



Association of Asian-specific BMI Categories with Age, Sex, and Elevated Blood Pressure among Opportunistically Screened Subjects in Punjab, India

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Received: 29 June 2026; Accepted: 15 July 2026

[Visual Abstract](#)

ABSTRACT

Introduction: Obesity/overweight has become an important public health issue. Obesity is a major contributor to noncommunicable diseases, especially among Indians. The present study evaluated the burden of BMI categories and their association with age, sex, and BP among adults screened during the May Measurement Month (MMM) initiative in Punjab using Asian BMI criteria.

Materials and methods: An observational study design implementing an opportunistic screening model was used to screen 24,685 adults aged 18–80 years during the MMM initiative in Punjab. Subjects were categorized according to Asian BMI criteria. Associations of BMI categories with age, sex, and elevated BP (≥ 140 mm Hg systolic and/or ≥ 90 mm Hg diastolic) were analyzed using Chi-square tests, multivariable logistic regression, modified Poisson regression, and multinomial logistic regression.

Results: The present study showed that 6.2% of subjects were underweight, 25.6% had normal BMI, 17.1% were overweight, and 51.1% were obese using Asian BMI criteria; 68.2% had BMI ≥ 23 kg/m². Obesity was more prevalent in the 18–60-year age group than in the 61–80-year age group (52.9% vs 44.2%, $p < 0.001$), among males compared with females (55.9% vs 45.8%, $p < 0.001$), and among subjects with elevated BP compared with normal BP (60.0% vs 46.8%, $p < 0.001$). Multivariable analyses demonstrated independent associations of obesity with male sex (adjusted OR 1.59, 95% CI 1.51–1.67) and elevated BP (adjusted OR 1.49, 95% CI 1.40–1.58), while the older age group of 61–80 years was associated with lower odds of obesity (adjusted OR 0.75, 95% CI 0.70–0.81). The low values of Nagelkerke R² analysis show that only a small part of BMI categories are influenced by variables like age, sex, and BP because obesity has a multifactorial pathophysiology influenced by several factors not included in the present study.

Conclusion: A substantial burden of excess BMI was observed among subjects screened in Punjab. Obesity was strongly associated with younger age, male sex, and elevated BP, underscoring the need for integrated obesity and hypertension prevention strategies.

Keywords: Asian BMI categories, Body mass index, Elevated BP, Obesity, Punjab.

Journal of The Association of Physicians of India (2026); 10.59556/japi.74.1692

INTRODUCTION

Globally, overweight and obesity are becoming major public health issues because of increased morbidity and mortality linked to the increased prevalence of noncommunicable diseases (NCDs) such as hypertension (HTN), diabetes, dyslipidemia, and cardiovascular diseases (CVDs). South Asian populations, including India, face increased metabolic risk at lower levels of adiposity compared to Western populations; that is why Asian-specific BMI cutoffs were recommended for risk stratification in South Asian populations. The Asian-specific BMI cutoffs define a BMI of < 18.5 kg/m² as underweight, 18.5–22.9 kg/m² as normal weight, 23.0–24.9 kg/m² as overweight, and ≥ 25.0 kg/m² as obesity.^{1,2} The WHO BMI classification defines a BMI of < 18.5 kg/m² as underweight, 18.5–24.9

kg/m² as normal weight, 25–29.9 kg/m² as overweight, and ≥ 30.0 kg/m² as obesity.¹ Data from the National Family Health Survey (NFHS) show a substantial increase in excess body weight over the last decade. Data from NFHS-5 (2019–2021) among the 15–49-year age group show a 22.6% prevalence of overweight/obesity in India, including about 23.0% prevalence of overweight/obesity in women and 22.1% in men.³ NFHS used the standard WHO BMI classification. Recent data from NFHS-6 show that the burden of overweight/obesity in India has increased to about 29.0%, including 30.7% in women and 27.3% in men aged 15–49 years.⁴

Punjab has consistently shown the highest burden of overweight/obesity compared with other states. NFHS-5 data observed about 36.6% prevalence of

overweight/obesity in Punjab, including 40.8% burden of overweight/obesity among women and 32.3% among men, whereas recent NFHS-6 data showed an increase in the burden of overweight/obesity to about 41.1%, including 44.7% among women and 37.5% among men in Punjab.^{3,4} Data from Punjab show a higher burden of overweight/obesity compared with the Indian national average. The high burden of obesity is especially important for Punjab because clustering of risk factors increases the risk of CVDs and metabolic diseases. The ICMR-INDIAB national cross-sectional study, including 113,043 subjects aged 20 years and older, observed a 28.6% weighted prevalence of generalized obesity using Asian BMI cutoffs.^{5,6}

The present study was conducted to assess the burden of BMI categories and their association with age, sex, and BP among subjects screened opportunistically in Punjab during the MMM initiative. It is important to note that the present study used Asian-specific BMI cutoffs to categorize BMI, whereas NFHS-5, NFHS-6, and many other studies used conventional WHO

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How to cite this article: Brar MS, Gupta M, Gupta VK, et al. Association of Asian-specific BMI Categories with Age, Sex, and Elevated Blood Pressure among Opportunistically Screened Subjects in Punjab, India. *J Assoc Physicians India* 2026;74(10):16–22.

BMI categories for the general population. Adopting Asian BMI cutoffs for the present study is a methodological strength for estimating the actual burden of overweight/obesity as a cardiometabolic risk in Asian Indians and helps capture data on excess adiposity in Punjab.

AIMS AND OBJECTIVES

To study the association of Asian-specific BMI categories with age, sex, and elevated blood pressure among opportunistically screened subjects in Punjab, India.

MATERIALS AND METHODS

Participants and Study Design

The present study adopted an observational study design implementing an opportunistic screening model as part of the May Measurement Month (MMM) initiative, a worldwide blood pressure (BP) screening initiative by the International Society of Hypertension (ISH) and Indian Society of Hypertension (InSH). The screening initiative was conducted in 2017–2019, 2021, and 2024. The opportunistic screening model involved various screening centers and settings such as hospitals, community health care centers, general health checkups, and outreach camps, and used a walk-in recruitment method to reduce the possibility of selection bias from enrolling only health-conscious, aware, or symptomatic subjects. The MMM initiative was mainly carried out in May and sometimes extended into June or July. Institutional Ethics Committee approval was granted vide letter no. 2/2017/3.4.2017. The ethics committee approved verbal informed consent because the MMM screening initiative included an anonymous screening protocol recording only nonidentifiable variables such as age, sex, BMI, and BP, with a focus on anonymization and data security. The present study is aligned with the STROBE guidelines for observational studies. After obtaining verbal informed consent, subjects aged 18–80 years were recruited via convenience sampling. Information about other variables such as region, urban vs rural residence, socioeconomic profile, diet, salt intake, physical activity, alcohol/tobacco use, diabetes/lipid profile, and medication use was not recorded as part of the MMM initiative and therefore was not available for data analysis.

Body Mass Index

Body mass index (BMI) was calculated using the standard formula: weight (kg)/height (m)². Asian-specific BMI cutoffs were used to categorize BMI: <18.5 kg/m² as underweight, 18.5–22.9 kg/m² as

normal weight, 23.0–24.9 kg/m² as overweight, and ≥25 kg/m² as obesity.^{1,2}

For analysis, BMI was divided into two groups: BMI ≥23 kg/m² (overweight/obese) and BMI <23 kg/m² (underweight/normal).

Blood Pressure Measurement

Blood pressure (BP) was measured adopting standard protocols. Omron provided validated and calibrated automated oscillometric BP devices for the present study. Appropriate cuff sizes were used, including standard adult (mid-arm 22–32 cm) and large adult (32–42 cm) cuffs. BP was preferably recorded from the left arm after 5 minutes of rest. Subjects were seated comfortably with back support and both feet flat on the ground. Three BP readings were taken 1 minute apart, and the mean of the second and third readings was used for data analysis.

Definition of Hypertension

Hypertension (HTN) was defined according to the Indian guidelines on hypertension-IV (2019). HTN was diagnosed when BP was ≥140 mm Hg systolic and/or >90 mm Hg diastolic. Systolic HTN (SHTN) was defined as systolic BP (SBP) ≥140 mm Hg, and diastolic HTN (DHTN) as diastolic BP (DBP) ≥90 mm Hg.⁷

Since a single occasion measurement of BP and even the mean of second and third BP readings is not considered sufficient to make a clinically confirmed diagnosis of HTN. Therefore, in the present study, the categorization of recorded BP among screened subjects was labeled as elevated BP (>140 mm Hg systolic and/or >90 mm Hg diastolic), normal BP (<140/90 mm Hg), systolic HTN (>140 mm Hg), and diastolic HTN (>90 mm Hg), rather than as a confirmed diagnosis of HTN. A confirmed clinical diagnosis of HTN requires confirmation of elevated BP on repeated office BP measurements or by ambulatory/home blood pressure monitoring.⁷ Therefore, the present study presents BP data as the burden or prevalence of elevated BP rather than a confirmed diagnosis of HTN in the population.

Statistical Analysis

Data were analyzed using standard statistical methods. BMI was categorized according to Asian BMI cutoffs, and associations with variables such as age group, sex, and BP group were assessed using the Chi-square test. Multivariable logistic regression was used to estimate crude odds ratios (ORs), adjusted ORs, and adjusted prevalence ratios (APRs) with 95% confidence intervals, with BMI categories as the dependent

variables. Model performance was assessed using the Nagelkerke R² statistic, and multicollinearity among predictor variables was evaluated.

RESULTS

Table 1 shows the baseline characteristics of 24,685 subjects: 79.5% (19,628) were aged 18–60 years, and 20.5% (5,057) were aged 61–80 years; 52.6% (12,996) were males and 47.4% (11,689) were females. According to BP status, 21.5% (5,307) had normal BP (<140/90 mm Hg), whereas 32.5% (8,029) had elevated BP (≥140 mm Hg systolic and/or ≥90 mm Hg diastolic), 24.9% (6,158) had SHTN (>140 mm Hg), and 22.2% (5,483) had DHTN (>90 mm Hg). According to BMI categories, 31.8% (7,840) had underweight/normal BMI of <23 kg/m² and 68.2% (16,845) had overweight/obese BMI of ≥23 kg/m², including 6.2% (1,516) who were underweight (<18.5 kg/m²), 25.6% (6,324) who had normal BMI (18.5–22.9 kg/m²), 17.1% (4,229) who were overweight (23–24.9 kg/m²), and 51.1% (12,616) who were obese (≥25 kg/m²).

Table 2 shows the burden of BMI across categories and their association with age, sex, and BP. Among the total study population, 6.2% (1,516) were underweight, 25.6% (6,324) were normal weight, 17.1% (4,229) were overweight, and 51.1% (12,616) were obese. In the 18–60-year age group, 5.3% (1,048)

Table 1: Baseline characteristics of the study population according to blood pressure, age group, sex, and body mass index

Characteristic	% (n)
Study population (N = 24,685)	
Blood pressure	
BP <140/90	67.5 (16,656)
BP >140 and/or >90	32.5 (8,029)
SBP >140	24.9 (6,158)
DBP >90	22.2 (5,483)
Age group	
18–60 years	79.5 (19,628)
61–80 years	20.5 (5,057)
Sex	
Male	52.6 (12,996)
Female	47.4 (11,689)
BMI	
<23 kg/m ²	31.8 (7,840)
<18.5 kg/m ²	6.1 (1,516)
18.5–22.9 kg/m ²	25.6 (6,324)
≥23 kg/m ²	68.2 (16,845)
23–24.9 kg/m ²	17.1 (4,229)
≥25 kg/m ²	51.1 (12,616)

BP, blood pressure; BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure

Table 2: Distribution of BMI categories and their association with age group, sex, and blood pressure

Characteristic variables	BMI <18.5 kg/m ² , % (n)	BMI 18.5–22.9 kg/m ² , % (n)	BMI 23–24.9 kg/m ² , % (n)	BMI ≥25 kg/m ² , % (n)
Total burden (N = 24,685)	6.1 (1,516)	25.6 (6,324)	17.1 (4,229)	51.1 (12,616)
Age groups				
18–60 years (n = 19,628)	5.3 (1,048)	24.1 (4,734)	17.7 (3,465)	52.9 (10,381)
61–80 years (n = 5,057)	9.3 (468)	31.4 (1,590)	15.1 (764)	44.2 (2,235)
p-value	p < 0.001 (S)	p < 0.001 (S)	p < 0.001 (S)	p < 0.001 (S)
95% CI	5.8–6.4	25.1–26.2	16.7–17.6	50.5–51.7
Sex				
Male (n = 12,996)	4.8 (630)	21.1 (2,736)	18.2 (2,368)	55.9 (7,262)
Female (n = 11,689)	7.6 (886)	30.7 (3,588)	15.9 (1,861)	45.8 (5,354)
p-value	p < 0.001 (S)	p < 0.001 (S)	p < 0.001 (S)	p < 0.001 (S)
95% CI	5.8–6.4	25.1–26.2	16.7–17.6	50.0–51.7
Blood pressure				
BP <140/90 (n = 16,656)	7.2 (1,191)	28.6 (4,764)	17.4 (2,905)	46.8 (7,796)
BP >140 and/or >90 (n = 8,029)	4.0 (325)	19.4 (1,560)	16.5 (1,324)	60.0 (4,820)
p-value	p < 0.001 (S)	p < 0.001 (S)	p < 0.001 (S)	p < 0.001 (S)
95% CI	3.62–4.48	18.56–20.30	15.68–17.30	58.96–61.10

BMI, body mass index; BP, blood pressure; CI, confidence interval; S, statistically significant

Table 3: Distribution of subjects with BMI <23 kg/m² and ≥23 kg/m² according to age group, sex, and blood pressure

Characteristic variables	BMI <23 kg/m ² (underweight/normal BMI), % (n)	BMI ≥23 kg/m ² (overweight/obese BMI), % (n)
Total burden (N = 24,685)	31.8 (7,840)	68.2 (16,845)
Age groups		
18–60 years (n = 19,628)	29.5 (5,783)	70.5 (13,845)
61–80 years (n = 5,057)	40.7 (2,057)	59.3 (3,000)
p-value	p < 0.001 (S)	p < 0.001 (S)
95% CI	31.2–32.3	67.7–68.8
Sex		
Male (n = 12,996)	25.9 (3,366)	74.1 (9,630)
Female (n = 11,689)	38.3 (4,474)	61.7 (7,215)
p-value	p < 0.001 (S)	p < 0.001 (S)
95% CI	25.1–26.7	73.3–74.9
Blood pressure		
BP <140/90 (n = 16,656)	35.8 (5,955)	64.2 (10,701)
BP >140 and/or >90 (n = 8,029)	23.5 (1,885)	76.5 (6,144)
p-value	p < 0.001 (S)	p < 0.001 (S)
95% CI	22.6–24.4	75.6–77.4
Systolic blood pressure		
BP <140 (n = 18,527)	34.3 (6,354)	65.7 (12,173)
BP >140 (n = 6,158)	24.1 (1,486)	75.9 (4,672)
p-value	p < 0.001 (S)	p < 0.001 (S)
95% CI	23.1–25.2	74.8–76.9
Diastolic blood pressure		
BP <90 (n = 19,202)	33.5 (6,437)	66.5 (12,765)
BP >90 (n = 5,483)	25.6 (1,403)	74.4 (4,080)
p-value	p < 0.001 (S)	p < 0.001 (S)
95% CI	24.4–26.7	73.3–75.6

BMI, body mass index; BP, blood pressure; CI, confidence interval; S, statistically significant

were underweight, 24.1% (4,734) were normal weight, 17.7% (3,465) were overweight, and 52.9% (10,381) were obese. In the 61–80-year age group, 9.3% (468) were underweight, 31.4% (1,590) were normal weight, 15.1% (764) were overweight, and 44.2% (2,235) were

obese. The table shows a higher burden of underweight and a lower burden of obesity in the older age group, whereas overweight and obesity were more common in the younger age group; this difference was statistically significant ($p < 0.001$).

Results show that 4.9% (630) of males were underweight, 21.1% (2,736) were normal weight, 18.2% (2,368) were overweight, and 55.9% (7,262) were obese. Among females, 7.6% (886) were underweight, 30.7% (3,588) were normal weight, 15.9% (1,861) were overweight, and 45.8% (5,354) were obese. Overweight and obesity were more frequent among men, whereas underweight and normal weight were more common among women; this difference was statistically significant ($p < 0.001$).

Among subjects with normal BP, 7.2% (1,191) were underweight, 28.6% (4,764) were normal weight, 17.4% (2,905) were overweight, and 46.8% (7,796) were obese. Among subjects with elevated BP, 4.1% (325) were underweight, 19.4% (1,560) were normal weight, 16.5% (1,324) were overweight, and 60.0% (4,820) were obese. Obesity was more common in the elevated BP group than in the normal BP group, and the distribution of BMI categories differed significantly by BP status ($p < 0.001$).

Table 3 shows the association of two BMI groups—underweight/normal weight (<23 kg/m²) and overweight/obese (≥23 kg/m²)—with age, sex, and BP groups. Among all subjects, 31.8% (7,840) were underweight/normal weight, whereas 68.2% (16,845) were overweight/obese. In the 18–60-year age group, 29.5% (5,783) were underweight/normal weight and

Table 4: Distribution of BMI categories according to age groups

Age group	BMI <18.5 kg/m ² (underweight), % (n)	BMI 18.5–22.9 kg/m ² (normal), % (n)	BMI 23–24.9 kg/m ² (overweight), % (n)	BMI ≥25 kg/m ² (obese), % (n)
18–30 years	8.4 (509)	26.1 (1,579)	17.5 (1,055)	48.0 (2,905)
31–40 years	4.1 (228)	20.0 (1,112)	18.1 (1,006)	57.8 (3,208)
41–50 years	3.8 (200)	22.4 (1,175)	18.0 (943)	55.8 (2,916)
51–60 years	6.1 (270)	29.1 (1,308)	16.1 (725)	48.7 (2,189)
61–70 years	8.2 (199)	30.2 (730)	15.5 (376)	46.1 (1,117)
71–80 years	11.9 (111)	34.8 (325)	14.1 (131)	39.2 (368)

BMI, body mass index

Table 5: Multivariable logistic regression and modified Poisson regression analyses of age, sex, and blood pressure associated with BMI categories

Variable	Comparison	Crude OR (CI)	Adjusted OR (CI)	APR (CI)	p-value (OR)	p-value (APR)
BMI ≥25 kg/m ² (obesity)						
Age group	61–80 vs 18–60	0.71 (0.66–0.76)	0.75 (0.70–0.81)	0.85 (0.80–0.90)	p < 0.001 (S)	p < 0.001 (S)
Sex	Male vs female	1.50 (1.42–1.58)	1.59 (1.51–1.67)	1.23 (1.19–1.28)	p < 0.001 (S)	p < 0.001 (S)
BP	>140 and/or >90 vs <140/90	1.71 (1.62–1.81)	1.49 (1.40–1.58)	1.20 (1.15–1.25)	p < 0.001 (S)	p < 0.001 (S)
BMI 23–24.9 kg/m ² (overweight)						
Age group	61–80 vs 18–60	0.83 (0.76–0.90)	0.89 (0.81–0.97)	0.92 (0.86–0.98)	p = 0.009 (S)	p = 0.012 (S)
Sex	Male vs female	1.18 (1.10–1.26)	1.14 (1.06–1.22)	1.08 (1.02–1.14)	p < 0.001 (S)	p = 0.003 (S)
BP	>140 and/or >90 vs <140/90	0.93 (0.87–1.00)	0.98 (0.91–1.06)	0.99 (0.93–1.05)	p = 0.612 (N)	p = 0.720 (N)
BMI 18.5–22.9 kg/m ² (normal weight)						
Age group	61–80 vs 18–60	1.45 (1.35–1.55)	1.38 (1.29–1.48)	1.21 (1.15–1.27)	p < 0.001 (S)	p < 0.001 (S)
Sex	Male vs female	0.60 (0.57–0.64)	0.56 (0.53–0.60)	0.69 (0.65–0.72)	p < 0.001 (S)	p < 0.001 (S)
BP	>140 and/or >90 vs <140/90	0.60 (0.57–0.64)	0.66 (0.62–0.71)	0.75 (0.71–0.79)	p < 0.001 (S)	p < 0.001 (S)
BMI <18.5 kg/m ² (underweight)						
Age group	61–80 vs 18–60	1.82 (1.62–2.04)	1.67 (1.48–1.88)	1.41 (1.27–1.56)	p < 0.001 (S)	p < 0.001 (S)
Sex	Male vs female	0.62 (0.56–0.69)	0.58 (0.52–0.65)	0.64 (0.58–0.71)	p < 0.001 (S)	p < 0.001 (S)
BP	>140 and/or >90 vs <140/90	0.55 (0.49–0.62)	0.61 (0.54–0.69)	0.69 (0.61–0.77)	p < 0.001 (S)	p < 0.001 (S)

APR, adjusted prevalence ratio; BMI, body mass index; BP, blood pressure; CI, confidence interval; N, statistically nonsignificant; OR, odds ratio; S, statistically significant

70.5% (13,845) were overweight/obese. In the 61–80-year age group, 40.7% (2,057) were underweight/normal weight and 59.3% (3,000) were overweight/obese. Overweight/obesity was more common in the younger age group, whereas underweight/normal weight was relatively more common among older subjects; this difference was statistically significant ($p < 0.001$). Association of BMI categories with males and females shows that 25.9% (3,366) of males were underweight/normal weight and 74.1% (9,630) were overweight/obese. Whereas 38.3% (4,474) of females were underweight/normal weight and 61.7% (7,215) were overweight/obese. Males had a higher burden of overweight/obesity than females; this difference was statistically significant ($p < 0.001$). In the normal BP group, 35.8% (5,955) were underweight/normal weight and 64.2% (10,701) were overweight/obese,

whereas in the elevated BP group, 23.5% (1,885) were underweight/normal weight and 76.5% (6,144) were overweight/obese. Similarly, in the normal systolic BP group, 34.3% (6,354) were underweight/normal weight and 65.7% (12,173) were overweight/obese, whereas in the systolic HTN group, 24.1% (1,486) were underweight/normal weight and 75.9% (4,672) were overweight/obese. In the normal diastolic BP group, 33.5% (6,437) were underweight/normal weight and 66.5% (12,765) were overweight/obese, whereas in the diastolic HTN group, 25.6% (1,403) were underweight/normal weight and 74.4% (4,080) were overweight/obese. Results show a positive association between higher BMI and elevated BP, including systolic and diastolic BP; these differences were statistically significant ($p < 0.001$).

Table 4 shows the burden of BMI categories across age groups. Among

subjects in the 18–30-year age group, 8.4% (509) were underweight, 26.1% (1,579) were normal weight, 17.5% (1,055) were overweight, and 48.0% (2,905) were obese. In the 31–40-year age group, 4.1% (228) were underweight, 20.0% (1,112) were normal weight, 18.1% (1,006) were overweight, and 57.8% (3,208) were obese. In the 41–50-year age group, 3.8% (200) were underweight, 22.4% (1,175) were normal weight, 18.0% (943) were overweight, and 55.8% (2,916) were obese. In the 51–60-year age group, 6.1% (270) were underweight, 29.1% (1,308) were normal weight, 16.1% (725) were overweight, and 48.7% (2,189) were obese. In the 61–70-year age group, 8.2% (199) were underweight, 30.2% (730) were normal weight, 15.5% (376) were overweight, and 46.1% (1,117) were obese. In the 71–80-year age group, 11.9% (111) were underweight, 34.8% (325) were normal weight, 14.1% (131) were overweight, and 39.2% (368) were

Table 6: Multinomial logistic regression analysis for obesity and overweight among characteristic variables using normal BMI as the reference category

Variable	Overweight RRR (95% CI)	Obesity RRR (95% CI)	p-value
Age 61–80 years	0.65 (0.58–0.72)	0.54 (0.49–0.60)	$p < 0.001$ (S)
Male sex	2.03 (1.87–2.21)	2.84 (2.64–3.06)	$p < 0.001$ (S)
Elevated BP	1.41 (1.29–1.54)	2.25 (2.09–2.42)	$p < 0.001$ (S)

Normal BMI, <23 kg/m²; overweight BMI, 23–24.9 kg/m²; obesity, ≥ 25 kg/m²; BMI, body mass index; BP, blood pressure; CI, confidence interval; RRR, relative risk ratio; S, statistically significant

Table 7: Nagelkerke R² values for the logistic regression models across BMI categories

Model	Nagelkerke R ²
BMI ≥ 25 kg/m ² (obese)	0.055–0.065
BMI 23–24.9 kg/m ² (overweight)	0.012–0.020
BMI 18.5–22.9 kg/m ² (normal)	0.045–0.055
BMI <18.5 kg/m ² (underweight)	0.018–0.030

obese. Results show a progressive rise in BMI within the age groups with a modest decline in the overweight BMI group. On the other hand, the burden of obesity was higher among younger age groups as compared to older age groups.

Table 5 shows multivariable logistic regression and modified Poisson regression analyses of age, sex, and BP groups associated with BMI categories.

In the obese group, subjects aged 61–80 years had a crude OR of 0.71 (95% CI: 0.66–0.76), an adjusted OR of 0.75 (95% CI: 0.70–0.81), and an APR of 0.85 (95% CI: 0.80–0.90) compared with those aged 18–60 years. Males had a crude OR of 1.50 (95% CI: 1.42–1.58), an adjusted OR of 1.59 (95% CI: 1.51–1.67), and an APR of 1.23 (95% CI: 1.19–1.28) compared with females. The elevated BP group had a crude OR of 1.71 (95% CI: 1.62–1.81), an adjusted OR of 1.49 (95% CI: 1.40–1.58), and an APR of 1.20 (95% CI: 1.15–1.25) compared with the normal BP group. These results suggest that obesity was significantly associated with male sex, elevated BP, and younger age.

In the overweight group, subjects aged 61–80 years had a crude OR of 0.83 (95% CI: 0.76–0.90), an adjusted OR of 0.89 (95% CI: 0.81–0.97), and an APR of 0.92 (95% CI: 0.86–0.98) compared with those aged 18–60 years. Males had a crude OR of 1.18 (95% CI: 1.10–1.26), an adjusted OR of 1.14 (95% CI: 1.06–1.22), and an APR of 1.08 (95% CI: 1.02–1.14) compared with females. The elevated BP group had a crude OR of 0.93 (95% CI: 0.87–1.00), an adjusted OR of 0.98 (95% CI: 0.91–1.06), and an APR of 0.99 (95% CI: 0.93–1.05) compared with the normal BP group. Results suggest no strong independent association

Table 8: Variance inflation factor (VIF) values for age group, sex, and blood pressure

Variable	VIF
Age group	1.08
Sex	1.03
Blood pressure	1.09

between elevated BP and the overweight BMI category after adjustment.

In the normal-weight group, subjects aged 61–80 years had a crude OR of 1.45 (95% CI: 1.35–1.55), an adjusted OR of 1.38 (95% CI: 1.29–1.48), and an APR of 1.21 (95% CI: 1.15–1.27) compared with those aged 18–60 years. Males had a crude OR of 0.60 (95% CI: 0.57–0.64), an adjusted OR of 0.56 (95% CI: 0.53–0.60), and an APR of 0.69 (95% CI: 0.65–0.72) compared with females. The elevated BP group had a crude OR of 0.60 (95% CI: 0.57–0.64), an adjusted OR of 0.66 (95% CI: 0.62–0.71), and an APR of 0.75 (95% CI: 0.71–0.79) compared with the normal BP group. Results suggest that older age was associated with this BMI category, while males and the elevated BP group were less likely to be in the normal-weight range.

In the underweight group, subjects aged 61–80 years had a crude OR of 1.82 (95% CI: 1.62–2.04), an adjusted OR of 1.67 (95% CI: 1.48–1.88), and an APR of 1.41 (95% CI: 1.27–1.56) compared with those aged 18–60 years. Males had a crude OR of 0.62 (95% CI: 0.56–0.69), an adjusted OR of 0.58 (95% CI: 0.52–0.65), and an APR of 0.64 (95% CI: 0.58–0.71) compared with females. The elevated BP group had a crude OR of 0.55 (95% CI: 0.49–0.62), an adjusted OR of 0.61 (95% CI: 0.54–0.69), and an APR of 0.69 (95% CI: 0.61–0.77) compared with the normal BP group. Results suggest that underweight BMI was more likely in the older age group but less likely among males and subjects with elevated BP.

Table 6 shows multinomial logistic regression for the obesity and overweight groups using normal BMI as the reference category. Subjects aged 61–80 years had a lower relative risk ratio (RRR) for overweight (RRR 0.65, 95% CI: 0.58–0.72) and obesity (RRR 0.54, 95% CI: 0.49–0.60). Males had substantially

higher relative risks of overweight (RRR 2.03, 95% CI: 1.87–2.21) and obesity (RRR 2.84, 95% CI: 2.64–3.06). The elevated BP group also had higher relative risks of overweight (RRR 1.41, 95% CI: 1.29–1.54) and obesity (RRR 2.25, 95% CI: 2.09–2.42). Results suggest a clear graded relationship between male sex, elevated BP, and higher BMI categories, with the strongest association observed in the obesity group.

Overall, the results of the present study suggest a high burden of obesity in the study population, with strong associations with male sex, elevated BP, and younger age groups (18–60 years), whereas the older age group (61–80 years) showed a higher burden of underweight BMI. The adjusted models show that higher BMI and elevated BP cluster together, suggesting a strong cardiometabolic association in the study population.

Table 7 shows Nagelkerke R² values for the logistic regression models across BMI categories. The low values across all models indicate that only a modest proportion of the variation in BMI category was explained by the included variables of age, sex, and BP. The model for the obese group showed the highest explanatory power, with Nagelkerke R² values of 0.055–0.065, indicating that age, sex, and BP together explained about 5.5%–6.5% of the variation in the obese group. The model for the normal-weight group showed slightly lower R² values of 0.045–0.055, indicating that the variables explained about 4.5%–5.5% of the variation in this group. The model for the underweight group showed low explanatory power, with R² values of 0.018–0.030, suggesting that this group was largely determined by variables not included in the study. The model for the overweight group showed the weakest fit, with R² values of only 0.012–0.020, indicating that the model explained 1.2%–2.0% of the variation in this group. Analysis of the Nagelkerke R² values indicates that although age, sex, and BP were predictors in the models, they had limited ability to explain variation across BMI groups. Other unmeasured variables such as region, socioeconomic status, diet, physical activity, comorbidities, and lifestyle factors may play an important role in determining BMI category.

Table 8 shows the variance inflation factor (VIF) values for the variables included in the model. All values were close to 1, including 1.08 for age group, 1.03 for sex, and 1.09 for BP, indicating negligible multicollinearity. Generally, VIF values below five are considered acceptable, and values near one indicate almost no overlap among variables. These results suggest that the independent variables are not strongly correlated with one another, supporting

the stability and reliability of the regression coefficients. The low VIF values support the inclusion of age, sex, and blood pressure together in the analysis.

Discussion

The results of the present study showed that, by Asian BMI criteria, 31.8% were underweight/normal weight and 68.2% were overweight/obese. Overall, 6.2% were underweight, 25.6% were normal weight, 17.1% were overweight, and 51.1% were obese, suggesting a very high burden of overweight/obesity among subjects screened in Punjab. This burden was substantially higher than the 22.6% reported in NFHS-5 and 29.0% reported in NFHS-6 data.^{4,5} Even the Punjab-specific NFHS-5 and NFHS-6 data showed overweight/obesity burdens of 36.6% and 41.1%, respectively, which were substantially lower than those documented in the present study.^{4,5} The higher burden in the present study may be explained by the use of Asian-specific BMI criteria, whereas NFHS used WHO criteria.

The results of the present study showed a noteworthy relationship between BMI and age. Obesity was observed in 52.9% of subjects aged 18–60 years compared with 44.2% of those aged 61–80 years, and the difference was statistically significant. The proportion of underweight subjects increased from 5.3% in the 18–60-year group to 9.3% in the 61–80-year group. Among subjects aged 18–60 years, 29.5% were in the underweight/normal BMI category, and 70.5% were in the overweight/obesity category; among those aged 61–80 years, 40.7% were in the underweight/normal BMI category, and 59.3% were in the overweight/obesity category. The difference was statistically significant in both BMI categories. Obesity was more common in younger age groups than in older age groups, whereas underweight became more common with age. Multivariable analysis suggested that the older age group, compared with the younger age group, had lower odds of obesity (adjusted OR 0.75, 95% CI: 0.70–0.81) and overweight (adjusted OR 0.89, 95% CI: 0.81–0.97), but higher odds of underweight (adjusted OR 1.67, 95% CI: 1.48–1.88) and normal BMI (adjusted OR 1.38, 95% CI: 1.29–1.48). Multinomial logistic regression analysis suggested that the 61–80-year age group had a lower RRR for overweight (0.65, 95% CI: 0.58–0.72, $p < 0.001$) and obesity (0.54, 95% CI: 0.49–0.60, $p < 0.001$), with normal BMI as the reference category. The higher burden of overweight/obesity in the younger age group and underweight/normal weight in the older age group may be explained by reduced

appetite, comorbidities, chronic illness, and sarcopenia in older subjects.⁸ NFHS-5 and NFHS-6 data generally show a rising burden of obesity from younger to middle-aged adults, possibly because these surveys included only subjects aged 15–49 years, whereas the present study included subjects aged 18–80 years; this difference may help explain the decline in overweight/obesity in the older age group.^{4,5}

The present study observed a significantly higher burden of overweight/obesity among males than females (74.1% vs 61.7%), in contrast to nationally representative data from NFHS-5 (22.1% vs 23.0%) and NFHS-6 (27.3% vs 30.7%), which^{4,5} consistently showed a lower prevalence of overweight/obesity among males as compared to females. Similarly, a lower prevalence of overweight/obesity among males as compared to females was observed in Punjab-specific data from NFHS-5 (32.3% vs 40.8%) and NFHS-6 (37.5% vs 44.7%).^{4,5} The observation in the present study aligns with observations from the ICMR-INDIAB-23 study reporting a higher prevalence of the metabolically obese non-obese (MONO) phenotype in males as compared to females (44.7% vs 43.1%), whereas the ICMR-INDIAB-23 study reported a lower prevalence of overall BMI-based obesity among males.^{5,6} Multivariable logistic regression analysis showed that males had 1.14 times higher odds of being overweight (adjusted OR: 1.14; 95% CI: 1.06–1.22; $p < 0.001$) and 1.59 times higher odds of being obese (adjusted OR: 1.59; 95% CI: 1.51–1.67; $p < 0.001$) compared with females. The analysis also showed lower odds of normal weight (adjusted OR 0.56) and underweight (adjusted OR 0.58) among males compared with females. Multinomial logistic regression analysis suggested that males had a higher RRR for overweight (RRR: 2.03, 95% CI: 1.87–2.21, $p < 0.001$) and obesity (RRR: 2.84, 95% CI: 2.64–3.06, $p < 0.001$), with normal BMI as the reference category. The male predominance of overweight/obesity in the present study may be influenced by several factors not considered in the study, such as dietary habits, alcohol intake, sedentary lifestyle, occupational factors, urban/rural patterns, and other health-risk behaviors.^{8,9} Moreover, the present study included subjects aged 18–80 years and used Asian BMI criteria, whereas NFHS data included subjects aged 15–49 years and used WHO BMI criteria; these differences may have influenced the male predominance in the overweight/obesity groups in Punjab. The present observations underscore the importance of regional sex-specific data on BMI categories.

Among subjects with elevated BP, 60.0% were obese, 4.1% were underweight, 19.4% were normal weight, and 16.5%

were overweight. Among subjects with normal BP, 46.8% were obese, 7.2% were underweight, 28.6% were normal weight, and 17.4% were overweight; the distribution differed significantly by BP status ($p < 0.001$). Results showed a strong and independent association between the obesity BMI category and elevated BP, whereas the overweight BMI category did not show a significant association. In the multivariable logistic regression analysis, subjects with elevated BP had 1.49 times higher odds of being obese than those with normal BP (adjusted OR: 1.49, 95% CI: 1.40–1.58, $p < 0.001$). For the overweight BMI category, the adjusted OR was 0.98 (95% CI: 0.91–1.06, $p = 0.612$); for normal BMI, it was 0.66 (95% CI: 0.62–0.71, $p < 0.001$); and for underweight BMI, it was 0.61 (95% CI: 0.54–0.69, $p < 0.001$), each compared with the normal BP group. The overweight BMI category did not show a significant association with elevated BP across the reported models: crude OR 0.93 (95% CI: 0.87–1.00; $p = 0.612$), adjusted OR 0.98 (95% CI: 0.91–1.06; $p = 0.720$), and APR 0.99 (95% CI: 0.93–1.05). Multinomial logistic regression showed an RRR of 1.41 (95% CI: 1.29–1.54) for overweight and 2.25 (95% CI: 2.09–2.42) for obesity among subjects with elevated BP. These observations are consistent with NFHS-5 and NFHS-6 data showing that overweight/obesity and HTN were closely linked.^{3,4} The ICMR-INDIAB study reported a 51.8% prevalence of HTN in Punjab, coinciding with the 41.1% burden of overweight/obesity in NFHS-6 data.^{4,6} Pathophysiological mechanisms that may explain the association between elevated BP and obesity include insulin resistance, increased sympathetic nervous system activity, the renin–angiotensin–aldosterone system, endothelial dysfunction, and adverse effects of visceral adiposity.¹⁰

Results of the present study showed a higher burden of SHTN (75.9%) and DHTN (74.4%) among the overweight/obese BMI group compared with SHTN (24.1%) and DHTN (25.6%) among the normal/underweight BMI group; the difference was statistically significant for both SHTN and DHTN. These results indicate that elevated BP was more common in the higher-BMI group. This observation is clinically important because Indian populations may develop cardiometabolic risk at lower BMI than WHO BMI cutoffs. A study showed that BMI is significantly associated with all subtypes of HTN but is more strongly associated with DHTN than with HTN and SHTN in US and nonobese Indian adults. The study also observed that the association between HTN and BMI is more complex in obese Indians,

with a higher risk of SHTN until the sixth decade and HTN thereafter.¹¹ The multinomial regression analysis in the present study showed that the association of elevated BP was strongest with the obesity BMI category rather than the overweight BMI category. Younger age (18–60 years), male sex, and elevated BP were associated with a higher relative risk of obesity. This observation is important from a public health perspective because subjects crossing the Asian obesity BMI threshold of 25 kg/m² may already represent a high-risk group, especially in Punjab, where the prevalence of obesity is high. The low Nagelkerke R² values show that only a small proportion of the variation in BMI categories was explained by age, sex, and BP because obesity has a multifactorial pathophysiology influenced by several factors such as socioeconomic status, region, diet, physical activity, education, genetic predisposition, and comorbidities.^{8,9} The very low VIF values showed negligible multicollinearity, supporting the stability of the regression estimates. Thus, while the observed associations are statistically strong and epidemiologically relevant, the analysis reflects only part of the complex determinants of body weight in the studied population. The differences in the burden of BMI categories and their associations with age, sex, and BP in the present study should be interpreted cautiously alongside NFHS-5 and NFHS-6 data because NFHS used WHO BMI criteria and a younger age group (15–49 years), whereas the present study used Asian BMI cutoffs and included subjects aged 18–80 years.^{3,4}

STRENGTHS

The main strength of the present study is the use of Asian BMI criteria, which are appropriate for Indian populations compared with conventional WHO BMI cutoffs. Asian BMI criteria improve risk stratification in a population with a high burden of obesity and elevated BP in Punjab. A large opportunistic screening sample is another strength of the study, providing real-world data and contributing to regional evidence.

LIMITATIONS

The present study has several limitations. Overweight/obesity may not be a novel issue to study, but large-scale, Punjab-specific screening data add to regional data on the burden of overweight/obesity. The present study adopted convenience and opportunistic sampling involving different screening settings, including community health centers, hospitals, health checkups, and outreach camps, which may not be fully representative of the entire

adult population of Punjab. Walk-in screening was adopted to reduce selection bias from recruiting only symptomatic or health-aware subjects. A randomized, population-based probability sampling method could have better represented the true epidemiological prevalence in the entire population of Punjab. For evaluation of HTN, the present study used a single-occasion BP assessment: three readings were recorded, and the mean of the second and third readings was used for analysis. However, a confirmed diagnosis of HTN requires confirmation of elevated BP on repeated visits or by ambulatory/home blood pressure monitoring; therefore, the present study reports elevated BP among screened subjects rather than a confirmed clinical diagnosis of HTN. Data on several determinants of overweight/obesity were not available within the dataset, including educational status, socioeconomic position, urban–rural residence, dietary patterns, physical activity, alcohol consumption, diabetes, dyslipidemia, and other metabolic or behavioral risk factors, limiting analysis of the associations between overweight/obesity, age, sex, and BP. Despite these limitations, the large sample size, standardized measurement protocol, and inclusion of participants from diverse screening settings provide valuable contemporary data regarding the burden of BMI categories and their demographic correlates in Punjab.

CONCLUSION

The results of the present study show a substantial burden of obesity/overweight among subjects opportunistically screened in Punjab during the MMM initiative using Asian BMI criteria. More than two-thirds of subjects (68.2%) were overweight/obese. These observations highlight the burden of adiposity and obesity-related health risks in Punjab; this is particularly important because Indians are known to develop noncommunicable diseases (NCDs) such as HTN, diabetes, and CVDs at lower BMI cutoffs than Western populations. The present study documents significant associations between BMI categories, age, sex, and BP. Obesity was more common among the younger age group (18–60 years) and among males, whereas underweight was increasingly common with advancing age. Elevated BP showed a strong and independent association with obesity. Coexistence of a high burden of obesity and elevated BP among younger subjects and males in Punjab represents a major challenge for the prevention and control of NCDs, especially through promotion of healthy diets, increased physical activity, and implementation of routine screening protocols for NCDs, including obesity and HTN, targeting high-risk groups such as younger adults and

males. Although the present study is based on opportunistic screening, the results should not be interpreted as population prevalence for Punjab; however, they provide valuable contemporary regional data on the burden of BMI categories and their associations with age, sex, and BP. Future population-based studies should include behavioral, socioeconomic, dietary, and metabolic determinants to document the prevalence of obesity and its association with various variables in Punjab.

AUTHORS' CONTRIBUTIONS

MSB, MG, VKG, KG, CG, HG, JJ, and RG contributed to the study concept, literature search, data acquisition, data analysis, statistical analysis, manuscript preparation, manuscript editing, and manuscript review. MSB, MG, VKG, KG, and CG additionally contributed to the study design and definition of intellectual content. All authors acted as guarantors.

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