelated to the VitD status and sex of the Libyan young adults (Table 2). However, young adult females had a higher risk of developing sleeping problems ($p = 0.006$), psychological disorders ($p = 0.012$), headache ($p = 0.005$), and osteoporosis ($p = 0.023$). Among the Libyan adults, the VitD deficient group had 8.30% (N = 20) males (mean level: 7.50 ± 2.16 ng/dL) and 33.2% (N = 80) females (mean level: 5.29 ± 2.35 ng/dL), with females having a significantly lower VitD level ($p = 0.0001$) than the males (Table 3). The VitD insufficient adult group had 14.11% (N = 34) males (mean level: 19.40 ± 4.42 ng/dL) and 32.78% (N = 79) females (mean level: 17.57 ± 5.31 ng/dL), with females having lower VitD levels than the males ($p = 0.080$) (Table 3). The VitD sufficient adult group had 3.31% (N = 8) males (mean level: 34.75 ± 10.36 ng/dL) and 8.30% (N = 20) females (mean level: 37.90 ± 9.16 ng/dL), with no significant VitD level differences between the sexes in this group (Table 3).

Table 3. VitD status and other health indicators in Libyan adults (≥26 years) according to VitD cut-off groups and sex.

	Adults (≥26 years)														
	VitD Deficient (≤10 ng/dL)				*p*-Value	VitD Insufficient (10.1–29.9 ng/dL)				*p*-Value	VitD Sufficient (≥30 ng/dL)				*p*-Value
	Males		Females			Males		Females			Males		Females		
	N	%	N	%		N	%	N	%		N	%	N	%	
	20	**8.30**	**80**	**33.2**		**34**	**14.11**	**79**	**32.78**		**8**	**3.31**	**20**	**8.30**	
VitD (ng/dL)	7.50 ± 2.16		5.29 ± 2.35		0.000	19.40 ± 4.42		17.57 ± 5.31		0.080	34.75 ± 10.36		37.90 ± 9.16		0.434
BMI (kg/m^2)	28.74 ± 4.47		29.74 ± 6.01		0.486	27.59 ± 4.34		29.86 ± 5.70		0.040	29.01 ± 2.61		28.34 ± 6.09		0.769
FBS (mg/dL)	202.75 ± 78.67		149.65 ± 49.03		0.008	144.50 ± 61.90		136.46 ± 48.08		0.457	156.88 ± 52.58		128.05 ± 52.13		0.199
HbA1c (%)	7.08 ± 1.89		6.44 ± 1.76		0.162	6.43 ± 1.73		6.16 ± 1.77		0.460	6.71 ± 1.44		5.80 ± 1.84		0.222
HDL (mg/dL)	49.35 ± 14.29		49.80 ± 12.46		0.889	54.00 ± 15.76		59.73 ± 37.45		0.392	50.88 ± 12.44		53.00 ± 13.95		0.711
LDL (mg/dL)	112.34 ± 44.30		104.54 ± 38.54		0.434	109.85 ± 26.88		103.96 ± 33.42		0.366	131.87 ± 46.36		111.00 ± 43.45		0.270
Cholesterol (mg/dL)	217.65 ± 79.76		246.36 ± 113.37		0.289	211.88 ± 92.59		244.13 ± 132.34		0.200	279.75 ± 149.62		208.60 ± 95.01		0.142
TAG (mg/dL)	149.75 ± 54.51		146.16 ± 48.81		0.775	127.38 ± 36.93		139.01 ± 38.80		0.141	123.12 ± 32.12		137.30 ± 43.99		0.418
Ca^{2+} (mg/dL)	9.80 ± 1.75		9.57 ± 1.88		0.628	9.39 ± 1.94		9.93 ± 1.81		0.158	10.46 ± 1.53		9.87 ± 0.91		0.218

N = number; % = percentage within age group; BMI = body mass index; FBS = fasting blood sugar; HbA1c = glycosylated hemoglobin; HDL = high-density lipoproteins; LDL = low-density lipoproteins; TAG = triglycerides; Ca^{2+} =calcium; VitD = vitamin D.

BMI was significantly higher in VitD insufficient adult females than in VitD insufficient adult males ($p = 0.040$) and the FBS level was significantly higher in VitD deficient adult males than in females ($p = 0.008$; Table 3). The rest of the studied health indicators appeared to be VitD status- and sex-unrelated in Libyan adults (Table 3). However, VitD insufficient male subjects had a higher risk of increased weight (obesity) ($p = 0.014$) and DM ($p = 0.036$) than their female counterparts.

4. Discussion

Accumulating evidence suggests that VitD plays a role, especially a "non-classical" one, in maintaining health and preventing diseases [1]. VitD deficiency in pregnant females has been implicated in multiple complications [2]. The aim of this study was to determine the possible association of VitD status with some health indicators. There were highly significant positive associations between VitD status and HDL and LDL levels and significant negative associations between VitD status and TAG, after adjustments for sex, age, and BMI. In particular, the cross-sectional associations between VitD status and HDL/TAG were strong and significant in both sexes and in all the age and BMI subgroups tested.

The prevalence of VitD deficiency [25-(OH) D, 20 ng/mL] is high in many European countries [19]. A multi-ethnic population in the United Arab Emirates 191 was VitD deficient, but the European contingent living in the same region was VitD sufficient. Other studies have reported a wide range of ethnic differences. One study found a VitD insufficiency rate of 91% in Moroccans [20]. In the USA, Arab American women living in Southeast Detroit have dangerously low VitD levels [21]. These findings and others suggest potential genetic influences that predispose people of Arab backgrounds to VitD deficiency [22].

Although the generally accepted way of assessing VitD status is by measuring the circulating 25(OH)D concentration, there is little consensus on the assay method to be used and the cut-off values for normal and abnormal ranges [23]. Here, we defined VitD deficiency as a VitD level <20 ng/mL and severe deficiency as a level <10 ng/mL. A level of 20–30 ng/mL was considered insufficient, whereas a level >30 ng/mL was considered sufficient. These cut-off values are widely used in the American literature, although some authorities consider normal levels to be above 40 or 50 ng/mL [24].

VitD deficiency/insufficiency has been shown to be prevalent in a large cohort of children, adolescents, and young adults [25]. Our findings showed low levels of VitD in the Libyan adult group, with the majority of them having subnormal VitD levels and half

of them being VitD deficient, which agrees with previous results [26]. Furthermore, when Libyan adults were divided into young adults and adults, the results revealed that Libyan young adults had lower levels of VitD than adults.

Few studies have investigated VitD status in the Libyan population. However, the available data identify both nations as prone to VitD deficiency. In a recent study examining the VitD status in more than 400 Libyan residents, approximately 80% of the participants were VitD deficient (serum concentrations lower than 50 nmol/L) [27]. This study reported the highest proportion of VitD inadequacy in a Libyan adult women subgroup (25–64 years old). The low VitD status was associated with a sedentary lifestyle and poor sun exposure, which may be due to cultural costumes and avoiding the use of short sleeves and revealing clothes [27].

According to the latest European Food Safety Authority recommendations, the intake of VitD should not be lower than 15 µg per day, whereas the Institute of Medicine recommends an intake of 10 µg per day or more for adult women [27]. We also observed a lower VitD status among Libyan women. A recent study including apparently healthy Libyan residents indicated that Libyan women (aged 25–64 years) are especially prone to VitD deficiency, with more than 80% of the 40 participants having an inadequate VitD status [27,28]. Similarly, our findings revealed that Libyan adult females had lower levels of VitD than males.

VitD deficiency is a common public health problem worldwide, being associated with many medical outcomes, including osteoporosis [29], type-1 diabetes [30], CVDs [11], and cancer [31]. Although young Libyan adults had lower VitD levels than adults, this deficiency was not associated with changes in the studied health indicators but with other health conditions, such as sleeping problems, psychological disorders, headaches, and osteoporosis. Conversely, VitD insufficiency or deficiency was associated with these health indicators in Libyan adults ($\geq$26 years). Additionally, VitD deficient females had a higher risk of headache and osteoporosis.

VitD deficiency is an increasingly prevalent public health concern in developed countries [32] and there is evidence that VitD metabolism, storage and action influence and, in turn, are influenced by adiposity. Obese individuals have an increased risk of VitD deficiency; however, the underlying mechanisms are unclear. Here, we explored the causality of the relationship between VitD status and BMI. Our findings revealed low levels of VitD in Libyan adults (as the majority of them had subnormal VitD levels and half of them were VitD deficient) and increased BMI values. Moreover, VitD insufficiency was associated with a higher BMI in adult females than in males, consistent with previous results [26]. VitD deficiency was associated with a higher risk of increased BMI values in males. The association of the VitD status with BMI has been attributed to excessive storage of VitD in fat tissue, thereby leading to decreased serum concentrations [33].

Sufficient levels of VitD are also essential for controlling diabetes. There is increasing evidence that VitD deficiency may contribute to the onset of diabetes. DM, which is characterized by elevated blood glucose levels, is becoming increasingly common. One reason for this is the increasing prevalence of obesity. VitD deficiency is likely associated with obesity [10]. Our findings demonstrated that VitD deficiency was associated with a higher risk of DM in men. Furthermore, VitD deficiency was associated with higher FBS in adult males than in females.

Multiple epidemiological studies have linked the VitD status (deficiency) to an increased CVD risk [11]. VitD deficiency is a largely unacknowledged epidemic associated with CVD risk and mortality [11]. Approximately one billion people worldwide have low levels of VitD, the principal circulating storage form of VitD and 25(OH)D deficiency (37 nmol/L), which are independently associated with cardiovascular events in patients with hypertension [11]. Dyslipidemia is a major risk factor for CVDs. However, aggressive LDL-C lowering only reduces all-cause mortality and major coronary events by 30%.

The relationship between serum VitD levels and lipids, which are among the main risk factors for CVDs [11], is uncertain [1,16,34]. There is a cross-sectional association between

the serum VitD levels and lipids and a longitudinal association over 14 years between the serum VitD levels and TAG, which may explain the relationship between low serum VitD levels and mortality [34,35]. We found a negative association between VitD deficiency and high TAG levels in the adult age group. We also found a negative association between VitD deficiency and low HDL levels. Consistent with a prior study [2,34,35], our findings indicate that higher serum VitD levels are related to a more desirable and favorable lipid profile with low serum levels of TAG, LDL, and HD.

5. Conclusions

This study found that VitD deficiency was prevalent in the large, selected cohort of male and female children, adolescents, young adults, and adults. It was also found to be more prevalent in young adults than in the other age groups. In addition, our findings showed that VitD deficiency was more prevalent in males than in females in the adult age group. Moreover, high VitD levels were associated with a favorable lipid profile.

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