SUMMARY AND CONCLUSIONS

BACKGROUND

The non-communicable diseases (NCDs) are becoming increasingly common causing a double burden on many of the countries worldwide. The major reason being rapid urbanization resulting in considerable changes in lifestyle with attendant health problems. Diabetes mellitus which is defined as a heterogeneous chronic metabolic disorder principally characterized by persistent hyperglycemia resulting from defects in insulin action and /or insulin secretion is one of the most divesting NCD in terms of both morbidity and mortality among the people. Prevalence of diabetes is increasing globally and it is one of the major health problems of the 21st century. As per the IDF Diabetes Atlas (2014); the prevalence estimates of diabetes and impaired glucose intolerance are even higher for all Asian countries and are expected to increase further in the next two decades. The present trend indicates that more than 60% of the world's diabetic population will be in Asia. Presently among the top ten countries with the largest number of diabetic adults, five are in Asia; with China topping the list (113.9 million diabetics) followed by India which has 65.1 million persons affected by diabetes. The important risk factors being:

(1) Urbanization and migration,

(2) Aging due to continued increase in life expectancy

(3) Genetic makeup i.e. the thrifty genotype and phenotype

(4) Racial predisposition due to high rates of both internal and external migration

(5) Anthropometric characteristics such as obesity especially central obesity

(6) Insulin resistance.

Although therapies for type-II diabetes and its complications have improved over the last few decades, the increasing burden of the disease highlights the need for innovative approaches for its prevention and management. Vitamin-D in recent times has been identified to be one of the important and useful elements towards prevention and treatment of type-II diabetes mellitus. There is mounting evidence suggesting that vitamin-D may influence several non-skeletal medical conditions, including cardiovascular disease, cancer, autoimmune disorders and type-II diabetes (Mitri, Muraru, & Pittas, 2011) and the resulting concern is that suboptimal status may increase the risk of these diseases.

Vitamin-D is a group of fat-soluble prohormone with two major biologically inert precursors D3 (cholecaciferol) and D2 (ergocalciferol). Vitamin-D is normally produced in the skin through a robust photolytic process acting on a derivative of cholesterol; 7-dehydrocholesterol to produce pre-vitamin D, which is then slowly isomerised to vitamin-D_3 (Velluz & Amiard, 1949). Vitamin-D_3 is the natural form of vitamin-D produced in the skin. Serum 25-hydroxyvitamin D (25 (OH) D) is the major circulating metabolite of vitamin-D and reflects the vitamin-D inputs from cutaneous synthesis and dietary intake. The serum concentration of this metabolite of vitamin-D is the most commonly used and the most sensitive index of vitamin-D status (Holick, 2004). An important fact about vitamin-D is that it is required throughout the life as it is not just needed for the formation of bones but also likely plays a crucial role in several other physiologic systems of the body. This non-skeletal function is brought about by the vitamin D receptors (VDR), which help to utilize Vitamin-D in the body and are present on more than 30 different tissues including pancreas, myocardium, lymphocytes, etc in the body. This widespread distribution of VDR signifies important role of vitamin-D in humans (Norman, 2006).

Epidemiological data indicates that vitamin-D deficiency is pandemic, even the healthy and the young are not spared. Vitamin D deficiency is diagnosed when 25(OH)D <20 ng/mL, vitamin D insufficiency is defined as 25(OH)D of 21–29 ng/mL, and 25(OH)D >30 ng/mL is considered sufficient (Holick et al., 2011). It has been estimated that around1 billion people worldwide are vitamin D deficient or insufficient. Earlier it was thought that India being in the tropical region receiving ample sunlight throughout the year is spared of VDD. But a series of studies from different parts of the country have pointed towards widespread VDD in Indians of all age groups including toddlers, school children, pregnant women and their neonates and adult males and females residing in rural or urban areas (Arya et al., 2004; Sachan et al., 2005; Harinarayan, 2005; Marwaha et al., 2005; Harinarayan, et al., 2008). Deficient vitamin D status has also been associated with decreased insulin secretion and increased insulin resistance in humans. Moreover literature also suggests that substitution with vitamin D in the deficient state is associated with improvement in insulin secretion and glucose tolerance. These studies thus suggest a link between vitamin D deficiency and type 2 diabetes mellitus (Afzal, Bojesen, & Nordestgaard, 2013).

Thus as VDD has several potential implications, there is a need for systematic efforts directed towards finding the importance of widespread VDD concerning regions in India. Vitamin-D

in food supply is limited and most often inadequate to prevent deficiencies. Thus supplemental vitamin-D is necessary to keep hypovitaminosis at bay and help the body carry on the physiological functions normally. But there still remains some confusion regarding what level of 25(OH)D should be attained for both bone health and reducing risk for VDD associated acute and chronic diseases and the question how much vitamin-D should be supplemented keeping in mind the various clinical conditions remains unanswered. Taking in view the above literature and the yet to be answered queries, the research study was undertaken with the following key objectives-

1. To map the prevalence of vitamin D deficiency (VDD) among free living adult population and subjects with type-II diabetes mellitus in Vadodara city.

2. To identify the determinants of vitamin-D status and study its association with clinical conditions like overweight/obesity, diabetes, hypertension & CVDs.

3. To study the metabolic aberrations in relation to vitamin D deficiency in the study populations.

4. To study the efficacy of vitamin-D supplementation dose on serum vitamin-D status and cardio-metabolic profile of the subjects with type-II diabetes mellitus.

5. To study the washout effect of the vitamin-D supplementation on anthropometry, HbA1c levels and lipid profile of the subjects with type-II diabetes mellitus after eight weeks of post supplementation.

6. To compare the vitamin-D status of the diabetic and non-diabetic populations and see the difference in biophysical measurements, physical activity pattern and nutrient intake of the subjects and levels of various biochemical parameters.

7. To develop nutrition health education material for restoring and maintaining a healthy vitamin-D status among the subjects.

The present research work was carried out in four phases as described below:

➢ Phase I: Prevalence of vitamin-D deficiency and determinants of vitamin-D status among free-living adult population of Vadodara city.

➢ Phase II: Impact of Vitamin-D supplementation on cardio-metabolic profile of subjects with type-II diabetes mellitus.

➢ Phase III: Comparison between diabetic and non-diabetic populations.

➢ Phase IV: Development of Nutrition Health Education (NHE) Material.

PHASE I: PREVALENCE OF VITAMIN-D DEFICIENCY AND DETERMINANTS OF VITAMIN-D STATUS AMONG FREE-LIVING ADULT POPULATION OF VADODARA CITY

This phase of the research was a cross-sectional study conducted among 129 apparently healthy subjects (82 females and 47 males) of age 30-60 years residing in Vadodara city. Vadodara city was divided into five zones and one society from each zone was purposively selected. Then through snow-ball effect the subjects who gave positive written consent for participation were enrolled till the required sample size was obtained. The main objective was to map the prevalence of vitamin D deficiency among the subjects and identify the major determinants of vitamin D status. Background information was collected using a pretested questionnaire and biophysical measurements were recorded using standards tools and procedures. After an overnight fast, blood samples were collected by a trained technician for the various biochemical estimations which included serum 25(OH)D for vitamin D status, lipid profile, iron status, glycemic profile, thyroid hormones, liver and kidney function tests. The estimations were carried out in an accredited laboratory. The findings from this phase are summarised as under-

<u>Background information</u>

- The population studied was literate and majority of them were Hindus (98.4%).
- Most of the women were engaged in household work (84.1%) while men were engaged in office work or had their own business.
- The mean age of the subjects was 44.3 ± 9.1 years.
- The family history of diseases was highest for hypertension (53.5%) followed by diabetes mellitus (41.1%) among the subjects.
- About 22.5% of the subjects were taking nutritional supplements with 4.6% taking vitamin-D supplements either in combination of calcium and iron or alone.
- The Dependence Syndrome pattern revealed that around 10.6% males were consuming gutka regularly and 6.4% consumed alcohol occasionally. No such habit was observed among females.
- According to the physical activity assessed by International Physical Activity (Short) Questionnaire for seven days most of the subjects were moderately active (58.9%).

Dietary information

- Majority of the population was vegetarian (68.2%) and frequency of consuming the probable good sources of vitamin-D was low.

- Only 11.6% subjects were practicing blending of oils maximum at duration of three months and the most commonly used combination was Groundnut + Cotton seed + Corn oil.

- Fat intake was very high among all the subjects and it contributed to about 33.5% & 35% of the total calories in females and males respectively.

- The per day consumption of oil (42.8 ± 0.02 g/day), salt (7.7 ± 0.005 g/day) and sugar (32.7 ± 0.02 g/day) was very high among all the subjects. The per day salt consumption of females was significantly higher as compared to males.

Non-invasive factors for vitamin D status

- About 15% of the subjects had dark coloured skin, which is regarded as a risk factor for vitamin-D deficiency, while most of the subjects belonged to the wheatish skin colour category (54.3%).

- Majority of the subjects had sun exposure for 2-4 times a week (44.6%) and about 72.8% subjects reported an exposure of more than 20 minutes.

- 24.8% of the subjects reported to have a history of fractures of which 29.2% belonged to the youngest age group of 30-40 years.

Risk factor analysis

- A high prevalence of obesity (48.8%) and abdominal obesity (more than 80%) was found among the subjects.

- A high prevalence of vitamin-D deficiency was detected among the adult population with significantly higher number of females being deficient ($p<0.01$).

- Most of the males had mild deficiency (74.5%) while majority of females were moderately deficient (51.2%). Only two females of all subjects suffered from severe vitamin-D deficiency.

- Around 41% subjects were found to be anemic with significantly higher number of females as compared to males ($p<0.001$).

- A high prevalence of hyperlipidemia was observed among the subjects. Around 41% had hypercholesterolemia, 19% of the subjects had hyper-triglyceridemia, 64.3% had

elevated LDL cholesterol levels and protective HDL lipoprotein was low in nearly 42% of the subjects.

- As per ATP-III classification around 32% subjects had metabolic syndrome with significant higher prevalence among males ($p<0.05$).

- Atherogenic Index of Plasma (AIP) was found to be high in 69% of the subjects, while HsCRP level was high in nearly 60% of the subjects.

- The glycemic profile, thyroid hormone levels, liver function test and kidney parameters were found to be in physiologically normal range for the subjects.

- Female gender and high BMI, waist circumference and WSR showed significantly higher odds for poor vitamin-D status among the subjects.

- When the subjects were segregated based on their BMI, it was seen that HDL cholesterol decreased significantly with increase in BMI.

- The analysis across vitamin-D quartiles revealed that percent body fat, LDL-C, HDL-C, FBS and TSH levels decreased significantly with increase in vitamin-D levels, while Hb, GGT and uric acid levels increased significantly.

- In the multiple linear regression model; % body fat, age, TSH, haemoglobin, LDL cholesterol, T3 and FBS emerged as predictors for the vitamin-D status of the subjects.

Conclusions

The present study thus mapped a high prevalence of vitamin D deficiency based on their serum 25(OH)D levels, among the apparently healthy adults. Female subjects were seen to be more prone to the deficiency mainly because of the long indoor hours spent by them. The indices of abdominal obesity and percent body fat were identified as strong determinants of poor vitamin D status among the population. Regarding the predictors of vitamin D levels, the biochemical parameters- thyroid hormones, total cholesterol and fasting blood glucose emerged as significant suppressors while hemoglobin showed a positive relationship. Despite such a alarming prevalence and so many associated conditions, vitamin D levels do not form a part of routine health checkups. Thus creating awareness regarding this vitamin and its biological importance among the population needs prompt action.

PHASE II: IMPACT OF VITAMIN-D SUPPLEMENTATION ON CARDIO-METABOLIC PROFILE OF SUBJECTS WITH TYPE-II DIABETES MELLITUS

The second phase of the research dealt with type-2 diabetes mellitus subjects. Total 209 subjects were enrolled in the study from a purposively selected diabetic clinic in Vadodara city. Background information, anthropometric and blood pressure measurements were taken for all the subjects as a part of the formative research. Out of the enrolled subjects, 114 agreed for the biochemical estimations. The detailed risk factor analysis which included the dietary habits, physical activity pattern and biochemical estimations was conducted on them. Ninety-four subjects were identified as vitamin D deficient with serum 25(OH)D levels <20 ng/mL; who were then selected for the supplementation study which was a randomised control trial. The subjects were randomly divided into two groups. The supplementation group received weekly sachet of 60,000 IU (1500 µg) of cholecalciferol granules for eight weeks to be consumed orally, while no treatment was given to the control group. A dropout of 24 subjects was seen, thus seventy subjects completed the study (40 in supplementation group and 30 in control group). The same group of subjects was observed for another eight weeks to examine the washout effect post supplementation. However only forty-eight subjects (35 in supplementation group and 15 in control group) gave consent for further participation. Anthropometric measurements, blood pressure levels and biochemical estimations which included serum 25(OH)D, lipid profile and HbA1c levels were examined for the forty-eight subjects at the end of sixteen weeks. The conclusions drawn from this phase of the study are summarised below-

Formative Research

- Most of the enrolled subjects were Hindus (88.5%) and about 6% of the women were found to be illiterate.
- Mean age of subjects was 52.7 years and majority of them belonged to the 51-60 years age group (47.4%).
- The family history of diseases was highest for diabetes mellitus (65.1%) followed by hypertension (55%) and then coronary heart disease (19.6%).

- The self reported medical history of the subjects revealed that maximum subjects had hypertension (57.9%) followed by dyslipidemia (22.5%) with prevalence for both being high among males as compared to females.

- About 25% of the subjects were not going for regular health checkups while 28.6% of the subjects were going for check-ups every three months.

- The mean duration of disease was 6.1 years among the subjects with time period ranging from 1 to 28 years. Females were suffering from T2DM for a longer period as compared to males.

- About 75% of the subjects were not aware if any of the precipitating sign or symptom for diabetes mellitus was experienced by them. In rest the most commonly experienced symptoms were fatigue (23.4%) followed by unexplained weight loss (20.6%)

- Most of the subjects (85.6%) were taking oral drugs as therapeutic measure to control their blood sugar levels.

- About 38% of the subjects had undergone surgeries, among whom majority had got their cataract removed (24%).

- Among the subjects enrolled about 34% had a history of fractures which was highest for legs (41.7%) followed by hand fractures (30.5%).

- About 35.4% of the population was taking nutritional supplements with multivitamin supplements (51.3%) as the most commonly consumed. Around 16% of the subjects were taking vitamin-D supplements.

- The dependency syndrome was seen mostly among male subjects with about 19% consuming tobacco and around 6% were cigarette smokers.

- The dietary practices of the subjects revealed that majority were consuming vegetarian diets (64.6%) followed by non-vegetarian diets (27.8%). Only 5.8% were practicing rotation of oil and most of them (75%) did it at every three months. Cotton seed oil (39%) was the most commonly consumed oil among the respondents, while among the milk variety, *Shakti* brand of Baroda Dairy was most consumed (37.7%).

- The mean per day consumption of all the three culprits of diseases- oil (49.9 ± 23.3 g/day), salt (9.4 ± 4.8 g/day) and sugar (25.9 ± 18.3 g/day) was high among all the subjects.

- In respect to the non-invasive determinants of vitamin D deficiency, most of the subjects had wheatish skin complexion (53.6%) and about 65.6% of those going out in sun had sun exposure more than 20 minutes per day.

- A high prevalence of obesity based on BMI (71.3%) was observed among the population studied. The prevalence of abdominal obesity based on WC (73.7%) and WSR (93.3%) was significantly high among females as compared to male subjects.

- As per the JNC VIII classification, systolic blood pressure was high in about 39.7% and diastolic blood pressure in about 32% of the subjects thus categorizing them as hypertensive.

Detailed risk factor analysis

- The physical activity pattern revealed that about 68% of the subjects were moderately active; with more men (74.2%) falling in this category. Females were seen spending longer time in sitting activities as compared to their male counter-parts (6.1 vs 5.7 hours per day).

- The nutrient intake information revealed that fat intake was double the RDA among all the subjects and contributed majority energy obtained from macronutrients (38-39%), while RDA for energy and proteins was not met. The β carotene and iron intake was <50% of RDA for both female and male subjects. Only the vitamin-C intake met the RDA among the subjects.

- The consumption pattern of good sources of vitamin D showed that on daily basis ghee (63.2%) followed by milk (45.6%) was the most consumed. Frequency of consuming curd (50%) and buttermilk (47.4%) by most of the subjects was found to be once a week. As majority of the subjects were vegetarian, the consumption of eggs, fish and other non-vegetarian foods was very less.

- Mean value of serum 25(OH)D for the subjects was found to be 14.2 ng/ml and almost 87% of the subjects were vitamin-D deficient with prevalence being non-significantly higher among females as compared to males (92.3% vs 85.5% respectively).

- Among the vitamin D deficient subjects, about 60.5% subjects were falling under mild category and 28.1% in moderate category with higher number of females as compared to males in both categories but none of the subjects had severe deficiency.

- As per WHO guidelines, around 25% of the subjects were found to be anemic with none of the subjects in the severe category. The overall prevalence of anemia was significantly higher among females as compared to male subjects (28.8% vs 22.6% respectively).

- The mean HbA1c value among the subjects was 8.7% which was above the desired 7% according to ATP III guidelines, thus indicating unsatisfactory control.

- The lipid profile of the subjects revealed that 35% subjects had hypercholesterolemia with females having significant higher prevalence. Further about 35% had hypertriglyceridemia, 65% of the subjects had elevated LDL cholesterol levels and protective HDL lipoprotein was low in 50% of the subjects.

- Around 88% of the subjects were falling into high risk category for the Atherogenic Index of Plasma levels. The inflammatory marker, HsCRP was high in nearly 79% of the subjects with females having significantly higher levels.

- The levels of thyroid hormones, kidney parameters and the liver function tests were all found to be in the physiologically normal range for all the subjects.

- When the subjects were segregated as per their vitamin D levels, WSR and percent body fat were significantly higher in the low vitamin-D group as compared to the high vitamin-D group. None of the non-invasive parameters for vitamin D status showed significant difference across the groups.

- Hypercholesterolemia was significantly high among the low vitamin-D group with very high odds for being a risk factor (OR=7.5, 95% CI 0.9-60.3; p=0.027). The prevalence of inflammation was also found to be significantly higher in the low vitamin-D group (82.2 vs 53.8 %, p=0.018).

- Across the vitamin D quartiles among the subjects, waist-circumference, WSR and the percent body fat showed a significant decrease from 1st to 4th quartile while LDL cholesterol showed a significant declining trend from 2nd to 4th quartile.

- When the subjects were divided as per the duration of diabetes, prevalence of obesity and abdominal obesity was high in the subjects with ≤5 years of duration as compared to the >5 years duration group.

- The status of vitamin-D when studied across the duration of diabetes showed that the prevalence of deficiency (levels less than 20ng/ml) was significantly more in the shorter duration group as compared to the other group (95.2 vs 80.8%, p<0.05).

- The mean values for HbA1c and average blood sugar were higher in the subjects with duration of diabetes more than five years as compared to less than five years group.

- The prevalence of dyslipidemia was non-significantly higher among the group having diabetes from a shorter period as compared to the longer duration group. However the level of total cholesterol and the inflammatory marker, Hs-CRP were significantly higher in short duration group.

- The prevalence of metabolic syndrome was mapped using IDF and ATP-III classification. The prevalence was significantly high among females as compared to males and those subjects with shorter duration of diabetes as compared to the other group for both the criteria, while it was non-significantly higher among the subjects with vitamin D levels <20ng/mL as compared to the high level group.

- The correlations between vitamin-D levels and the non-invasive parameters revealed that duration of diabetes and per-capita income of the individual was positively significantly correlated while a significant negative correlation was observed between the vitamin-D levels and anthropometric measurements-WC, WSR, BMI & % body fat. Among the biochemical parameters serum T4 showed significant positive correlation while total cholesterol, LDL cholesterol and total proteins showed significant negative correlation with vitamin D levels.

- The multiple linear regression model showed that duration of diabetes and high levels of total T4 had positive coefficients with vitamin D levels while total proteins and LDL-C emerged as suppressors.

Supplementation study

- The mean age of the subjects was 54.0±7.7 years and average duration of diabetes was 5.5±5.3 years. Prevalence of hypertension was significantly higher among the supplementation group as compared to the controls (65 vs 36.7%, *p*=0.019).

- In respect to the nutrient intakes of the subjects, no significant difference was observed among the groups at the end of the supplementation period.

- After supplementation the serum 25(OH)D levels increased significantly among both the groups, however the control group still remained in the deficiency category. In the supplementation group around 80% of the subjects achieved the sufficiency status for serum 25(OH)D levels.

- Among the biophysical measurements, weight (p=0.001), waist circumference (p=0.025), waist-stature ratio (p=0.031), systolic blood pressure (p=0.035) and diastolic blood pressure (p=0.010) significantly decreased in the supplementation group. Between the group analysis revealed that weight (p=0.027) and waist circumference (p=0.012) decreased significantly in the supplementation group as compared to the controls.

- LDL-C decreased significantly (p<0.001) for the both the groups after supplementation. Between the groups post supplementation, the supplementation group had significantly lower levels for total cholesterol (p=0.037), LDL-C (p=0.035) and the ratios TC/HDL-C (p=0.022) and LDL/HDL (p=0.021) as compared to the control group.

- A non-significant reduction was observed for HbA1c levels in both the groups and the fall was more in the supplementation as compared to control group.

- LDL cholesterol and hemoglobin reduced significantly while serum 25(OH)D increased significantly in both supplementation and control groups post supplementation irrespective of their initial total cholesterol and triglyceride levels as well across the duration of diabetes.

Washout effect

- The increased serum vitamin-D levels after eight weeks of supplementation dropped down significantly at 16 weeks (8 weeks of washout period) in both the groups, however the levels were significantly higher as compared to baseline. Only 14% of the subjects in supplementation group who had attained sufficiency levels could sustain them after 16 weeks.

- The anthropometric parameters of the subjects revealed that there was a significant decrease in waist circumference among supplementation group at end of 16 weeks, while other measurements decreased non-significantly in both the groups.

- The systolic blood pressure and diastolic blood pressure increased in both the groups from 8 to 16 weeks of the study, but the supplementation group had significantly lower diastolic BP at 16 weeks as compared to control group (p=0.041).

- In view of the lipid profile, all the parameters reduced after 8 weeks of supplementation in supplementation group with significant drop in LDL-C and

LDL/HDL ratio; however the levels of both these parameters increased significantly after the washout period at 16 weeks.

- A non-significant decrease in HbA1c values was observed in supplementation group at both 8 and 16 weeks of the study period. No such favorable trend was seen for the control group.

Conclusions

The results of the our study indicate that 60,000 IU (1500 µg) of vitamin-D3 granules given for eight weeks in Indian adults with T2DM could increase their serum 25(OH)D levels to the sufficiency range. Also a declining trend was observed in the anthropometric measurements and lipid profile at the end of supplementation. Thus it can be concluded that vitamin-D3 granules would help to favourably alter the status of obesity and hyperlipidemia which are the usual co-morbidities of diabetes mellitus. The study did not report a significant fall in the HbA1c level which calls for further long term research to see the definite effect of vitamin-D3 on the control of diabetes and its risk.

Further, the increased vitamin D levels could not be sustained over a period of another eight weeks and the favourable changes in lipid profile also reverted back at the end of washout period. Thus it can be concluded that, for sustained improvement in 25(OH)D levels and cardio-metabolic profile, vitamin D supplementation has to be ongoing after the 8 weeks of vitamin D- loading schedule in these subjects.

PHASE III: COMPARISON BETWEEN DIABETIC AND NON-DIABETIC POPULATIONS

The research had two very different populations in respect to their disease profile. One was apparently healthy and a non-diabetic group (129 subjects) while the other was suffering from type-2 diabetes mellitus (114 subjects). The age of both the population was comparable as the subjects were adults in the range of 30-65 years. The background information, anthropometric measurements, blood pressure levels were taken for all the subjects using standard procedures. The biochemical estimations were carried out in an authorised laboratory. The main aim of this comparison was to identify the difference in various measurements and also to evaluate whether the diabetic group was more prone to vitamin-D deficiency and other metabolic alterations due to the presence of disease. The findings of this phase are summarised below-

- The diabetic subjects showed a significantly higher prevalence of obesity and blood pressure levels as compared to the non-diabetic subjects.

- The dietary intake of all most all the nutrients was low among the diabetic subjects. The nutrient intake of both the groups did not match the RDA, except for fat intake which exceeded the recommended allowance of 30 gm/day.

- The non-diabetics were found to be significantly more physically active as compared to the diabetics.

- The mean vitamin-D level was comparable in both the groups and was much lower than the recommended >30 ng/mL, and thus indicated a high of prevalence of deficiency (about 88%) among the subjects of both the populations.

- The prevalence of anemia was significantly higher among the non-diabetics as compared to the diabetic population ($p<0.05$).

- Prevalence of hypertriglyceridemia along with altered atherogenic indices and increased levels of inflammatory marker Hs-CRP was significantly higher among the diabetics as compared to non-diabetic subjects.

- Serum T3 was significantly higher for non-diabetic subjects, while T4 was higher for diabetic subjects. Both the elevations were seen only among the female subjects of the respective populations.

- Liver and kidney function tests revealed that the parameters were comparable and in the physiological normal range for both the populations.

- The diabetic population had significantly higher prevalence of metabolic syndrome as compared to the non-diabetic population for both the ATP III (78.1 vs 31.8 %, $p<0.001$) and IDF (64.9 vs 3 %, $p<0.001$) classification.

- Percent body fat and LDL-C were the two variables which showed a significant negative correlation with vitamin-D status of the subjects in both the populations.

- The selected multiple linear regression model showed that for both the groups, indices of central obesity, thyroid dysfunction and LDL-C emerged as significant suppressors of optimum vitamin-D status.

Conclusions

A high prevalence of vitamin D deficiency was observed in both the populations irrespective of their disease profile. This situation calls for immediate action on the part of all the three- the population which suffers the deficiency, the physicians who are the treatment givers and the academicians/researchers who by disseminating their study findings can aid in the management of the deficiency. Whether the prevention and management should involve perennial fortification of common foods such as milk or flour with vitamin D or change in lifestyle including exposure to sunshine, or simply taking continuous vitamin-D as maintenance dose needs to be investigated further.

PHASE IV: DEVELOPMENT OF NUTRITION HEALTH EDUCATION (NHE) MATERIAL

As summarised in the above phases of the study an alarmingly high prevalence of vitamin D deficiency based on the serum 25(OH)D levels was observed among both the healthy and the diabetic population of Vadodara city. Along with vitamin D deficiency, obesity was also highly prevalent and so were many of the metabolic conditions like hyperlipidemia, anemia, inflammation and metabolic syndrome. All these conditions can be prevented as well as managed by dietary and lifestyle changes. The analysis revealed that indices of abdominal obesity and LDL cholesterol were the common suppressors of vitamin D status among the population which can be easily rectified with healthy eating behaviours and habits. The ways and methods to bring about these changes need to be propagated in an appropriate manner through an easily understandable channel thus to have a positive impact. Hence as the study was undertaken in the Department of Foods and Nutrition and keeping the requirement in mind a Nutrition Health Education (NHE) material which dealt with the issue of healthy eating behaviours, benefits of physical activity, importance of sun exposure as a source of vitamin D and the concepts related to diabetes mellitus was developed as a counselling material. However the efficacy of this NHE was not examined in the present research and neither was its impact evaluated. This can be taken up as a full-fledged research topic later in future.

RECOMMENDATIONS

Thus the present research is unique in the sense that it has added to the existing knowledge regarding prevalence of vitamin D deficiency in western India specifically in Vadodara city, and about vitamin D metabolism by showing that the levels can be increased by supplementation but are not maintained over a period of time in people with T2DM. However as the guidelines for vitamin D requirement for Indians are not framed and the vitamin D content in Indian foods is missing from the nutrient data base, the nutrition information could not be analysed to the satisfaction. Hence the following recommendations are laid down for consideration in future from the present research-

Despite the close link of vitamin D with human health, vitamin D inadequacy is not widely recognized as a problem by physicians, academicians and patients in India, which indicates efforts for creating greater awareness among these populations.

Estimation of serum vitamin D levels should be a regular parameter to be included in routine biochemical check-ups, more so by the female population.

It is high time that agencies like NIN-ICMR work-out the vitamin D requirements for Indian population and come up with data base of the vitamin D content in Indian foods.

Policies for either food fortification or supplementation of vitamin D should be framed promptly by the nodal agencies. While framing these policies the importance and need of maintenance dose should be emphasized to prevent as well as manage the deficiency.

Also as different medications interfere with vitamin-D absorption, matching the subjects according to medications taken, in future research will reveal a clear picture of changes in biochemical profile as an impact of vitamin-D supplementation.

Actions needed from the Government's desk

Vitamin D deficiency is prevalent across all socioeconomic strata. It is imperative that policymakers understand the gravity of the situation pertaining vitamin D status and as a consequence—the untold burden on the healthcare system in India. Few actions need to be taken by the government of India (Ritu & Gupta, 2014):

1. Provision and revision of RDA (Recommended Daily Allowance) values for vitamin D and calcium intake, by ICMR (Indian Council of Medical Research) is imperative.

2. Educational Programs:

    i) Adequate investment of money, time and effort is required to develop, launch and sustain public awareness programs regarding vitamin D deficiency and its implications.

    ii) The curricula of medical colleges need to be updated pertaining to information regarding vitamin D, and its skeletal and extraskeletal benefits.

    iii) Social workers and school teachers can be duly informed and educated, so they spread the word about necessity for vitamin D sufficiency and the ways to achieve it.

    iv) School going children could benefit from distribution of vitamin D fortified foods at midday meals in schools and compulsory daily physical exercise in schools.

3. The masses should be educated on the benefits of a combination of sun exposure, vitamin D fortified food items, supplements and regular physical exercise via mass media programs, with the aid of tele-media and print media.

4. Vitamin D supplements: Affordable, good quality and readily available vitamin D supplements for the masses are needed.

5. Fortification of foods with vitamin D:

    i) First and foremost possibility thinking is required. Political and administration's will and support should be available from the development stage of the fortification program and equally importantly sustained.

    ii) Involvement of the food industry by encouraging private enterprises operating at the national and local level is required regarding production of fortified food items, availability of standardized vitamin D formulation(s) and information on the marketing potential of the fortified items.

6. Affordable and widely accessible testing facilities for vitamin D levels should be made available to individuals who are at high risk of clinical vitamin D deficiency.

7. Last, but not the least, government should extend support to research groups, so that the impact of supplementation programs and fortification strategies in actual practice may be studied and monitored and more efficacious ways developed. Continued research and epidemiological studies are required, to clearly state the enormity of the vitamin D deficiency status and its implications on general health of Indians, countrywide.