Interaction of Sex, Age, Body Mass Index and Race on Hypertension Prevalence in the American Population: A Cross-sectional Study

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Abstract

Background: Hypertension is a major risk factor for many chronic diseases and mortality. We carried out this study aimed to investigate the possible effects of the interaction of sex, age, BMI and race on the prevalence of hypertension.

Methods: By using the data of a sample-adjusted 2656 women and 2515 men in the American National Health and Nutrition Examination Survey 2015-2016, we analyzed the interaction of sex, age, BMI and race by logistic regression. Hypertension was defined as an SBP ≥130 mmHg or DBP ≥80 mmHg or taking anti-hypertensive medication.

Results: Totally, there were 2776 (53.68%) hypertensive patients. Interactions were found between sex and age, BMI and age, race and age. The adjusted odds ratio (aOR) for age 60-80 (aOR 19.26 [95% CI 14.14–26.23]) and 40 to 59 (4.56 [3.54–5.88]) were significantly higher than the reference group (age 20 to 39) in women, and also in men (6.44 [4.80–8.63]) and (2.84[2.23–3.61]), respectively. And this risk trend was consistent in the BMI group and the race group.

Conclusion: Association between obesity and the risk of hypertension varies according to the age and race of the population and age had a stronger effect on hypertension in women than in men. Differences in age and race should be considered when providing corresponding antihypertensive measures. Although the exact mechanism of hypertension remains to be further studied, these findings suggested that early prevention and intervention measures can effectively reduce the risk of hypertension, especially in women.

Background

Hypertension is one of the known public health problems and is common in various countries and regions around the world[1]. It is a recognized risk factor for stroke[2], kidney disease[3]and mortality[4]and it kills nearly 9.4 million people worldwide every year[5], making it the main cause of early death. A report released in October 2017 by the America Centers for Disease Control and Prevention found that nearly 30% of American adults had hypertension[6]. Forecasts showed that by 2030, the prevalence of hypertension will increase by 7.2% from the 2013 estimates. Therefore, the prevention of hypertension is an ongoing challenge.

Overweight/obesity, age and gender are the three most important factors that independently affect the risk of hypertension[7–9]. The obesity rate of the American population is rising due to lifestyle such as a lack of exercise and unhealthy diet, particularly among women. About 60–70% of hypertension in adults can be directly attributable to obesity[10]. But, the impact of BMI on the risk of high blood pressure may change with age, the Framingham cohort study found that the effect of the interaction between age and BMI on DBP was − 0.422 ($P < 0.0001$)[11]. In addition, a Japanese study found that gender and BMI have an interactive effect on hypertension[12]. However, considering the differences in physical conditions and

race between the American population and the Asian population, the age difference between gender, BMI, race and hypertension in the American population remains unclear.

Therefore, we made full use of National Health and Nutrition Examination Survey (NHANES) 2015–2016 data to explore the risk factors of hypertension in the American population. The main goals include: (1) to determine the prevalence of hypertension; and (2) to evaluate hypertension based on the interactive analysis of gender, BMI, age and race Impact. Our research provides comprehensive information on the assessment of age differences in the association between gender, BMI, race, and hypertension in the American population.

Methods

Study Population

NHANES is a nationally representative cross-sectional survey designed to assess the nutritional and health status of the America population. It used a complex multi-stage probability sampling design and selected representative non-institutional civilian population in the United States. Our research subject was the population surveyed in the NHANES database from 2015 to 2016, excluding people with missing or incomplete blood pressure values and pregnant women, in the end, the study included a total of 5171 participants over the age of 20 (2515 men and 2656 women) (Table 1).

Informed Consent for Studies

The Institutional Review Board of the National Center for Health Statistics approved the NHANES research protocol for the 2015–2016 survey years and obtained oral and written informed consent from all participants. And the study in accordance with the ethical guidelines of the 1975 Declaration of Helsinki.

Blood Pressure Measurement

All blood pressure values (systolic and diastolic) were measured according to the American Heart Association and NHANES related procedures[13]. First, participants sit still for 5 minutes, and then their sitting blood pressure was measured three times by a qualified inspector using a mercury sphygmomanometer. If the blood pressure measurement was interrupted, incomplete or incorrect, a fourth attempt would be made. Finally, we calculated the average systolic blood pressure (SBP) and diastolic blood pressure (DBP).

Definition of Hypertension

It was defined as taking prescription drugs for antihypertensive treatment. Also, participants who had a directly measured mean systolic blood pressure at least 130 mmHg and/or mean diastolic blood pressure

at least 80 mmHg were diagnosed with hypertension according to the 2017 guidelines for adult hypertension clinical practice guidelines[14].

Underlying Factors of Hypertension

Subjects were divided into three age groups (20 to 39, 40 to 59, and 60 to 80 years) and into three BMI groups (< 25, 25–29.9, and ≥ 30 kg/m^2) and into five race groups (Mexican American, other Hispanic, non-Hispanic White, non-Hispanic Black, and other Race-Including Multi-Racial). In addition to sex, age, BMI and race, we investigated the impact of other potential confounding factors, which included: education [less than 9th grade, 9–11 years old (including 12th grade without diploma), high school graduate/GED or equivalent, some university or AA degree and college degree or above], history of diabetes and dyslipidemia, the value of aspartate aminotransferase(AST), alanine aminotransferase(ALT), gamma-glutamyl transferase(GGT), triglyceride(TG), fasting blood glucose(FBG), low density lipoprotein cholesterol(LDLC), high density lipoprotein cholesterol(HDLC), total cholesterol(TC), and we also surveyed smoking status (never smoked, used to but quit now, currently smoking),drinking habits (never, <1drinks /day, 1-1.9 drinks/day, ≥ 2 drinks/day) and physical activities (never, aerobic activity < 150 min/week, aerobic activity ≥ 150 min/week).

Statistical Analysis

Continuous variables were expressed as mean and standard deviation or quartile (25th and 75th percentiles). Student's t-test was used to compare the mean values between participants with and without hypertension. Chi-square tests were used to compare the percentage of categorical variables between individuals with and without hypertension. Wilcoxon rank sum test were used to compare the interquartile range of non-normal data distribution variables between individuals with and without hypertension. We conducted interaction analysis by logistic regression. The first step is to eliminate the influence of confounding factors and define the reference value of age as 20–39 years old. We analyzed the influence of pairwise interaction and three-way interaction. If the ternary interaction was meaningful, assessing the two-way interaction between BMI and age can be stratified by sex. If the three-way interaction was not significant and the two-way interaction was significant, then controlling the effects of other interaction and confounding factors, the main effect of one variable was evaluated stratified by the other variable. When α was less than 0.05 at both tails, the result was considered statistically significant. All data were analyzed using SAS 9.4 program.

Results

Table 1 lists the basic characteristics of the study subjects. Of the 5171 participants, approximately half (48.63%) of the study population was men, and the prevalence of hypertension was 53.68%. Compared with participants without hypertension, those with hypertension tended to be older and more likely to be obese. Participants with hypertension received lower education level. In terms of biochemical indicators and history of illness, hypertensive patients tended to have higher AST, ALT, GGT values and lower HDLC, FBG and a higher prevalence of diabetes and dyslipidemia. People who had ever smoking, furthermore

smoking currently and never drinking, 1-1.9 drinks/day and ≥ 2 drinks/day and aerobic activity ≥ 150 min/week, the risk of hypertension would greatly increase. There was no significant difference in LDLC between participants with and without hypertension.

In the overall population, people who were overweight (OR 1.52 [95% CI 1.26–1.85]) or obese (2.64 [2.17–3.21]) had a significantly increased risk of hypertension compared with people with BMI < 25 kg/ m² and consistent with gender groups and age groups (Table 2). The association between overweight/obesity and hypertension varied significantly by age, race or ethnicity. The stratified analysis showed that the effect of obesity on hypertension decreased with age (Table 2). Therefore, we conducted further analysis by age, race or ethnicity and pointed out the different effects of age on the relationship between overweight/obesity and hypertension (Fig. 1). In the 60–80 age group, being overweight is only positively associated with high blood pressure among Other Hispanic (2.28 [1.03–5.06]). In the 20–39 and 40–59 age groups, obesity is positively associated with hypertension in all ethnic groups. However, in the 60–80 age group, the association between obesity and high blood pressure is only positively associated among Other Hispanics, non-Hispanic whites, and non-Hispanic blacks (2.93 [1.33–6.47], 1.85 [1.19–2.88] and 2.37 [1.06–5.31]).

Table 2
Odds ratios (95% CI) for the associations between BMI and hypertension.

Independent Variables	BMI < 25 kg/ m²	BMI 25.0 – 29.9 kg/m²	BMI ≥ 30.0 kg/m²
Overall	Ref	1.52(1.26–1.85)	2.64(2.17–3.21)
Sex			
Male	Ref	1.70(1.31–2.21)	2.65(2.00-3.53)
Female	Ref	1.42(1.06–1.91)	2.84(2.15–3.75)
Age groups, years			
20–39	Ref	1.69(1.17–2.44)	3.83(2.68–5.47)
40–59	Ref	1.37(1.00-1.86)	2.44(1.79–3.34)
60–80	Ref	1.50(1.04–2.17)	1.64(1.11–2.43)
Race or ethnicity			
Mexican American	Ref	1.55(0.85–2.80)	3.32(1.84–5.98)
Other Hispanic	Ref	1.43(0.76–2.68)	2.41(1.32–4.40)
Non-Hispanic White	Ref	1.23(0.89–1.71)	1.92(1.37–2.69)
Non-Hispanic Black	Ref	1.79(1.13–2.85)	3.02(1.91–4.78)
Other Race	Ref	1.93(1.25–2.96)	3.23(1.96–5.34)
Unadjusted confounders.			

Table 3 lists the interaction the effects of two-way interactions (sex*age, sex*BMI, age* BMI, race*BMI and race*age) and three-way interactions (sex*age*BMI) on hypertension were analyzed by logistic regression. As shown in Table 3, the two-way interaction between sex and age ($P < 0.001$) and age and BMI ($P = 0.047$) and race and age ($P = 0.001$) were significant.

Table 3
The interaction effects of sex, age, BMI and Race on the prevalence of hypertension.

Independent Variables	Wald Statistic	DF	*P*
Sex*Age	24.31	2	< 0.001
Sex*BMI	1.33	2	0.513
Age*BMI	9.62	4	0.047
Sex*Age*BMI	8.81	4	0.066
Race*BMI	4.71	8	0.788
Race*Age	27.03	8	0.001
Factors for adjustment were three continuous variables (AST, ALT and GGT) and seven categorical variables (race, education level, diabetes, dyslipidemia, smoking habit, alcohol consumption and physical activities).			

In the next step, we evaluated the effects of men and women stratified by age (Fig. 2) and also analyzed the effects of BMI and race on hypertension at different ages. We found the adjusted odds ratio (aOR) of age 40–59 (aOR 4.56 [95% CI 3.54–5.88]) and 60–80 (19.26 [14.14–26.23]) were significantly higher than the aOR of the reference group (age 20–39) in women. In men, the same is true for disease risk trends. As far as BMI is concerned, in the 40–59 age group, the three BMI groups had little difference in the risk of hypertension, but in the 60–80 age group, the impact of BMI < 25 kg/m^2 or overweight on high blood pressure rises sharply, but compared with them, the effect of obesity on hypertension has not changed much. Compared to other races, Other Hispanic were at the highest risk of developing hypertension between the age of 40–59 years (8.12 [4.64–14.23]) and 60–80 years (18.68 [9.86–35.40]). And Mexican Americans had the lowest risk of high blood pressure (2.16 [1.42–3.27]) in the 40–59 age group, but after the age of 60, the risk of hypertension is second only to other Hispanics. There is no significant difference in the risk of the other three races in the same age group.

Discussion

In this study of nationally representative data on American adults from 2015 to 2016, we found that after controlling for possible confounding factors, there is an interaction between gender and age, BMI and age, race and age on hypertension. We found that the risk of hypertension increased for both men and women after the age of 49, and the tendency was more significant in women. With the increase of age, especially in the elderly, compared with overweight and BMI < 25 kg/m^2, the effect of obesity on hypertension has not changed much. In addition, the interaction of age and race showed that Other

Hispanic had the highest prevalence of hypertension and among Mexican Americans aged 60–80 is 8 times that of those aged 40–59.

This study found a significant interaction between age and gender on the prevalence of hypertension. Previous studies had also found differences in the incidence of hypertension between men and women[5, 15]and it was consistent with our findings; in particular, the effect of hypertension on women was stronger than men. A review by the U.S. Centers for Disease Control and Prevention (CDC) noted that blood pressure may rise especially in women after menopause. By the age of 60 and 70, 70% of women had high blood pressure, and after 75, the number rose to nearly 80%[16]. This was in line with the findings of the increased prevalence of hypertension among women in our study after 49 years old. Although our research cannot provide a clear reason, this may be explained by following aspects. After entering menopause, estrogen level dropped and activated the renin-angiotensin system (RAS) and the sympathetic nervous system to maintain the body's electrolytes and fluid balance, which can lead to increased blood pressure[17]. In addition, there was also evidence that estrogen lost can cause endothelial dysfunction, which may lead to the development of hypertension. Acute increase in estradiol-mediated intracellular calcium will activate endothelial nitric oxide synthase to produce nitric oxide, while estradiol can increase mRNA expression of endothelial nitric oxide synthase in the long run[18]. Because nitric oxide can effectively promote vasodilation, which can reduce blood pressure. In short, decreased estrogen may explain increased risk of hypertension after the menopause. Unlike women, men's hormones would not drop apparently until they after 60 years old. The main reason for the greatly increased prevalence of hypertension in elderly men may be the decline of androgen level. Related studies have shown that androgen deficiency was associated with increased prevalence of hypertension[19]. As we all know, men's overweight or obesity rate will increase due to their slow metabolism after middle age. Visceral obesity can reduce the level of sex hormone-binding globulin and luteinizing hormone (LH), thereby affecting the bioavailability of male testosterone and androgens, while insufficient androgen can decrease atrial natriuretic peptide level then led to increase vasoconstriction blood pressure. It can be seen that the reason why elderly women suffer from hypertension higher than men was that women enter menopause ten years earlier than men enter old age, so the level of estrogen declines more severely than androgen.

Some previous longitudinal cohort studies have found the effect of overweight/obesity on the incidence of hypertension[20–23]. This was consistent with our research results. Our results based on a large U.S. population provided a comprehensive interpretation of the association between overweight/obesity and hypertension of a wide range of ages, and after adjusting for confounding factors, interaction analysis showed obesity has a reduced effect on hypertension in the elderly compared to overweight. A study in Italy showed that with the increase of BMI in the elderly, the risk of hypertension is gradually reduced[24]. This was consistent with our research results. It was suggested that the obesity of the elderly population may not be the decisive factor for the incidence of hypertension. It may be that obese elderly people receive more treatment and led to a reduction in cardiovascular risk factors. This study was also consistent with previous research results, that is, the effect of BMI on the risk of hypertension depends on age, that is, the effect in the young and middle-aged population is stronger than that of the elderly[25, 26].

In contrast, a 22-year follow-up study in China showed that the risk of hypertension was increasing with age and BMI[27]. The possible reason is related to ethnic and physical differences.

The interaction between age and race showed that Other Hispanic had the highest prevalence of hypertension. However, Mexican Americans have the lowest risk of disease between 40–59 years of age and the second highest risk of disease risk of between 60–80 years. One reason for the high prevalence of other Hispanic may be the high birth rate. The large-scale population increase prevents them from getting better formal education and poor awareness of prevention. In addition, Hispanics have a high obesity rate and a relatively higher risk of developing hypertension. This may be related to their overall lower socioeconomic status. Studies in developed countries have shown that obesity was inversely proportional to socioeconomic status, and American Indian descent also played a part, especially among Mexicans[28]. Another reason for the rapid increase in the risk of high blood pressure for elderly Mexicans is the same as that of other Hispanics. Because the proportion of the population is growing rapidly[29], and Mexican Americans are traditionally known for their low awareness, treatment and control rates of hypertension[30–32], Putting them at high risk of cardiovascular disease morbidity and mortality. In addition, an analysis of Mexican Americans had shown that hypertension was significantly correlated with genetic variation associated with angiotensin converting enzyme (ACE) activity[33, 34].

The main advantage of this study was the use of a large, continuous, nationally representative survey. Secondly, the blood pressure value was the average of three measurements and results were more reliable. Finally, it was the first study on the effect of the interaction of gender, age, BMI and race on hypertension in the US population, this would help implement corresponding antihypertensive measures among men and women of different ages, BMIs and races. However, the findings in this report were subject to some limitations. First, notes on cross-sectional studies also applied to our findings, so causal inference cannot be made. Secondly, some research data depended on self-reported information, it may be affected by recall bias. If the information they provide was fallacious, it may lead to misclassification. For instance, when individuals who were taking anti-hypertensive medications but did not acknowledge taking medications to lower their blood pressure and BP was normal at the time of examination and this condition would be classified as normotensive. However, in the process of collecting data, professional staff tried to maximize the authenticity of data such as age, height, weight, and whether they suffered from hypertension. Finally, although we have controlled some key confounding factors-especially smoking, drinking and physical exercises, but we cannot rule out the possibility of unobserved confounding factors.

Conclusion

In conclusion, we found the association between overweight/obesity and the risk of hypertension varies according to the age and race of the population and age had a stronger effect on hypertension in women than in men. The provision of corresponding antihypertensive measures should take into account the difference in age, race or ethnicity in the American population, and strategies should be taken to improve the prevention of hypertension, especially among women. And it is necessary to conduct further

prospective research to explore the underlying mechanism of the association between gender, age, BMI, race and hypertension risk.

Abbreviations

BMI: body mass index; SBP: systolic blood pressure; DBP: diastolic blood pressure; AST: aspartate aminotransferase; ALT: alanine aminotransferase; GGT: gamma- glutamyl transferase; TG: triglyceride; FBG: fasting blood glucose; LDLC: low density lipoprotein cholesterol; HDLC: high density lipoprotein cholesterol; TC: total cholesterol

Declarations

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Availability of data and materials

The datasets used during the present study are available from the corresponding author upon reasonable request.

Authors’ contributions

ZZ drafted the manuscript and revised the manuscript strictly. EZ, SD and XK contribute to the idea or design of the work. WZ, BL, HL and AC have contributed to the acquisition, analysis or interpretation of work data. QW and GL conceived and designed the study, participated in paper revision. Everyone gave final approval and agreed to be responsible for all work to ensure completeness and accuracy.

Competing interests

The authors declared that they have no competing interests.

Consent for publication

Not Applicable.

Ethics approval and consent to participate

The Institutional Review Board of the National Center for Health Statistics approved the NHANES research protocol for the 2015–2016 survey years and obtained oral and written informed consent from all participants. And the study in accordance with the ethical guidelines of the 1975 Declaration of Helsinki.

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Table

Due to technical limitations, table 1 is only available as a download in the Supplemental Files section.

Figures

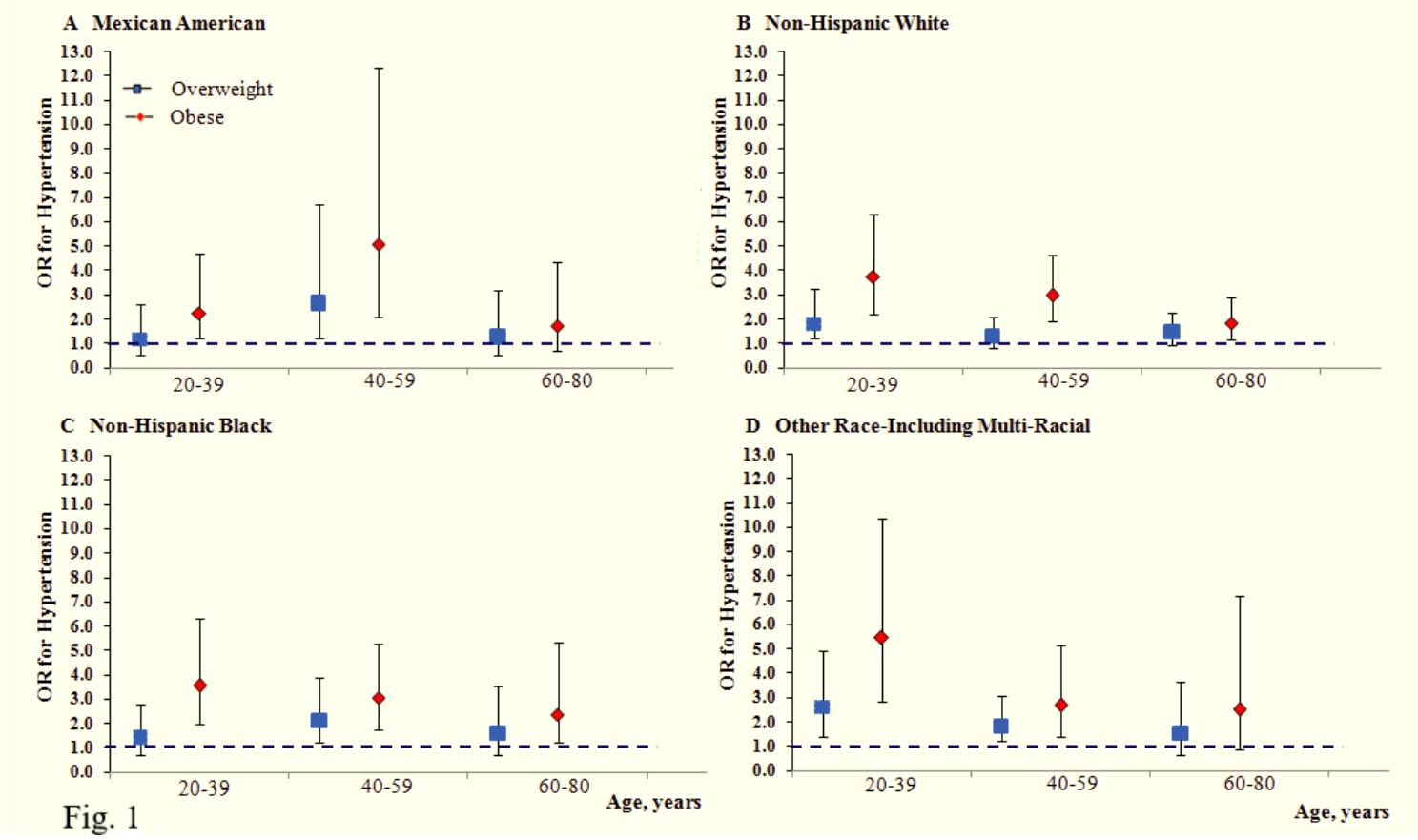

Figure 1

(A) Association between overweight /obesity and risk of hypertension in Mexican American by age group. (B) Association between overweight /obesity and risk of hypertension in Non-Hispanic White by age group. (C) Association between overweight /obesity and risk of hypertension in Non-Hispanic Black by age group. (D) Association between overweight /obesity and risk of hypertension in Other Race-Including Multi-Racial by age group.

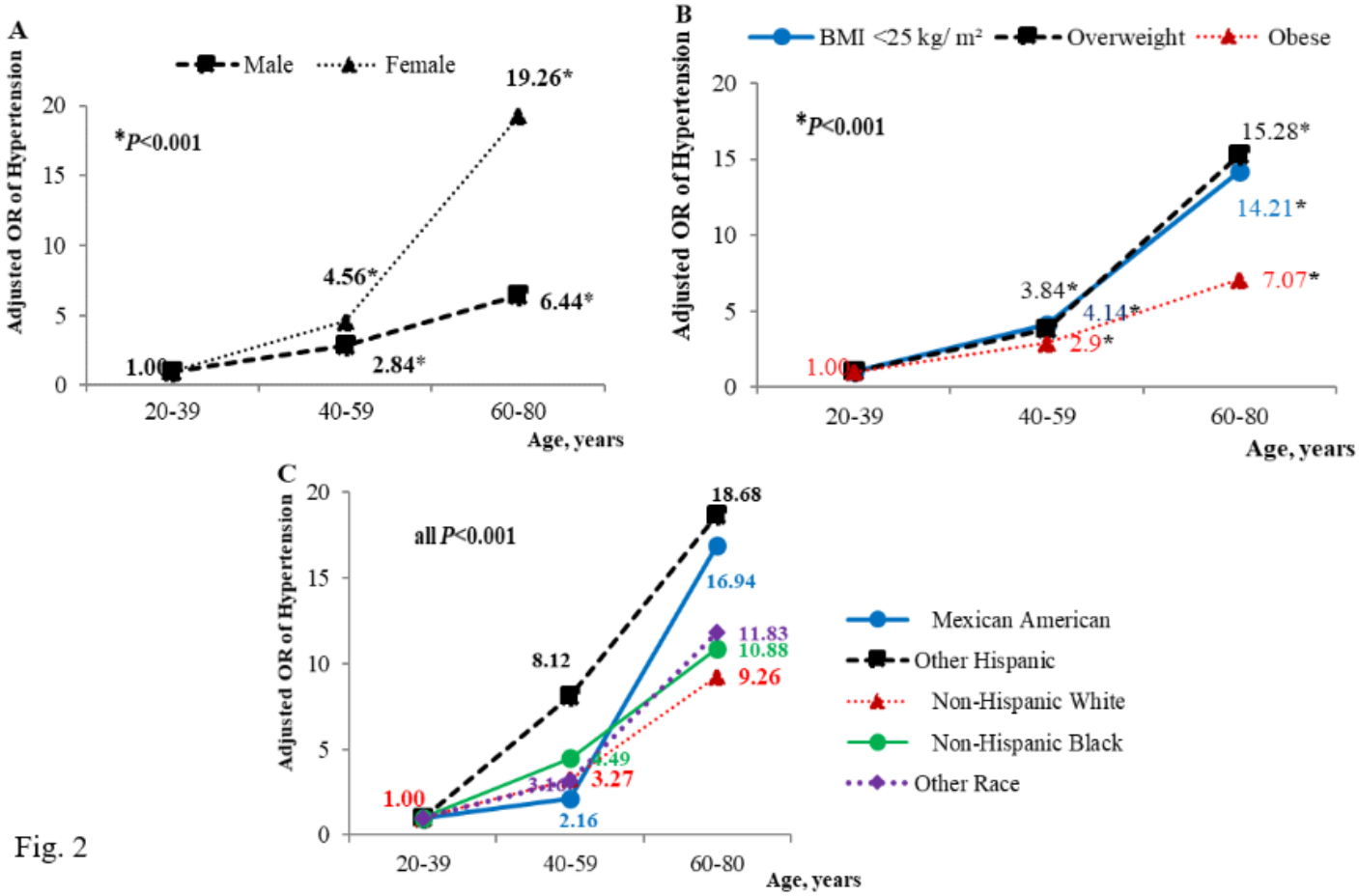

Figure 2

(A)Adjusted odds ratio of hypertension stratified by age for sex. (B) Adjusted odds ratio of hypertension stratified by age for BMI. (C) Adjusted odds ratio of hypertension stratified by age for race. Factors for adjustment were three continuous variables (AST, ALT and GGT) and seven categorical variables (race, education level, diabetes, dyslipidemia, smoking habit, alcohol consumption and physical activities).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx