**Name of Journal:** *World Journal of Hepatology*

**Manuscript NO:** 75254

**Manuscript Type:** ORIGINAL ARTICLE

***Retrospective Study***

**Differential distribution of gene polymorphisms associated with hypercholesterolemia, hypertriglyceridemia, and hypoalphalipoproteinemia among Native American and Mestizo Mexicans**

Torres-Valadez *et al.* Genetic polymorphisms and dyslipidemias in Mexicans

Rafael Torres-Valadez, Sonia Roman, Claudia Ojeda-Granados, Karina Gonzalez-Aldaco, Arturo Panduro

**Rafael Torres-Valadez, Sonia Roman, Claudia Ojeda-Granados, Karina Gonzalez-Aldaco, Arturo Panduro,** Department of Genomic Medicine in Hepatology, Civil Hospital of Guadalajara Fray Antonio Alcalde/Health Sciences Center, University of Guadalajara, Guadalajara, Jalisco 44280, Mexico

**Rafael Torres-Valadez,** Unidad Especializada en Investigación, Desarrollo e Innovación en Medicina Genómica Centro Nayarita de Innovación y Transferencia de Tecnología, Universidad Autónoma de Nayarit, Unidad Académica de Salud Integral, Tepic, Nayarit 63173, Mexico

**Author contributions:** Panduro A conceived and designed the study; Torres-Valadez R, Ojeda-Granados C and Gonzalez-Aldaco K carried out experimentation, and data collection; Panduro A, Torres-Valadez R, Roman S, Ojeda-Granados C, Gonzalez-Aldaco K did analyses and interpretation of data; Torres-Valadez R drafted the manuscript. All authors critically revised the manuscript for intellectual content. All authors revised and approved the final version of the manuscript.

**Corresponding author: Arturo Panduro, FAASLD, MD, PhD, Research Scientist,** Department of Genomic Medicine in Hepatology, Civil Hospital of Guadalajara Fray Antonio Alcalde/Health Sciences Center, University of Guadalajara, Hospital # 278 Col. El Retiro, Guadalajara, Jalisco 44280, Mexico. apanduro@prodigy.net.mx

**Received:** January 21, 2022

**Revised:** June 20, 2022

**Accepted:** July 6, 2022

**Published online:** July 27, 2022

**Abstract**

BACKGROUND

Dyslipidemias are metabolic abnormalities associated with chronic diseases caused by genetic and environmental factors. The Mexican population displays regional differences according to ethnicity with an impact on the type of dyslipidemia.

AIM

To define the main dyslipidemias, the frequency of lipid-related risk alleles, and their association with hyperlipidemic states among different ethnic groups in West Mexico.

METHODS

In a retrospective study, 1324 adults were selected to compare dyslipidemias and lipid-related gene polymorphisms. Demographic, clinical, and laboratory data were collected. A subgroup of 196 normal weight subjects without impaired glucose was selected for the association analyses. Genotyping was determined by allelic discrimination assay.

RESULTS

Hypercholesterolemia was the most prevalent dyslipidemia (42.3%). The frequency of the risk alleles associated with hypoalphalipoproteinemia (*ABCA1*) and hypercholesterolemia (*APOE*, *LDLR*) was higher in the Native Americans (*P* = 0.047). In contrast, the Mestizos with European ancestry showed a higher frequency of the risk alleles for hypertriglyceridemia (*APOE2,* *MTTP*) (*P* = 0.045). In normal weight Mestizo subjects, the *APOB* TT and *LDLR* GG genotypes were associated risk factors for hypercholesterolemia (OR = 5.33, 95%CI: 1.537-18.502, *P* = 0.008 and OR = 3.90, 95%CI: 1.042-14.583, *P* = 0.043, respectively), and displayed an increase in low-density lipoprotein cholesterol levels (*APOB*: β = 40.39, 95%CI: 14.415-66.366, *P* = 0.004; *LDLR*: β = 20.77, 95%CI: 5.763-35.784, *P* = 0.007).

CONCLUSION

Gene polymorphisms and dyslipidemias showed a differential distribution. Regional primary health care strategies are required to mitigate their prevalence considering the genetic and environmental features which could have important implications for personalized medicine within the new era of precision medicine.

**Key Words:** Dyslipidemia; Ethnicity; Genes; Obesity; Lipids; Liver disease; Diet

**©The** **Author(s) 2022.** Published by Baishideng Publishing Group Inc. All rights reserved.

**Citation**：Torres-Valadez R, Roman S, Ojeda-Granados C, Gonzalez-Aldaco K, Panduro A. Differential distribution of gene polymorphisms associated with hypercholesterolemia, hypertriglyceridemia, and hypoalphalipoproteinemia among Native American and Mestizo Mexicans. *World J Hepatol* 2022; 14(7): 1408-1420

**URL**: <https://www.wjgnet.com/1948-5182/full/v14/i7/1408.htm>

**DOI**: https://dx.doi.org/10.4254/wjh.v14.i7.1408

**Core Tip:** Dyslipidemia is a metabolic alteration caused by gene-environmental interactions influenced by ethnicity. Genetic polymorphisms can modify the frequency and outcome of the hyperlipidemic state. Our results showed a differential distribution of gene polymorphisms associated with hypercholesterolemia (*APOE4*, *LDLR*), hypertriglyceridemia (*APOE2, MTTP*), and hypoalphalipoproteinemia (*ABCA1*) among Native Americans and Mestizo Mexicans of West Mexico. Hypercholesterolemia was the predominant dyslipidemia. In normal weight subjects, the *APOB* TT and *LDLR* GG genotypes increased the risk for hypercholesterolemia in the context of the Mestizo ethnicity. Regional personalized-medicine prevention strategies based on the host's genetic and environmental factors are required to decrease the prevalence of dyslipidemias.

**INTRODUCTION**

Obesity is a leading health problem worldwide of epidemic proportions affecting the health of many societies regardless of socioeconomic status[1]. Currently, 75.2% of the Mexican adult population has excess weight (39.1% overweight and 36.1% obesity), and in recent years, Mexico has ranked first and second in the worldwide list of obesity[2,3]. Globalization is one of the main drivers of the national nutrition transition occurring in the last four decades[4]. It has shifted the consumption of the staple traditional Mexican diet towards high-calorie processed food products and sugary beverages, leading to unhealthy body weight and type 2 diabetes mellitus (T2DM) in the general population[5,6]. The leading causes of mortality in Mexico are T2DM, cardiovascular disease (CVD), and liver cirrhosis due to different etiologies; however, excess weight plays an important role in the development of these pathologies[7,8].

Dyslipidemia is one of the main metabolic alterations involved in these obesity-related co-morbidities[9]. Commonly, hypertriglyceridemia (HTG) is associated with insulin resistance which in turn causes both T2DM and liver fibrosis/cirrhosis, while hypercholesterolemia (HChol) is associated with CVD[10]. However, up to 30% of obese people do not have lipid abnormalities, while normal weight patients can present dyslipidemia[11,12]. It is also feasible that lean patients may present with nonalcoholic steatohepatitis (NASH), while some obese patients show no fatty liver or NASH[12]. These contrasting findings suggest that genetic and environmental factors are involved.

In terms of population genetics, 85% of Mexico's inhabitants are denoted Mestizos (MTZ) due to the admixture of Native American (NA), European, and African ancestral source populations that were initiated 500 years ago after the Spanish conquest. In comparison, 10% and 5% are exclusively descendants of NA and African forefathers, respectively[13]. Concomitantly, with foodstuffs and food cuisine, a cultural syncretism between the eastern hemisphere (Spain, Africa, France, England) and the west (the Americas) took place, including the different geographic and ecological regions of Mexico[14]. Therefore, Mexico's population genetics and food culture are widely heterogenic, and the impact of these determinants can vary by region.

In this sense, the association of several single nucleotide polymorphisms (SNPs) located at different loci with dyslipidemias and their impact on non-communicable chronic diseases among the Mexicans has been acknowledged[15]. Distinctively, *APOE4*, *APOB* -516 C/T, as well as the *LDLR* A1413G and C52T are known to modulate the low-density lipoprotein cholesterol (LDL-c) levels and the susceptibility for HChol and CVD[16]. In the case of high-density lipoprotein cholesterol (HDL-c), the *ABCA1* R230C variant has been strongly associated with hypoalphalipoproteinemia (HALP), particularly in NA[17]. Additionally, the *MTTP*-943 G/T and the *MTHFR* C677T variants, as well as the *APOE2* allele, have been associated with increased triglycerides levels[18,19,20].

West Mexico´s population is characterized by NA inhabitants living in the rural areas, while the geographically dispersed MTZ populations have a variable degree of European and NA ancestries[21]. Previously, we documented that the *APOE4* allele is widespread among the NA but decreases significantly among the MTZ population with marked European ancestry, while conversely, the *APOE2* allele is predominant among this group[21,22]. However, studies jointly accessing these lipid-related gene polymorphisms have not been carried out among West Mexican populations. Thus, this study aimed to define the main dyslipidemias, the frequency of lipid-related risk alleles, and their association with hyperlipidemic states among different subpopulations.

**MATERIALS AND METHODS**

***Study population and design***

In this comparative cross-sectional study, a total of 1324 un-related adult individuals were retrospectively evaluated from January 2015 to December 2019 at the Department of Genomic Medicine in Hepatology, Civil Hospital of Guadalajara, "Fray Antonio Alcalde" in Guadalajara, Jalisco, Mexico. Each subject was interviewed, and a standardized questionnaire was used to register demographics, medical history, and laboratory data. The main exclusion criteria were the presence of any type of cancer, autoimmune and thyroid diseases, drug use in the last six months of recruitment, pregnant women, and use of hypolipidemic drugs.

In this study, populations of West Mexico with evidence of a representative NA ancestral component[22] were included, Nahua (NAH) (*n* = 84) and Wixárika (WXK) or “Huicholes” (*n* = 106) are indigenous ethnic groups, and five Mestizo populations: Guadalajara (GDL), Jalisco (*n* = 754), Tepic (TPC), Nayarit (*n* = 184), Cuquio (CUQ), Jalisco (*n* = 131), Villa Purificación (VP), Jalisco (*n* = 32), and San Miguel el Alto (SMA), Jalisco (*n* = 33). NA were identified according to the ethnic group, native language spoken, use of traditional attire, parents belonging to the ethnic group, and residence in a rural community. The Mestizo populations were defined as those born in Mexico, spoke Spanish, had Mexican parents, and did not belong to any native ethnicity.

For the association analyses between HChol and the related SNPs, 193 Mestizo subjects from GDL, Jalisco with normal weight determined by a body mass index (BMI) of 18.5-24.9 kg/m2 and a body fat percentage of < 20% for men and < 30% for women, as well as without impaired glucose defined by fasting serum glucose of < 100 mg/dL and homoeostasis model assessment for insulin resistance (HOMA-IR) index < 2.5 were selected. This study subgroup was established as a reference population to decipher the influence of these genetic polymorphisms on dyslipidemia, since it is mestizo group with a more balanced genetic ancestry between NA and Europeans.

***Definition for dyslipidemias***

Dyslipidemias were defined according to the National Cholesterol Education Program expert panel on detection, evaluation, and treatment of high blood cholesterol in adults (ATP III) and Mexican Official Norm 037 for the prevention, treatment, and control of dyslipidemias (NOM-037-SSA-2012): HChol was total cholesterol (TC) ≥ 200 mg/dL; HTG as triglycerides (TG) ≥ 150 mg/dL; HALP as HDL-c ≤ 40 mg/dL for men and ≤ 50 mg/dL for women; and high LDL-c as LDL-c ≥ 130 mg/dL[23,24].

***Body composition***

Body composition and BMI were assessed by bioelectrical impedance (InBody 3.0, Analyzer Body Composition, Biospace, South Korea) or a Tanita TBF\_300A instrument (Tanita Corporation, Japan). Normal weight (18.5–24.9 kg/m2), overweight (25.0–29.9 kg/m2), and obesity (≥ 30 kg/m2) were defined according to World Health Organization criteria[25].

***Laboratory tests***

Blood samples (10 mL) were obtained by venipuncture after a 12-h overnight fast. Biochemical tests included glucose, insulin, alanine aminotransferase, aspartate aminotransferase, gamma-glutamyl transferase, TC, TG, and HDL-c. All biochemical tests were determined with the AU5800 Clinical Chemistry System (Beckman Coulter's Inc. United States). The concentration of LDL-c was calculated using the Friedewald equation[26]. The very low-density lipoprotein-cholesterol (VLDL-c) was estimated by the formula of TC-(LDL-c + HDL-c). The HOMA-IR index was calculated with fasting plasma glucose (mg/dL) × fasting serum insulin (mU/L)/405. IR was defined as a HOMA-IR index of 2.5 or above to assess IR as a metabolic alteration.

***DNA extraction and genotyping characterization***

As previously described, genomic DNA (gDNA) was extracted from leukocytes using a modified salting-out method[27]. The genotypes of each SNPs were determined by a real-time PCR system using TaqMan® SNP Genotyping Assays (Applied Biosystems, Foster, CA, United States). The characteristics of context sequence of these probes correspond to the following catalog numbers: C\_11720861\_10 for *ABCA1* (rs9282541), C\_7615488\_10 for *APOB* (rs934197), C\_8726910\_10 and C\_8726960\_10 for *LDLR* (rs5930 & rs14158), C\_1202883\_20 for *MTHFR* (rs1801133), C\_ 8934089\_10 for *MTTP* (rs1800591), and C\_3084793\_20 and C\_904973\_10 for *APOE* (rs429358 & rs7412) (ThermoFisher Scientific). gDNA was used at a final concentration of 20 ng. PCR conditions were initial enzyme activation for 10 min at 95 °C, followed by 40 cycles of denaturalization for 15 s at 95 °C and alignment/extension for 1 min at 60 °C in a StepOnePlus thermocycler (Applied Biosystems, Foster, CA, United States). For genotype error checking, three positive controls corresponding to the possible genotypes for each SNP and a blank were included in every 96-well plate. A 20% of randomly selected samples were re-genotyped, of which 100% were concordant. Genotypic and allelic frequencies were obtained by the direct counting method. The Hardy-Weinberg equilibrium expectation was assessed by Arlequin version 3.1.

***Statistical analysis***

Kolmogorov-Smirnov test was used to analyze the normal distribution of all quantitative variables. Continuous variables were expressed as mean ± SD and categorical variables were reported as frequencies and percentages. Data with normal distribution was analyzed with parametric statistical tests (student's *t*-test and one-way ANOVA with the respective post-hoc analyses) and non-normal data through non-parametric statistical tests (Kruskal-Wallis and Mann-Whitney U). The chi-square was used when variables were categorical. Univariate and multivariate logistic and linear regression tests were performed to analyze the association of *APOB* -516C/T and *LDLR* A1413G SNPs as a risk factor for HChol. The results were expressed as odds ratio with 95%CI and *R*2. All the tests with significant *P* value were corrected by the Bonferroni method. Statistical analyses were performed in the statistical program IBM SPSS Statistics version 21.0 for Windows (IBM Corp, Inc., Chicago, IL, United States). Statistical significance was set at *P* < 0.05 to two-tailed.

***Ethical guidelines***

The study protocol complied with the last updated ethical guidelines of the 2013 Declaration of Helsinki from Fortaleza, Brazil. This study was revised and approved by the Institutional Review Board. All patients signed a written informed consent before enrollment, and anonymized data was employed to continue the statistical analysis.

**RESULTS**

***Clinical and lipidic characteristics of the study populations***

The clinical characteristics and the lipid profile of study populations from West Mexico are depicted in Table 1. The average age and gender frequencies were similar among the seven groups, except for the higher frequency of men in the MTZ from TPC compared with the other groups (*P* = 0.001). All the groups had excess weight, but the MTZ group from GDL had the highest BMI (33.8 ± 10.3 kg/m2, *P* = 8 × 10-27). The lipid profile showed differences by study group. MTZ from TPC had higher serum levels of TC, TG, and LDL-c compared to the rest of the study groups (*P* < 0.05). On the other hand, the NAH group showed lower levels of HDL-c than those from CUQ and WXK groups (*P* = 0.011).

***Prevalence of dyslipidemias in West Mexico populations***

Table 2 shows the prevalence of dyslipidemias in the populations from West Mexico. The most prevalent dyslipidemia was HChol, with 42.3%. HTG was detected in 40.4%, HALP in 37.8%, and high LDL-c in 35.8% of all study subjects. Among study populations, heterogeneity in the frequency of dyslipidemias was observed. The MTZ from TPC and VP had the highest frequency of HChol and HTG (75.5%, 65.6%, and 51.1%, 46.9% respectively, *P* = 0.001). The NAH group showed a lower frequency of HChol (7.1%), as well as MTZ from VP and WXK group a lower prevalence of HALP compared to the other study groups (15.6% and 26.4%, respectively, *P* = 0.002) (Table 2).

***Frequency of risk alleles of SNPs associated with dyslipidemias in West Mexican populations***

The genetic risk alleles associated with HALP (*ABCA1* R230C*,* RC + CC genotypes) and HChol (*APOE4* allele and *LDLR* 1413G allele) were more prevalent in the NAH and WXK groups compared to the other study groups (*P* = 0.047) (Table 3). The MTZ from VP and SMA showed a higher frequency of the risk alleles that have been associated with HTG (*APOE2* allele and *MTTP* -943G/T, T allele) compared with the other groups (*P* = 0.045) (Table 3).

***Association of APOB -516C/T and LDLR A1413G polymorphisms with hypercholesterolemia in normal-weight MTZ individuals***

The clinical and biochemical characteristics of the 193 MTZ subjects selected to evaluate the possible effect of these Hchol-related polymorphisms are shown in Table 4. In this study subgroup, 38.9% (*n* = 75) had any type of dyslipidemia and HChol was the most prevalent with 27.9% (*n* = 54) (Table 4).

Table 5 depicts the lipid profile and frequency of dyslipidemias according to the SNPs *APOB* -516C/T and *LDLR* A1413G genotypes. *APOB* homozygous TT genotype carriers had significantly higher levels of TC (*P* = 0.033) and LDL-c (*P* = 0.017), as well as a higher frequency of HChol (*P* = 0.012) (Table 5). Besides, the carriers of the homozygous GG genotype of *LDLR* had significantly higher levels of LDL-c (*P* = 0.042) and higher frequency of HChol (*P* = 0.034) (Table 5).

As shown in Table 6, the frequency of subjects with HChol was greater among carriers of the homozygous genotypes TT of *APOB* and GG of *LDLR* than the non-HChol (26.1% *vs* 6.9%, *P* = 0.005; 60.9% *vs.* 38.6%, *P* = 0.043, respectively). Also, both genotypes, TT of *APOB* and GG of *LDLR* were associated with HChol (OR = 5.33, 95%CI: 1.537-18.502, *P* = 0.008; OR = 3.90 95%CI: 1.042-14.583, *P* = 0.043, respectively) (Table 6).

Finally, through a linear regression test, an increase of 30% higher LDL-c was associated with the homozygous TT genotype of *APOB* (*R*2 = 0.30, β = 40.39, 95%CI: 14.415-66.366, *P* = 0.004), and an increase of 11% higher LDL-c was associated with the GG genotype of *LDLR* (*R*2 = 0.11 β = 20.77, 95%CI: 5.763-35.784, *P* = 0.007) (Table 7).

**DISCUSSION**

Dyslipidemias are severe abnormalities commonly associated with excessive body fat, a pathogenic factor contributing to the development of co-morbidities such as T2DM, fatty liver disease, and CVD[28]. However, genetic and environmental factors cause differences across the country in the incidence of these pathologies. Previously, we have documented the admixed genetic architecture of West Mexico[21,22]. In this region, NAH and WXK are representative of the NA genetic component, while the inhabitants of TPC, GDL, CUQ, VP, and SMA are historically known to carry a significant European genetic component. Therefore, we hypothesized that the distribution of dyslipidemias and the lipid-related alleles could be variable according to the ancestral inheritance. Herein, we present the first study jointly detecting several lipid-related risk alleles that confer dyslipidemia among the West Mexican population. An evident heterogeneity in the type of dyslipidemia and lipid-related risk alleles was observed between the study groups consistent with their genetic and environmental background.

Overall, the most prevalent dyslipidemia was HChol (42.3%). These data were discrepant with the National Health and Nutrition Survey 2006 and 2018, with HALP in nearly 60% nationwide[29,30]. A plausible explanation is that national surveys tend to focus on central regions of the country in which the NA component is predominant compared to West Mexico, in which the European ancestry is more prevalent. Furthermore, the breakdown analysis of the type of dyslipidemias adjusted by study group revealed that the NA had lower HChol (7.1%) while the MTZ from TPC and VP had higher rates of HChol (75.5% and 65.6%) and HTG (51.1% and 46.9%), respectively.

Given this panorama of dyslipidemias, we explored the frequency of several SNPs associated with these lipid abnormalities finding that the NA groups showed genetic susceptibility for HChol and HALP (*ABCA1* 230C allele, *APOE4* allele and *LDLR* 1413G allele); while the frequency of the risk alleles associated with HTG (*APOE2* allele and *MTTP* -943T allele) were higher in MTZ groups with a significant European ancestry. Notably, the *MTHFR* 677T risk allele prevalence revealed a high to low gradient (from NA to MTZ) which may have implications for fatty liver disease[31]. Thus, in conjunction, these findings highlight the importance of considering the ancestral components regarding the genetic susceptibility for lipid-related chronic diseases.

Furthermore, in this study, the TT genotype of *APOB* and GG genotype of *LDLR* were associated as risk factors for HChol. APOB is the main structural protein of LDL lipoprotein, essential for the assembly and secretion of chylomicrons and VLDL lipoprotein, and it is the primary ligand for LDLr mediated internalization of LDL-c in target tissues[33]. An imbalance between the production and degradation of APOB-containing lipoproteins leads to the development of HChol and, potentially, atherosclerosis[32]. In this context, *in vitro* studies have documented that the “T” allele of the *APOB* -516C/T polymorphism increases the transcription of the *APOB* gene by more than 40%. Consequently, this causes a substantial increase in plasma LDL-c concentration[34].

Moreover, it was reported that in a healthy Swedish population, the -516T allele of this SNP increased the plasma LDL-c concentration by 12%, and in a French population was associated with a high plasma LDL-c concentration and the presence of carotid atherosclerotic disease[34,35]. In this study, the TT genotype of *APOB* -516C/T polymorphism increased the plasma LDL-c concentration by 30% in lean subjects. This is the highest percentage of LDL-c increase associated with the TT genotype of *APOB* reported so far. This information highlights that despite a lower frequency of -516T allele of *APOB* compared to other populations, the genetic effect on the plasma LDL-c concentration is more remarkable.

The most common genetic causes of HChol are mutations in the gene that codes the LDLr. These mutations drastically alter the functional activity of this surface receptor, thereby delaying the clearance of LDL particles[36]. Several studies have documented the relation of *LDLR* A1413G polymorphism with pathologies involving lipid disorders. For example, this genetic variant was found in 17% of patients with familial hypercholesterolemia from Iran[37], and in the United States, this same polymorphism was associated with Alzheimer’s disease[38]. In this study, the GG genotype of *LDLR* A1413G polymorphism was associated with HChol and increased plasma LDL-c concentration by 11%. This study is the first to establish a direct association between the GG genotype of *LDLR* with the levels of LDL-c and the presence of hypercholesterolemia in a healthy population from Mexico and Latin America.

The implications of these findings require addressing the role of the interrelationship between diet-related adaptive alleles and the current diet of the population. In this sense, NA groups have followed a frugal lifestyle for millennia in which lipid-related alleles may have been positively selected to cope with the Paleolithic and Neolithic Mesoamerican environments[39]. Their traditional diets mainly contained low amounts of saturated fats and were high in mono- and polyunsaturated vegetal fats and high complex carbohydrates which are protective against lipid-related chronic diseases despite the host’s “risk alleles”[40,41]. However, lifestyle changes caused by the current nutrition transition place at risk both the NA population and MTZ, regardless of the degree of European ancestry. Likewise, the MTZ may be at higher risk for HTG particularity if they are carriers of the European risk alleles if changes in the dietary pattern occur. In this sense, the current dietary patterns in Mexico are notably unhealthy, characterized as obesogenic and hepatopathogenic leading to considerable increase in the prevalence of non-communicable chronic diseases such as T2DM, CVD, and nonalcoholic fatty liver disease[12,20,41,42].

Furthermore, dietary patterns are different by region nationwide. In West Mexico, the intake of pork meat is higher throughout the entire year. A traditional practice is eating pork rind “carnitas,” cracklings, and doing barbecues almost every weekend. On the other hand, the fast-paced lifestyle in the central region of the country led to the consumption of processed food, which is rich in saturated fatty acids, trans fat, and simple carbohydrates[42]. These elements have been associated with the presence of dyslipidemias, particularly HTG and HALP[43]. These results reflect that the epidemiological pattern of dyslipidemias is not homogeneous throughout the country and the necessity to perform comparatively specific studies per region in Mexico and other countries.

This study has some limitations. First, despite that several representative populations of West Mexico with different ancestral compositions were included, it was not possible to complete the genetic profile of all populations. Nonetheless, the frequencies of risk alleles reported in this study are sufficient to demonstrate a differential distribution of gene polymorphisms associated with dyslipidemias among Native Americans and Mestizo Mexicans (Table 3). Next, the cross-sectional design may limit a complete extrapolation of the results obtained. Finally, the data was recorded through standardized questionnaires that provide sufficient and detailed information; information bias may be present. Thus, further prospective and longitudinal studies involving lipid-related genetic variants and lifestyle factors (physical activity, behavior, and mental health) are required.

In summary, the frequency of dyslipidemias in West Mexico differed from the national reports. The NA groups (WXK and NAH) showed a greater genetic susceptibility for developing HChol and HALP. The TT genotype of *APOB* -516C/T and GG genotype of *LDLR* A1413G were associated as risk factors for HChol and increased LDL-c levels in Mestizo healthy population.

**CONCLUSION**

Given the differential distribution of gene polymorphisms and rate of dyslipidemias found in this study, primary health care strategies are required to establish preventive actions to mitigate their prevalence considering the regional genetic and cultural differences, which could have important implications for personalized medicine within the new era of precision medicine.

**ARTICLE HIGHLIGHTS**

***Research background***

Further investigations are needed to provide medical and nutritional therapies based on the genetic background of the population and the role of lifestyle changes including diet, exercise and mental health.

***Research motivation***

Given the differential distribution of gene polymorphisms and rate of dyslipidemias found in this study, primary health care strategies are required to establish preventive actions to mitigate their prevalence considering the regional genetic and cultural differences, which could have important implications for personalized medicine within the new era of precision medicine.

***Research objectives***

We aimed to describe if there are important differences between Native American and Mestizo Mexicans in regard to the type of dyslipidemias and lipid-related genetic polymorphisms.

***Research methods***

In this retrospective study, 1324 adults were selected to compare dyslipidemias and lipid-related gene polymorphisms. Demographic, clinical, and laboratory data were collected. A subgroup of 196 normal weight Mestizo subjects without impaired glucose was selected for the association analyses. Genotyping was determined by allelic discrimination assay.

***Research results***

The Native Americans showed a greater genetic susceptibility for developing hypercholesterolemia (HChol) (*APOE4*, *LDLR*) and hypoalphalipoproteinemia (*ABCA1*). The TT genotype of *APOB* -516C/T and GG genotype of *LDLR* A1413G were associated risk factors for HChol and increased low-density lipoprotein cholesterol levels in Mestizo healthy population.

***Research conclusions***

Deciphering the role of ethnicity in the type of dyslipidemia and defining the prevalence of lipid-related gene polymorphisms.

***Research perspectives***

Genetic and environmental factors are involved in the onset and progression of dyslipidemias among the Mexican population.

**ACKNOWLEDGEMENTS**

This work contains material from R. Valadez-Torres´s PhD thesis to obtain his doctoral research degree: “Doctorado en Ciencias de Biología Molecular en Medicina”, PNPC-CONACYT-MEXICO, Universidad de Guadalajara. The authors thank Eloy A. Zepeda-Carrillo, PhD for the Wixárika database.

**REFERENCES**

1 **Health at a Glance 2019: OECD Indicators**. Organisation for Economic Co-operation and Development. 2019 Nov 7 [cited 8 June 2020]. Available from: http://www.oecd.org/health/health-systems/health-at-a-glance-19991312.htm

2 Instituto Nacional de Estadística y Geografía and Instituto Nacional de Salud Pública (2020) Encuesta Nacional de Salud y Nutrición 2018-19: Resultados Nacionales. Cuernavaca, México: Instituto Nacional de Salud Pública

3 **Popkin BM**, Adair LS, Ng SW. Global nutrition transition and the pandemic of obesity in developing countries. *Nutr Rev* 2012; **70**: 3-21 [PMID: 22221213 DOI: 10.1111/j.1753-4887.2011.00456.x]

4 **Popkin BM**, Reardon T. Obesity and the food system transformation in Latin America. *Obes Rev* 2018; **19**: 1028-1064 [PMID: 29691969 DOI: 10.1111/obr.12694]

5 **Roman S**, Ojeda-Granados C, Ramos-Lopez O, Panduro A. Genome-based nutrition: an intervention strategy for the prevention and treatment of obesity and nonalcoholic steatohepatitis. *World J Gastroenterol* 2015; **21**: 3449-3461 [PMID: 25834309 DOI: 10.3748/wjg.v21.i12.3449]

6 **Córdova-Villalobos JA**, Barriguete-Meléndez JA, Lara-Esqueda A, Barquera S, Rosas-Peralta M, Hernández-Avila M, de León-May ME, Aguilar-Salinas CA. [Chronic non-communicable diseases in Mexico: epidemiologic synopsis and integral prevention]. *Salud Publica Mex* 2008; **50**: 419-427 [PMID: 18852939 DOI: 10.1590/s0036-36342008000500015]

7 **INEGI (Instituto Nacional de Estadística y Geografía)**. Mortality. [accessed 2021 Jan 19]. Available from: https://www.inegi.org.mx/sistemas/olap/registros/vitales/mortalidad/tabulados/ConsultaMortalidad.asp

8 **Méndez-Sánchez N**, Villa AR, Chávez-Tapia NC, Ponciano-Rodriguez G, Almeda-Valdés P, González D, Uribe M. Trends in liver disease prevalence in Mexico from 2005 to 2050 through mortality data. *Ann Hepatol* 2005; **4**: 52-55 [PMID: 15798662]

9 **Klop B**, Elte JW, Cabezas MC. Dyslipidemia in obesity: mechanisms and potential targets. *Nutrients* 2013; **5**: 1218-1240 [PMID: 23584084 DOI: 10.3390/nu5041218]

10 **Sparks JD**, Sparks CE, Adeli K. Selective hepatic insulin resistance, VLDL overproduction, and hypertriglyceridemia. *Arterioscler Thromb Vasc Biol* 2012; **32**: 2104-2112 [PMID: 22796579 DOI: 10.1161/ATVBAHA.111.241463]

11 **Højland Ipsen D**, Tveden-Nyborg P, Lykkesfeldt J. Normal weight dyslipidemia: Is it all about the liver? *Obesity (Silver Spring)* 2016; **24**: 556-567 [PMID: 26868960 DOI: 10.1002/oby.21443]

12 **Sepulveda-Villegas M**, Roman S, Rivera-Iñiguez I, Ojeda-Granados C, Gonzalez-Aldaco K, Torres-Reyes LA, Jose-Abrego A, Panduro A. High prevalence of nonalcoholic steatohepatitis and abnormal liver stiffness in a young and obese Mexican population. *PLoS One* 2019; **14**: e0208926 [PMID: 30608932 DOI: 10.1371/journal.pone.0208926]

13 **Rubi-Castellanos R**, Martínez-Cortés G, Muñoz-Valle JF, González-Martín A, Cerda-Flores RM, Anaya-Palafox M, Rangel-Villalobos H. Pre-Hispanic Mesoamerican demography approximates the present-day ancestry of Mestizos throughout the territory of Mexico. *Am J Phys Anthropol* 2009; **139**: 284-294 [PMID: 19140185 DOI: 10.1002/ajpa.20980]

14 **Román S,** Ojeda-Granados C, Panduro A. Genética y evolución de la alimentación de la población en México. *Rev Endocrinol Nut* 2013; **21**: 42-51 [DOI: 10.3989/asclepio.2001.v53.i2.158]

15 **Huerta-Chagoya A**, Moreno-Macías H, Sevilla-González M, Rodríguez-Guillén R, Ordóñez-Sánchez ML, Gómez-Velasco D, Muñóz-Hernández L, Segura-Kato Y, Arellano-Campos O, Cruz-Bautista I, Aguilar-Salinas CA, Tusié-Luna T. Contribution of Known Genetic Risk Variants to Dyslipidemias and Type 2 Diabetes in Mexico: A Population-Based Nationwide Study. *Genes (Basel)* 2020; **11** [PMID: 31968565 DOI: 10.3390/genes11010114]

16 **Abd El-Aziz TA**, Mohamed RH. LDLR, ApoB and ApoE genes polymorphisms and classical risk factors in premature coronary artery disease. *Gene* 2016; **590**: 263-269 [PMID: 27236033 DOI: 10.1016/j.gene.2016.05.032]

17 **Aguilar-Salinas CA**, Canizales-Quinteros S, Rojas-Martínez R, Mehta R, Villarreal-Molina MT, Arellano-Campos O, Riba L, Gómez-Pérez FJ, Tusié-Luna MT. Hypoalphalipoproteinemia in populations of Native American ancestry: an opportunity to assess the interaction of genes and the environment. *Curr Opin Lipidol* 2009; **20**: 92-97 [PMID: 19280764 DOI: 10.1097/mol.0b013e3283295e96]

18 **Yin RX**, Wu DF, Wu JZ, Cao XL, Aung LH, Miao L, Long XJ, Liu WY, Zhang L, Li M. Interactions of several lipid-related gene polymorphisms and cigarette smoking on blood pressure levels. *Int J Biol Sci* 2012; **8**: 685-696 [PMID: 22606049 DOI: 10.7150/ijbs.4401]

19 **Gonzalez-Aldaco K**, Roman S, Torres-Reyes LA, Panduro A. Association of Apolipoprotein e2 Allele with Insulin Resistance and Risk of Type 2 Diabetes Mellitus Among an Admixed Population of Mexico. *Diabetes Metab Syndr Obes* 2020; **13**: 3527-3534 [PMID: 33116704 DOI: 10.2147/DMSO.S268329]

20 **Torres-Valadez R**, Ramos-Lopez O, Frías Delgadillo KJ, Flores-García A, Rojas Carrillo E, Aguiar-García P, Bernal Pérez JA, Martinez-Lopez E, Martínez JA, Zepeda-Carrillo EA. Impact of *APOE* Alleles-by-Diet Interactions on Glycemic and Lipid Features- A Cross-Sectional Study of a Cohort of Type 2 Diabetes Patients from Western Mexico: Implications for Personalized Medicine. *Pharmgenomics Pers Med* 2020; **13**: 655-663 [PMID: 33273843 DOI: 10.2147/PGPM.S277952]

21 **Aceves D**, Ruiz B, Nuño P, Roman S, Zepeda E, Panduro A. Heterogeneity of apolipoprotein E polymorphism in different Mexican populations. *Hum Biol* 2006; **78**: 65-75 [PMID: 16900882 DOI: 10.1353/hub.2006.0021]

22 **Ojeda-Granados C**, Panduro A, Gonzalez-Aldaco K, Sepulveda-Villegas M, Rivera-Iñiguez I, Roman S. Tailoring Nutritional Advice for Mexicans Based on Prevalence Profiles of Diet-Related Adaptive Gene Polymorphisms. *J Pers Med* 2017; **7** [PMID: 29125573 DOI: 10.3390/jpm7040016]

23 **National Cholesterol Education Program (NCEP) Expert Panel on Detection,** Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III). Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) final report. *Circulation* 2002; **106**: 3143-3421 [DOI: 10.1161/circ.106.25.3143]

24 **Norma Oficial Mexicana NOM-037-SSA2-2012**. Para la prevención, tratamiento y control de las dislipidemias. 2012; [cited 2021 Jan 19]. Available from: http://www.dof.gob.mx/nota\_detalle.php?codigo=5259329fecha=13/07/2012

25 **World Health Organization**. Nutrition Landscape Information System (NLIS) Country profile indicators. Interpretation guide World Health Organization. 2010; [cited 2021 Jan 19]. Available from: https://www.who.int/nutrition/nlis\_interpretation\_guide.pdf

26 **Friedewald WT**, Levy RI, Fredrickson DS. Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. *Clin Chem* 1972; **18**: 499-502 [PMID: 4337382]

27 **Miller SA**, Dykes DD, Polesky HF. A simple salting out procedure for extracting DNA from human nucleated cells. *Nucleic Acids Res* 1988; **16**: 1215 [PMID: 3344216 DOI: 10.1093/nar/16.3.1215]

28 **Jung UJ**, Choi MS. Obesity and its metabolic complications: the role of adipokines and the relationship between obesity, inflammation, insulin resistance, dyslipidemia and nonalcoholic fatty liver disease. *Int J Mol Sci* 2014; **15**: 6184-6223 [PMID: 24733068 DOI: 10.3390/ijms15046184]

29 **Aguilar-Salinas CA**, Gómez-Pérez FJ, Rull J, Villalpando S, Barquera S, Rojas R. Prevalence of dyslipidemias in the Mexican National Health and Nutrition Survey 2006. *Salud Publica Mex* 2010; **52** Suppl 1: S44-S53 [PMID: 20585729 DOI: 10.1590/s0036-36342010000700008]

30 **Romero-Martínez M**, Shamah-Levy T, Vielma-Orozco E, Heredia-Hernández O, Mojica-Cuevas J, Cuevas-Nasu L, Rivera-Dommarco J; Grupo de trabajo Ensanut 2018-19\*. [National Health and Nutrition Survey 2018-19: methodology and perspectives]. *Salud Publica Mex* 2019; **61**: 917-923 [PMID: 31869555 DOI: 10.21149/11095]

31 **Sun MY**, Zhang L, Shi SL, Lin JN. Associations between Methylenetetrahydrofolate Reductase (MTHFR) Polymorphisms and Non-Alcoholic Fatty Liver Disease (NAFLD) Risk: A Meta-Analysis. *PLoS One* 2016; **11**: e0154337 [PMID: 27128842 DOI: 10.1371/journal.pone.0154337]

32 **Borén J**, White A, Wettesten M, Scott J, Graham L, Olofsson SO. The molecular mechanism for the assembly and secretion of ApoB-100-containing lipoproteins. *Prog Lipid Res* 1991; **30**: 205-218 [PMID: 1823939 DOI: 10.1016/0163-7827(91)90017-y]

33 **Morita SY**. Metabolism and Modification of Apolipoprotein B-Containing Lipoproteins Involved in Dyslipidemia and Atherosclerosis. *Biol Pharm Bull* 2016; **39**: 1-24 [PMID: 26725424 DOI: 10.1248/bpb.b15-00716]

34 **van 't Hooft FM**, Jormsjö S, Lundahl B, Tornvall P, Eriksson P, Hamsten A. A functional polymorphism in the apolipoprotein B promoter that influences the level of plasma low density lipoprotein. *J Lipid Res* 1999; **40**: 1686-1694 [PMID: 10484616]

35 **Sposito AC**, Gonbert S, Turpin G, Chapman MJ, Thillet J. Common promoter C516T polymorphism in the ApoB gene is an independent predictor of carotid atherosclerotic disease in subjects presenting a broad range of plasma cholesterol levels. *Arterioscler Thromb Vasc Biol* 2004; **24**: 2192-2195 [PMID: 15358600 DOI: 10.1161/01.ATV.0000144810.10164.50]

36 **Paththinige CS**, Sirisena ND, Dissanayake V. Genetic determinants of inherited susceptibility to hypercholesterolemia - a comprehensive literature review. *Lipids Health Dis* 2017; **16**: 103 [PMID: 28577571 DOI: 10.1186/s12944-017-0488-4]

37 **Farrokhi E**, Shayesteh F, Asadi Mobarakeh S, Roghani Dehkordi F, Ghatreh Samani K, Hashemzadeh Chaleshtori M. Molecular characterization of Iranian patients with possible familial hypercholesterolemia. *Indian J Clin Biochem* 2011; **26**: 244-248 [PMID: 22754187 DOI: 10.1007/s12291-011-0113-7]

38 **Gopalraj RK**, Zhu H, Kelly JF, Mendiondo M, Pulliam JF, Bennett DA, Estus S. Genetic association of low density lipoprotein receptor and Alzheimer's disease. *Neurobiol Aging* 2005; **26**: 1-7 [PMID: 15585340 DOI: 10.1016/j.neurobiolaging.2004.09.001]

39 **Ojeda-Granados C**, Abondio P, Setti A, Sarno S, Gnecchi-Ruscone GA, González-Orozco E, De Fanti S, Jiménez-Kaufmann A, Rangel-Villalobos H, Moreno-Estrada A, Sazzini M. Dietary, Cultural, and Pathogens-Related Selective Pressures Shaped Differential Adaptive Evolution among Native Mexican Populations. *Mol Biol Evol* 2022; **39** [PMID: 34597392 DOI: 10.1093/molbev/msab290]

40 **Ko A**, Cantor RM, Weissglas-Volkov D, Nikkola E, Reddy PM, Sinsheimer JS, Pasaniuc B, Brown R, Alvarez M, Rodriguez A, Rodriguez-Guillen R, Bautista IC, Arellano-Campos O, Muñoz-Hernández LL, Salomaa V, Kaprio J, Jula A, Jauhiainen M, Heliövaara M, Raitakari O, Lehtimäki T, Eriksson JG, Perola M, Lohmueller KE, Matikainen N, Taskinen MR, Rodriguez-Torres M, Riba L, Tusie-Luna T, Aguilar-Salinas CA, Pajukanta P. Amerindian-specific regions under positive selection harbour new lipid variants in Latinos. *Nat Commun* 2014; **5**: 3983 [PMID: 24886709 DOI: 10.1038/ncomms4983]

41 **Ojeda-Granados C**, Panduro A, Rivera-Iñiguez I, Sepúlveda-Villegas M, Roman S. A Regionalized Genome-Based Mexican Diet Improves Anthropometric and Metabolic Parameters in Subjects at Risk for Obesity-Related Chronic Diseases. *Nutrients* 2020; **12** [PMID: 32121184 DOI: 10.3390/nu12030645]

42 **Campos-Pérez W,** González-Becerra K, Ramos-López O., Silva-Gómez JA, Barrón-Cabrera E, Roman S, Panduro A, Martínez-López E. Same Dietary but Different Physical Activity Pattern in Normal-weight and Overweight Mexican Subjects. *J Food Nutr Res* 2016; **4**: 729-735 [DOI: 10.12691/jfnr-4-11-5]

43 **Bjornstad P**, Eckel RH. Pathogenesis of Lipid Disorders in Insulin Resistance: a Brief Review. *Curr Diab Rep* 2018; **18**: 127 [PMID: 30328521 DOI: 10.1007/s11892-018-1101-6]

**Footnotes**

**Institutional review board statement:** The study was reviewed and approved by the Institutional Review Board of the Civil Hospital of Guadalajara, Guadalajara, Jalisco, Mexico.

**Informed consent statement:** All patients signed a written informed consent before enrollment, and anonymized data was employed to continue the statistical analysis.

**Conflict-of-interest statement:** All authors have no conflict of interest to disclose.

**Data sharing statement:** The dataset is available from the corresponding author at apanduro@prodigy.net.mx.

**Open-Access:** This article is an open-access article that was selected by an in-house editor and fully peer-reviewed by external reviewers. It is distributed in accordance with the Creative Commons Attribution NonCommercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: https://creativecommons.org/Licenses/by-nc/4.0/

**Provenance and peer review:** Invited article; Externally peer reviewed.

**Peer-review model:** Single blind

**Peer-review started:** January 21, 2022

**First decision:** June 7, 2022

**Article in press:** July 6, 2022

**Specialty type:** Gastroenterology and hepatology

**Country/Territory of origin:** Mexico

**Peer-review report’s scientific quality classification**

Grade A (Excellent): 0

Grade B (Very good): B, B

Grade C (Good): 0

Grade D (Fair): D

Grade E (Poor): 0

**P-Reviewer:** Moriyama K, Japan; Papazafiropoulou A, Greece; Skrypnik D, Poland **S-Editor:** Zhang H **L-Editor:** A **P-Editor:** Zhang H

**Table 1 Clinical characteristics and lipid profile of West Mexico populations**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Variables** | **Native American ancestry** | | **Mestizos (low-to-high European ancestry)** | | | | | **Total WMX** | ***P* value** |
| **NAH** | **WXK** | **TPC** | **GDL** | **CUQ** | **VP** | **SMA** |
| *n* (%) | 84 (9.5) | 106 (12.0) | 184 (20.8) | 321 (36.4) | 131 (14.8) | 32 (3.6) | 26 (2.9) | 884 (100) |  |
| Age (yr) | 29.5 ± 11 | 43.5 ± 15 | 52.5 ± 8.3 | 36.4 ± 12.6 | 48 ± 15.4 | 40.4 ± 21.1 | 44 ± 15 | 43.7 ± 14.8 | 0.022a |
| Male *n* (%) | 24 (29) | 41 (39) | 77 (42) | 91 (28) | 34 (26) | 13 (39) | 9 (35) | 289 (32.7) | 0.001d |
| Female *n* (%) | 60 (71) | 65 (61) | 107 (58) | 230 (72) | 97 (74) | 19 (61) | 17 (65) | 595 (67.3) | 0.001d |
| BMI (kg/m2) | 26.3 ± 4.3 | ND | 28.3 ± 4.7 | 33.8 ± 10.3 | 28.6 ± 5.8 | 26.4 ± 5.1 | 25.5 ± 3.8 | 29.9 ± 7.7 | 8 × 10-27c |
| TC (mg/dL) | 164.3 ± 39.8 | 190.4 ± 37.1 | 228.1 ± 49.2 | 187.7 ± 42.4 | 182.1 ± 34.4 | 210 ± 52.6 | 179.7 ± 37.2 | 199.3 ± 48.8 | 1 × 10-35a |
| TG (mg/dL) | 151.5 ± 86.2 | 150.6 ± 98.1 | 197.3 ± 123.6 | 161.6 ± 148.3 | 150.6 ± 95 | 171.7 ± 93.1 | 148.9 ± 86.4 | 169.7 ± 122.5 | 0.023a |
| LDL-c (mg/dL) | 95.6 ± 30.3 | 120.2 ± 31.7 | 158.4 ± 46.4 | 114.5 ± 36.9 | 107.3 ± 9.1 | 141.5 ± 38.3 | 111.3 ± 30.3 | 128.8 ± 44.7 | 1 × 10-30a |
| VLDL-c (mg/dL) | 29.1 ± 28.6 | 24.8 ± 10.6 | 29 ± 16 | 32.6 ± 30.4 | 30.3 ± 19.2 | 36.2 ± 23.3 | 29.8 ± 17.3 | 30.4 ± 23.0 | 0.350 |
| HDL-c (mg/dL) | 39.5 ± 6.8 | 46.2 ± 10.6 | 41.1 ± 10.8 | 42.5 ± 14.4 | 44.0 ± 9.6 | 43 ± 3.5 | 39.9 ± 8.1 | 42.3 ± 11.2 | 0.010b |

aTepic (TPC) *vs* the other groups by post hoc tests, *P* = 0.002.

bNahua (NAH) *vs* Cuquio (CUQ) & Wixárika group by post hoc tests, *P* = 0.015.

cGuadalajara (GDL) & NAH *vs* the other groups by post hoc tests, *P* = 0.001.

dTPC *vs* GDL, NAH & CUQ by post hoc tests, *P* = 0.035.

Values are presented as mean ± SD. Gender is expressed as number of cases and percentage. The one-way ANOVA for quantitative variables and Chi-square test for qualitative variables were the statistical approach. NAH: Nahua indigenous group; WXK: Wixárika indigenous group; ND: No data; TPC: Tepic; GDL: Guadalajara; CUQ: Cuquio; VP: Villa Purificación; SMA: San Miguel el Alto; WMX: West Mexico; BMI: Body mass index; TC: Total cholesterol; TG: Triglycerides; LDL-c: Low-density lipoprotein cholesterol; VLDL: Very low-density lipoprotein cholesterol; HDL-c: High-density lipoprotein cholesterol.

**Table 2 Prevalence of the type of dyslipidemias in West Mexico populations**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Dyslipidemia** | **Native American ancestry** | | **Mestizos (low-to-high European ancestry)** | | | | | **Total WMX (*n* = 884)** | ***P* value** |
| **NAH (*n* = 84)** | **WXK (*n* = 106)** | **TPC (*n* = 184)** | **GDL (*n* = 321)** | **CUQ (*n* = 131)** | **VP (*n* = 32)** | **SMA (*n* = 26)** |
| HChol | 6 (7.1) | 41 (38.7) | 139 (75.5) | 113 (35.2) | 43 (32.8) | 21 (65.6) | 11 (42.3) | 374 (42.3) | 0.001a |
| HTG | 35 (41.7) | 36 (34.0) | 94 (51.1) | 116 (36.1) | 49 (37.4) | 15 (46.9) | 12 (46.2) | 357 (40.4) | 0.001b |
| High LDL-c | 13 (15.5) | 43 (40.6) | 137 (74.5) | 72 (22.4) | 24 (18.3) | 21 (65.6) | 7 (26.9) | 317 (35.8) | 0.003a |
| HALP | 42 (50.0) | 28 (26.4) | 87 (47.3) | 112 (34.9) | 45 (34.3) | 5 (15.6) | 15 (57.7) | 334 (37.8) | 0.002c |

**a**Tepic (TPC) *vs* the other groups.

bTPC *vs* Wixárika (WXK) & Cuquio (CUQ) group.

**c**Villa Purificación & WXK *vs* the other groups.

The Chi-square test was the statistical approach. Values are presented as number of cases and percentage. NAH: Nahua indigenous group; WXK: Wixárika indigenous group; TPC: Tepic; GDL: Guadalajara; CUQ: Cuquio; VP: Villa Purificación; SMA: San Miguel el Alto; WMX: West Mexico; HChol: Hypercholesterolemia; HTG: Hypertriglyceridemia; HALP: Hypoalphalipoproteinemia.

**Table 3 Frequency of risk allele of polymorphisms associated with lipid disorders in West Mexican populations**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Lipid abnormality** | **SNPs**  **(risk allele)** | **Native American ancestry** | | **Mestizos (low-to-high European ancestry)** | | | | | **Total WMX**  **(*n* = 1324)** | ***P* value** |
| **NAH**  **(*n* = 84)** | **WXK**  **(*n* = 106)** | **TPC**  **(*n* = 184)** | **GDL**  **(*n* = 754)** | **CUQ**  **(*n* = 131)** | **VP**  **(*n* = 32)** | **SMA**  **(*n* = 33)** |
| Low HDL-c | *ABCA1* R230C (RC + CC genotypes) | 15 (17.9) | 43 (40.6) | 24 (13.0) | 53  (7.0) | 18 (13.7) | 4 (12.5) | 2  (6.1) | 159 (12.0) | 0.010c |
| High TCe | *APOE* (E4 allele) | 21 (12.5) | 53 (25.0) | ND | 145 (9.6) | ND | 2 (3.1) | 2 (3.0) | 223  (8.4) | 2 × 10-12a |
| *APOB*-516C/T (T allele) | 49 (29.2) | 58 (27.4) | ND | 433 (28.7) | ND | 24 (37.5) | 18 (27.3) | 582 (22.0) | 0.129 |
| *LDLR* A1413G (G allele) | 121 (72.0) | 161 (75.9) | ND | 1045 (69.3) | ND | 42 (65.6) | 44 (66.7) | 1413 (53.5) | 0.047a |
| *LDLR* C\*52T (C allele) | 124 (73.8) | 145 (68.4) | ND | 1068 (70.8) | ND | 55 (85.9) | 52 (78.8) | 1444 (54.7) | 0.045b |
| High TGe | *APOE* (E2 allele) | 0  (0) | 0  (0) | ND | 51 (3.4) | ND | 1  (1.6) | 7 (10.6) | 59  (2.2) | 0.028d |
| *MTTP*-493G/T (T allele) | 17 (10.1) | 2  (0.9) | ND | 253 (16.8) | ND | 11 (17.2) | 10 (15.2) | 293 (11.1) | 2 × 10-6b |
| *MTHFR* C677T (T allele) | 103 (61.3) | 111 (52.4) | 172 (46.7) | 670 (44.4) | 117 (44.6) | 25 (39.1) | 21 (31.8) | 930 (35.2) | 0.038b |

aNahua & Wixárika (WXK) *vs* the other groups.

bVilla Purificación & San Miguel el Alto (SMA) *vs* the other groups.

cWXK *vs* the other groups.

dSMA *vs* the other groups. The Chi-square test was the statistical approach.

eThe allelic frequencies were obtained considering the diploid number of chromosomes (2n).

Values are expressed as *n* (%). NAH: Nahua indigenous group; WXK: Wixárika indigenous group; TPC: Tepic; GDL: Guadalajara; VP: Villa Purificación; SMA: San Miguel el Alto; WMX: West Mexico; ND: No data; HDL-c: High-density Lipoprotein cholesterol; TC: Total Cholesterol; TG: Triglycerides.

**Table 4 Clinical and biochemical characteristics and frequency of dyslipidemias in normal weight** **Mestizos individuals**

|  |  |  |
| --- | --- | --- |
| **Variable** | **Reference values** | **Study group** |
| *n* |  | 193 |
| Age (yr) |  | 32.8 ± 12.3 |
| Male |  | 55 (28.5%) |
| Female |  | 138 (71.5%) |
| BMI (kg/m2) | 18.5-24.9 | 22.3 ± 1.1 |
| Total body fat (%) | < 24% | 21.3 ± 6.1 |
| Glucose (mg/dL) | < 100 | 84.4 ± 7.9 |
| HOMA-IR | < 2.5 | 1.7 ± 0.5 |
| TC (mg/dL) | < 200 | 180.1 ± 33.1 |
| TG (mg/dL) | < 150 | 112.2 ± 61.3 |
| LDL-c (mg/dL) | < 130 | 109.2 ± 27.6 |
| VLDL-c (mg/dL) | < 25 | 22.5 ± 12.3 |
| HDL-c (mg/dL) | > 40 | 49.4 ± 13.7 |
| AST (UI/L) | < 54 | 26.3 ± 10.5 |
| ALT (UI/L) | < 42 | 25.1 ± 14.1 |
| GGT (UI/L) | < 35 | 20.2 ± 5.3 |
| Dyslipidemia |  | 75 (38.9%) |
| HChol | (TC > 200 mg/dL) | 54 (27.9%) |
| HTG | (TG > 150 mg/dL) | 35 (18.1%) |
| High LDL-c | (LDL-c ≥ 130 mg/dL) | 39 (20.2%) |
| HALP | (HDL-c < 40 mg/dL) | 40 (20.7%) |

Values are presented as mean ± SD; *n*: Number of cases and percentage. MTZ: Mestizo; BMI: Body mass index; HOMA-IR: Homeostasis model assessment insulin resistance; TC: Total cholesterol; TG: Triglycerides; LDL-c: Low-density lipoprotein cholesterol; VLDL-c: Very low-density lipoprotein cholesterol; HDL: High-density lipoprotein cholesterol; AST: Aspartate aminotransferase; ALT: Alanine aminotransferase; GGT: Gamma-glutamyl-transferase; HChol: Hypercholesterolemia; HTG: Hypertriglyceridemia; HALP: Hypoalphalipoproteinemia.

**Table 5 Association of *APOB* -516C/T and *LDLR* A1413G polymorphism with lipid levels in normal weight** **Mestizos individuals**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Variable** | ***APOB* -516 C/T genotypes** | | | ***P* value** | ***LDLR* A1413G genotypes** | | | ***P* value** |
| **CC (*n* = 85)** | **CT (*n* = 54)** | **TT (*n* = 15)** | **AA (*n* = 22)** | **AG (*n* = 65)** | **GG (*n* = 63)** |
| TC (mg/dL) | 177.8 ± 31 | 178.2 ± 37.4 | 196.2 ± 27.6 | 0.033a | 177.2 ± 25.7 | 175.4 ± 33.1 | 182.9 ± 34.7 | 0.366 |
| TG (mg/dL) | 110.4 ± 68 | 119.9 ± 71.3 | 108.7 ± 25.9 | 0.574 | 106.9 ± 47.5 | 98.7 ± 44.6 | 124.3 ± 79.8 | 0.094 |
| LDL-c (mg/dL) | 106.3 ± 24 | 107.3 ± 30.6 | 129.5 ± 31.6 | 0.017a | 103.3 ± 23.9 | 106.2 ± 26.8 | 111.8 ± 29.5 | 0.042b |
| VLDL-c (mg/dL) | 22 ± 13.6 | 24.3 ± 14.3 | 21.8 ± 5.1 | 0.451 | 21.3 ± 9.5 | 19.7 ± 9.0 | 25.1 ± 16.0 | 0.075 |
| HDL-c (mg/dL) | 49.3 ± 13.9 | 48.5 ± 10.7 | 50.3 ± 16.9 | 0.908 | 51.1 ± 15.3 | 51.6 ± 11.8 | 46.8 ± 13.3 | 0.143 |
| Dyslipidemia, *n* (%) | | | | |  |  |  |  |
| HChol | 9 (11) | 8 (15) | 6 (40) | 0.012a | 1 (5) | 8 (12) | 14 (22) | 0.034b |
| HTG | 15 (18) | 14 (26) | 0 (0) | 0.076 | 3 (14) | 7 (11) | 15 (24) | 0.315 |
| High LDL-c | 13 (15) | 12 (22) | 7 (47) | 0.007a | 3 (14) | 10 (15) | 17 (27) | 0.046b |
| HALP | 19 (22) | 10 (18) | 3 (20) | 0.760 | 3 (14) | 8 (12) | 18 (13) | 0.178 |

aTT *vs* CC.

bGG *vs* AA.

The Kruskall Wallis test and U Mann-Whitney test for quantitative variables and Chi-square test for qualitative variables were the statistical approach. Values are expressed as mean ± SD, number of cases and percentage. MTZ: Mestizos; TC: Total cholesterol; TG: Triglycerides; LDL-c: Low-density lipoprotein cholesterol; VLDL-c: Very low-density lipoprotein cholesterol; HDL-c: High-density lipoprotein cholesterol; HChol: Hypercholesterolemia; HTG: Hypertriglyceridemia; HALP: Hypoalphalipoproteinemia.

**Table 6 Association of *APOB* and *LDLR* genotypes with hypercholesterolemia in normal weight Mestizos individuals**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Genotype** | **Non-HChol** | **HChol** | ***P* value** | **Genotype comparison** | **Odds ratio (95%CI)** | ***P* value** |
| *APOB* -516C/T genotypes | | | | | | |
| CC | 76 (58.0%) | 9 (39.1%) | 0.120 | TT *vs* CC | 5.33 (1.537-18.502) | 0.008 |
| CT | 46 (35.1%) | 8 (34.8%) | 0.895 | TT *vs* CC + CT | 4.63 (1.463-14.634) | 0.009 |
| TT | 9 (6.9%) | 6 (26.1%) | 0.005 | TT *vs* CT | 3.83 (1.069-13.746) | 0.039 |
| *LDLR* A1413G genotypes | | | | | | |
| AA | 21 (16.5%) | 1 (4.3%) | 0.135 | GG *vs* AA | 3.90 (1.042-14.583) | 0.043 |
| AG | 57 (44.9%) | 8 (34.8%) | 0.340 | GG *vs* AA + AG | 2.53 (1.216-5.282) | 0.013 |
| GG | 49 (38.6%) | 14 (60.9%) | 0.043 | GG *vs* AG | 2.24 (1.028-4.890) | 0.042 |

Values are expressed as number of cases and percentage. MTZ: Mestizos; HChol: Hypercholesterolemia. The Chi-square test and logistic regression test were the statistical approach.

**Table 7 Increased serum level of low-density lipoprotein cholesterol associated with *APOB* and *LDLR* genotypes in individuals with normal weight from West Mexico**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Genotype comparison** | ***R*2** | **β** | **95%CI** | ***P* value** |
| *APOB* -516C/T |  |  |  |  |
| TT *vs* CC | 0.30 | 40.39 | 14.415-66.366 | 0.004 |
| TT *vs* CC + CT | 0.23 | 39.79 | 16.226-63.363 | 0.001 |
| TT *vs* CT | 0.31 | 39.01 | 0.996-67.029 | 0.091 |
| *LDLR* A1413G |  |  |  |  |
| GG *vs* AA | 0.11 | 23.29 | 1.640-44.946 | 0.036 |
| GG *vs* AA + AG | 0.11 | 20.77 | 5.763-35.784 | 0.007 |
| GG *vs* AG | 0.08 | 19.74 | 0.915-37.270 | 0.082 |

Linear regression test was the statistical approach.



Published by **Baishideng Publishing Group Inc**

7041 Koll Center Parkway, Suite 160, Pleasanton, CA 94566, USA

**Telephone:** +1-925-3991568

**E-mail:** bpgoffice@wjgnet.com

**Help Desk:** https://www.f6publishing.com/helpdesk

https://www.wjgnet.com



**© 2022 Baishideng Publishing Group Inc. All rights reserved.**