



Associations of physical activity, energy intake, and dietary fiber intake with body mass index among adults in the Minanga Public Health Center, Manado City, Indonesia

Hubungan aktivitas fisik, asupan energi, dan asupan serat dengan indeks massa tubuh pada orang dewasa di Puskesmas Minanga, Kota Manado, Indonesia

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Article History:

Received: June 19, 2026; Revised: July 12, 2026; Accepted: July 22, 2026; Published: September 05, 2026.

Publisher:



Politeknik Kesehatan Aceh
Kementerian Kesehatan RI

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Abstract

In Indonesia, obesity continues to pose a pressing public health challenge shaped by both behavioral patterns and dietary habits. This study aimed to examine the relationship between physical activity, energy intake, dietary fiber intake, and selected sociodemographic characteristics and body mass index (BMI) among adults in the Minanga Public Health Center catchment area, Manado City, Indonesia. Methods: This cross-sectional study enrolled 95 adults from the Minanga Public Health Center catchment area, Manado City, Indonesia, between January and March 2025, with participants recruited through purposive sampling. Physical activity levels were quantified in MET-min/week using the Indonesian-validated International Physical Activity Questionnaire (IPAQ), and habitual dietary intake was captured using a validated Semi-Quantitative Food Frequency Questionnaire (SQ-FFQ). Descriptive statistics, Mann-Whitney U and Kruskal-Wallis tests, Spearman correlation, and multiple linear regression were used for data analysis. Results: Physical activity and dietary fiber intake showed inverse associations with BMI, whereas energy intake was positively associated with BMI. In the multivariate model, physical activity ($\beta = -0.405$; $p < 0.001$), energy intake ($\beta = 0.633$; $p < 0.001$), and dietary fiber intake ($\beta = -0.452$; $p < 0.001$) retained independent significance, with the model accounting for 75.1% of the variance in BMI (adjusted $R^2 = 0.742$). In conclusion, physical activity, energy intake, and dietary fiber intake independently predicted BMI in this population, providing evidence to guide obesity prevention efforts in primary care settings.

Keywords: Body mass index, dietary fiber, energy intake, physical activity

Abstrak

Di Indonesia, obesitas tetap menjadi tantangan kesehatan masyarakat yang signifikan, dibentuk oleh interaksi antara pola perilaku dan kebiasaan makan. Penelitian ini bertujuan mengkaji keterkaitan antara aktivitas fisik, asupan energi, asupan serat makanan, serta karakteristik sosiodemografi terpilih dengan indeks massa tubuh (IMT) pada orang dewasa di wilayah kerja Puskesmas Minanga, Kota Manado, Indonesia. Metode, Studi potong lintang ini melibatkan 95 orang dewasa di wilayah kerja Puskesmas Minanga, Kota Manado, yang direkrut melalui teknik purposive sampling selama Januari–Maret 2025. Tingkat aktivitas fisik diukur dalam satuan MET-min/minggu menggunakan International Physical Activity Questionnaire (IPAQ) versi Indonesia, sementara pola konsumsi pangan dinilai melalui Semi-Quantitative Food Frequency Questionnaire (SQ-FFQ) tervalidasi. Analisis data mencakup statistik deskriptif, uji Mann-Whitney U, uji Kruskal-Wallis, korelasi Spearman,

dan regresi linear berganda. Hasil, aktivitas fisik dan asupan serat makanan berhubungan negatif dengan IMT, sedangkan asupan energi berhubungan positif dengan IMT. Analisis regresi linear berganda menunjukkan bahwa aktivitas fisik ($\beta = -0,405$; $p < 0,001$), asupan energi ($\beta = 0,633$; $p < 0,001$), dan asupan serat makanan ($\beta = -0,452$; $p < 0,001$) berhubungan secara independen dengan IMT. Model akhir menjelaskan 75,1% varians IMT (adjusted $R^2 = 0,742$). Kesimpulan, aktivitas fisik, asupan energi, dan asupan serat makanan berhubungan secara independen dengan IMT. Perlu pertimbangan dalam pengembangan strategi pencegahan obesitas di pelayanan kesehatan primer.

Kata Kunci: Aktivitas fisik, asupan energi, indeks massa tubuh, pelayanan kesehatan primer, serat makanan

Introduction

Excess body weight, particularly overweight and obesity, has become one of the defining public health challenges of our time, affecting populations across the economic spectrum, from high-income nations to low- and middle-income settings. According to the World Health Organization's most recent estimates, global obesity had reached over one billion individuals by 2022, a figure that reflects decades of steady increase and confirms the condition's persistent global reach (World Health Organization, 2025). Obesity is a multifactorial disorder in which excessive body fat accumulation develops through a sustained positive energy balance and the interplay of behavioral, environmental, socioeconomic, and biological determinants (Koliaki et al., 2023; Blüher, 2025). This upward trend has direct clinical significance, as an elevated BMI is a well-recognized risk factor for a cluster of serious conditions, including cardiovascular disease, type 2 diabetes, hypertension, several forms of cancer, and premature death. The downstream effect is a mounting strain on healthcare systems and national economies (Blüher, 2025; World Health Organization, 2025).

Indonesia exemplifies this trajectory; the prevalence of adult obesity has increased markedly over the past two decades, rising from 21.8% in 2018 to 23.4% in 2023. Provincial breakdowns from the 2023 Indonesian Health Survey (SKI) place North Sulawesi third-highest nationally at 30.6%, a figure that points to the persistent burden of obesity in the province and reinforces the need to address nutrition-related health problems in its urban centers, including Manado (Ministry of Health of the Republic of Indonesia, 2023). Consequently, identifying the

behavioral factors associated with BMI in community populations is important. Understanding these associations in adults with varying BMI values may provide baseline evidence to support primary prevention strategies in primary healthcare settings.

Across populations, BMI fluctuations fundamentally trace back to the balance between the amount of energy consumed and the amount expended. When caloric intake consistently outpaces energy utilization, the surplus is stored as adipose tissue, driving progressive weight gain (Milhem & Komarnytsky, 2023). Within this balance, physical activity contributes to raising energy expenditure and enhancing metabolic efficiency, whereas dietary choices shape both the volume of energy consumed and its nutrient composition (World Health Organization, 2023). Beyond total caloric intake, dietary quality has gained increasing attention because specific dietary components may differentially influence satiety, energy regulation, gut microbiota composition, and long-term weight management (Sasidharan Pillai et al., 2024).

Effective strategies for preventing obesity hinge on understanding how physical activity and dietary patterns work together to shape BMI. Existing evidence consistently points to physical activity, energy intake, and dietary fiber as key regulators of body weight. Across systematic reviews and epidemiological studies, a recurring pattern emerges: insufficient physical activity correlates with higher BMI and greater obesity risk, whereas regular engagement in moderate-to-vigorous activity tends to be accompanied by a healthier body weight and more favorable metabolic profiles (Wang et al., 2024).

Diet also exerts a substantial influence on body weight regulation. Evidence from controlled and observational research alike

shows that chronically high energy intake particularly when driven by energy-dense, ultra-processed foods pushes the body into a sustained positive energy balance, fueling weight gain and increased adiposity over time (Hall et al., 2019; Moradi et al., 2022). In contrast, greater dietary fiber consumption is associated with a lower BMI and several physiological benefits, including enhanced satiety, improved glycemic regulation, and favorable alterations in gut microbiota profiles, all of which may support body weight control (Wu et al., 2023). Although these associations have been widely documented internationally, the magnitude and direction of these relationships may vary according to local dietary patterns, cultural practices and socioeconomic conditions.

Although evidence on obesity-related factors in Indonesia continues to accumulate, few community-based studies have examined physical activity, energy intake, and dietary fiber intake in a primary care context. This gap motivated the present study, which evaluated how physical activity, energy intake, and dietary fiber intake relate to body mass index (BMI) among community-dwelling adults in the Minanga Public Health Center catchment area, Manado City, Indonesia, adding locally grounded evidence on the behavioral determinants of BMI in this setting.

To this end, multiple linear regression was applied to examine the independent associations of physical activity, energy intake, dietary fiber intake, and selected sociodemographic factors with BMI among adults in the Minanga Public Health Center working area in Manado City. We anticipated that greater physical activity and dietary fiber intake would correspond to a lower BMI, whereas a higher energy intake would correspond to a higher BMI.

Methods

Study Design and Setting

This study adopted an analytical observational design with a cross-sectional method conducted in the working area of the Minanga Public Health Center, Manado City, North Sulawesi, Indonesia, from January to March 2025. A cross-sectional approach suited the study's aims well, as it allowed physical activity, dietary intake, and BMI to be captured concurrently at a single point

in time, thereby enabling assessment of the relationships among these variables within the community-based sample under study.

Population, Sample, and Sampling Technique

The target population consisted of adults aged 18–59 years residing within the catchment area of the Minanga Public Health Center. According to health center records, 1,152 individuals met the eligibility criteria. During study planning, complete variance estimates for the primary study variables were unavailable; therefore, a pragmatic target sample size of 100 participants was established to account for potentially incomplete data. Purposive sampling was used to recruit individuals based on predetermined eligibility criteria, and the final analysis included 95 participants with complete data.

We acknowledge that for analytical studies employing multiple linear regression, an a priori sample size calculation based on the expected effect size, significance level, statistical power, and prespecified number of candidate predictors would have provided a more rigorous justification for the required sample size. This limitation was considered when interpreting the study results.

Adults aged 18–59 years who lived in the study area, could speak, and provided written informed consent to participate were eligible. The exclusion criteria were pregnancy, lactation, acute illness during data collection, incomplete questionnaire responses, and cognitive or mental conditions that could interfere with participation in the interviews.

Following data cleaning and application of the eligibility criteria, 95 participants remained in the final analytical sample. Because detailed records of the recruitment process, including the number of individuals screened, refusals, exclusions, and reasons for exclusion, were not maintained during data collection, these details could not be reported retrospectively. This limitation has been acknowledged in the manuscript.

Research Variables

The body mass index (BMI) served as the dependent variable in this study, while the independent variables encompassed physical activity, energy intake, dietary fiber intake, protein intake, fat intake, and carbohydrate intake. Of these, protein, fat, and carbohydrate

intakes were examined at the bivariate stage but excluded from the final regression model, as none showed statistically significant associations with BMI.

The sociodemographic characteristics recorded included sex (male/female), employment status (employed/unemployed at the time of data collection), educational attainment (elementary, junior high, senior high, or college/university level), and age. Age was grouped descriptively into three categories 18–19, 20–24, and 25–59 years following classification conventions commonly used within the Indonesian health system, although it served primarily as a descriptive variable rather than a primary exposure in this analysis.

Instruments and Data Collection Procedures

A Semi-Quantitative Food Frequency Questionnaire (SQ-FFQ) was used to assess typical dietary intake, recording patterns of habitual food consumption during the previous month. To improve the accuracy of portion-size estimation, the intake was recorded against standard household measures referenced to the Indonesian Food Photograph Atlas, from which the average daily intakes of energy, protein, fat, carbohydrate, and dietary fiber were derived using the study's standardized nutrient analysis procedures. This instrument builds on previously developed and validated SQ-FFQ tools for Indonesian populations, including a recent study that demonstrated good agreement with an Estimated Food Record for assessing habitual consumption patterns (Ardiyanti & Diana, 2025). The Indonesian-validated International Physical Activity Questionnaire (IPAQ) was used to measure the physical activity levels (Dharmansyah & Budiana, 2021). Anthropometric data were obtained using calibrated equipment under standardized measurement protocols: body weight and height were recorded to the nearest 0.1 kg and 0.1 cm, respectively, from which BMI was derived as weight (kg) divided by the square of height (m²). Interviews, questionnaire administration, and anthropometric assessments constituted the primary data sources, complemented by secondary data drawn from Minanga Public Health Center records.

The Indonesian-validated IPAQ-Short Form (IPAQ-SF), which records activity during the previous seven days, was used to measure physical activity levels. Walking, moderate-

intensity, and vigorous-intensity components were added together to determine scores, which were expressed as metabolic equivalent task minutes per week (MET-min/week), in accordance with the official IPAQ scoring protocol. Standard IPAQ data-cleaning procedures, including the suggested truncation rules for extreme values, were applied throughout. Based on the official IPAQ cut-off points, participants were subsequently categorized as having low, moderate, or high physical activity. Previous research has demonstrated the validity and reliability of this approach in Indonesian adults (Dharmansyah & Budiana, 2021).

Anthropometric assessment involved measuring body weight and height using a digital weighing scale and microtoise under standardized procedures, recording weight to the nearest 0.1 kg and height to the nearest 0.1 cm. The researcher subsequently verified all measurements for completeness and accuracy prior to the analysis. BMI was derived as body weight in kilograms divided by the square of height in meters (kg/m²) (Zierle-Ghosh & Jan, 2026).

Trained data collectors obtained primary data through direct interviews, questionnaire-based assessments and anthropometric examinations. Information describing population characteristics was retrieved from records maintained by the Minanga Public Health Center and served as the source of secondary data.

Data Processing and Statistical Analysis

IBM SPSS Statistics was used for all data management and statistical analyses, starting with data entry and cleaning to guarantee correctness and internal consistency. The study variables and respondents were then described descriptively: continuous variables were summarized based on their distribution (mean $\pm$ standard deviation (SD) for normally distributed data and median with interquartile range (IQR) for non-normally distributed data), while categorical data were expressed as frequencies and percentages.

The Shapiro-Wilk test was used to verify the distributional assumptions for continuous variables. Non-parametric techniques were used for the bivariate analysis because several variables deviated from normality. The Mann-Whitney U test was used to examine BMI disparities by sex and job position, while the Kruskal-Wallis test was used to examine

variations between age groups and educational levels.

Correlation analysis was used to examine the relationships between BMI and the continuous variables (physical activity, energy intake, protein intake, fat intake, carbohydrate intake, and dietary fiber intake). Multiple linear regression was used to determine which behavioral variables maintained independent associations with BMI. Variables entering the multivariable model were selected based on the study objectives, prior epidemiological evidence, and bivariate findings.

The Durbin-Watson statistic, coefficient of determination (R^2), modified R^2 , and overall F-test were used to measure the model's performance. Tolerance values and variance inflation factors (VIF) were used to assess multicollinearity. Unstandardized coefficients (B), standardized coefficients (β), standard errors (SE), 95% confidence intervals (95% CI), and p-values were the results of regression analysis, with statistical significance set at $p < 0.05$.

The underlying regression assumptions of the model were methodically verified prior to interpretation: residual normality using histogram inspection and normal probability plots, homoscedasticity using scatterplots of standardized residuals against standardized predicted values, independence of residuals using the Durbin-Watson statistic, and multicollinearity checks using tolerance values and VIF. Leverage assessment, studentized residuals, and influential observation diagnostics (Cook's distance) were used to further analyze the robustness of the model; none of these methods showed significant breaches of the regression assumptions.

Potential Sources of Bias

Several methodological strategies were implemented to minimize potential bias. Standardized and validated instruments were used to assess the physical activity and dietary intake. Standardized protocols guided all anthropometric assessments, and calibrated equipment was used throughout the measurement. Despite these efforts, reliance on participants' self-reported dietary intake and physical activity data makes the study susceptible to biases. Selection bias may have been present because purposive sampling was

employed. These limitations were considered when interpreting the study's findings.

Ethical Considerations

The Health Research Ethics Committee of Universitas Brawijaya, Indonesia, granted ethical Approval No study (approval no. 144/UN10.F17.10.4/TU/2025). Prior to recruitment, all participants provided written informed consent, and participant confidentiality and anonymity were maintained at all times.

The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations for cross-sectional research were followed in the preparation of the manuscript, and a completed STROBE checklist was included as supplementary information.

Result and Discussion

Characteristics of Participants

The final analysis included 95 participants. As shown in Table 1, male respondents accounted for 55.8% of the sample, while female respondents accounted for 44.2%. Employment status was relatively balanced, with 50.5% of respondents employed and 49.5% unemployed.

Regarding educational attainment, the largest proportion of participants had completed senior high school (31.6%), followed by college/university (26.3%), junior high school (25.3%), and elementary school (16.8%). Age is summarized descriptively in Table 1.

Table 1. Characteristics of participants (n = 95)

Variable	n	%
Sex		
Male	53	55.8
Female	42	44.2
Employment status		
Unemployed	47	49.5
Employed	48	50.5
Education level		
Elementary school	16	16.8
Junior high school	24	25.3
Senior high school	30	31.6
College/University	25	26.3
Age group:		
Early adults (18–19 years)	39	41.1
Young adults (20–24 years)	29	30.5
Adults (25–59 years)	27	28.4

Distribution of Study Variables

The descriptive statistics of BMI, physical activity, and dietary intake are presented in Table 3. The mean BMI was 20.164 ± 1.683 kg/m² (median 20.00 kg/m², IQR 18.70–21.40). This summary statistic reflects the average BMI of the study participants and should not be interpreted as indicating that all participants had a normal nutritional status or were free from overweight or obesity. To further characterize the nutritional status of the sample, participants were classified into BMI categories using the WHO Asia-Pacific cut-off points, as presented in Table 2. Although the mean BMI fell within the normal range, 22.1% of participants were classified as

underweight and 4.3% as overweight-at-risk or obese, indicating that the mean value alone does not fully represent the distribution of nutritional status across all participants.

The mean physical activity score was 83.474 ± 39.213 (median, 79.00; IQR, 50.00–119.00). The average daily energy intake was 2109.895 ± 390.034 kcal (median: 2071.40, IQR: 1727.20–2439.00). The mean protein, fat, carbohydrate, and dietary fiber intakes were 68.851 ± 10.998 , 56.065 ± 9.822 , 252.658 ± 33.010 , and 22.132 ± 7.014 g, respectively. The corresponding median and interquartile range values for all continuous variables are shown in Table 3.

Table 2. Distribution of BMI categories (n = 95)

BMI category (WHO Asia-Pacific, 2004)	n	%
Underweight (<18.5 kg/m ²)	21	22.1
Normal weight (18.5–22.9 kg/m ²)	70	73.7
Overweight at risk (23.0–24.9 kg/m ²)	3	3.2
Obese (≥ 25.0 kg/m ²)	1	1.1

Note: BMI categories were classified according to the WHO Asia-Pacific (2004) cut-off points for the Asian population.

Table 3. Distribution of study variables (n = 95)

Variable	Unit	Mean $\pm$ SD	Median (IQR)
Body mass index*	kg/m ²	20.16 ± 1.68	20.00 (18.70–21.40)
Physical activity score*	MET-min/week	83.47 ± 39.21	79.00 (50.00–119.00)
Energy intake*	kcal/day	2109.90 ± 390.03	2071.40 (1727.20–2439.00)
Protein intake	g/day	68.85 ± 11.00	68.30 (62.80–76.20)
Fat intake*	g/day	56.07 ± 9.82	57.30 (46.80–61.60)
Carbohydrate intake	g/day	252.66 ± 33.01	252.70 (229.00–277.10)
Dietary fiber intake*	g/day	22.13 ± 7.01	22.30 (16.50–28.40)

*Non-normally distributed per Shapiro–Wilk test ($p < 0.05$); median (IQR) is the primary summary statistic for these variables, with mean $\pm$ SD retained for comparability with prior literature. Protein and carbohydrate intakes were normally distributed ($p > 0.05$).

The descriptive statistics for the continuous study variables are summarized in Table 3, where energy intake displayed the greatest variability (SD = 390.03 kcal/day) and BMI the least (SD = 1.68 kg/m²). Shapiro–Wilk testing showed that BMI, physical activity score, energy intake, fat intake, and dietary fiber intake deviated from normality (all $p < 0.05$), whereas protein and carbohydrate intakes did not (both $p > 0.05$). Given that five of the seven continuous variables were non-normally distributed, both the median (IQR) and mean $\pm$ SD are reported in Table 3, in line with the standard practice for such data. Non-parametric tests were applied to the relevant bivariate comparisons, and multiple linear regression was performed only after its underlying assumptions were satisfied.

Factors Associated with BMI

The results of the bivariate analysis are presented in Table 4. The median BMI remained broadly similar across categories of sex, employment status, education level, and age group, with no sociodemographic characteristic reaching statistical significance (all $p > 0.05$) and effect sizes ranging from negligible to small. In contrast, Spearman's correlation revealed meaningful associations among the continuous variables: physical activity ($r = -0.360$, 95% CI -0.517 to -0.177 ; $p < 0.001$) and dietary fiber intake ($r = -0.523$, 95% CI -0.662 to -0.358 ; $p < 0.001$) were moderately and inversely correlated with BMI, while energy intake showed a moderate positive correlation ($r = 0.593$, 95% CI 0.446 to 0.702 ; $p < 0.001$). In

contrast, protein, fat, and carbohydrate intakes showed no significant association with BMI, with

their confidence intervals spanning the null value (all $p > 0.05$).

Table 4. Bivariate analysis of factors associated with body mass index (BMI) (n = 95)

Variable	BMI, median (IQR), kg/m ²	Effect size (95% CI)	p-value
Sex			
Male	20.00 (18.60–21.40)	r = 0.008	0.937*
Female	20.05 (18.95–21.03)		
Employment status			
Employed	19.90 (18.45–21.60)	r = 0.033	0.748*
Unemployed	20.20 (18.98–21.23)		
Education level			
Primary school	20.00 (18.45–21.18)	$\epsilon^2 = 0.025$	0.153*
Secondary school	20.60 (19.70–22.15)		
Senior high school	19.15 (18.15–20.78)		
Higher education	20.10 (19.40–21.70)		
Age group			
18–24 years	20.40 (19.10–22.05)	$\epsilon^2 = 0.023$	0.076**
25–44 years	20.40 (19.10–21.10)		
45–59 years	19.10 (18.20–20.35)		
Continuous variables			
Physical activity	—	r = -0.360 (95% CI -0.517 to -0.177)	<0.001***
Energy intake	—	r = 0.593 (95% CI 0.446 to 0.702)	<0.001***
Protein intake	—	r = 0.049 (95% CI -0.155 to 0.257)	0.637***
Fat intake	—	r = 0.089 (95% CI -0.116 to 0.297)	0.392***
Carbohydrate intake	—	r = 0.105 (95% CI -0.095 to 0.298)	0.313***
Dietary fiber intake	—	r = -0.523 (95% CI -0.662 to -0.358)	<0.001***

Abbreviations: BMI, body mass index; IQR, interquartile range; CI, confidence interval.

Notes: *Mann–Whitney U test; **Kruskal–Wallis; ***Spearman correlation. BMI is presented as median (IQR) because it was not normally distributed. The effect size for the Mann–Whitney U test is reported as r ($= |Z|/\sqrt{N}$), and the effect size for the Kruskal–Wallis test is reported as epsilon-squared (ϵ^2). Spearman correlation coefficients are presented with bootstrap 95% confidence intervals (5,000 resampling).

Multiple Linear Regression Analysis

The fitted multiple linear regression model exhibited substantial explanatory power, accounting for 75.1% of the variance in BMI ($R = 0.866$, $R^2 = 0.751$, adjusted $R^2 = 0.742$; $F = 91.299$, $p < 0.001$). Because this proportion of explained variance was relatively high for behavioral data, the regression model was carefully audited against the original SPSS output. Data coding, duplicate records, regression diagnostics, and influential observations were also reviewed. No duplicate records or coding inconsistencies were found. The diagnostic evaluation indicated no substantial violation of the regression assumptions. Residual histograms and normal probability plots showed approximate normality of residuals, residual-versus-predicted-value scatterplots indicated homoscedasticity, multicollinearity was minimal (tolerance = 0.968–0.986; VIF = 1.013–1.033), and the Durbin–Watson statistic (1.458) suggested

acceptable independence of residuals. No influential observations that required exclusion were identified during the model diagnostics.

Even after adjusting for the other model variables, physical activity retained an inverse association with BMI ($B = -0.017$, $SE = 0.002$, $\beta = -0.405$, 95% CI -0.022 to -0.013, $p < 0.001$), while energy intake retained a positive association ($B = 0.0027$, $SE < 0.001$, $\beta = 0.633$, 95% CI 0.0021 to 0.0033, $p < 0.001$), and dietary fiber intake remained inversely associated with BMI ($B = -0.108$, $SE = 0.013$, $\beta = -0.452$, 95% CI -0.134 to -0.083, $p < 0.001$).

Table 5 indicates that all three variables remained statistically significant in the final regression model, with t-statistics ranging from 7.603 to 11.974 in absolute value (all $p < 0.001$). Multicollinearity diagnostics showed acceptable tolerance (0.968–0.986) and VIF (1.014–1.033) values, indicating no meaningful multicollinearity among the predictors.

Table 5. Multiple linear regression model for body mass index (BMI) (n = 95)

Variable	B	SE	β	95% CI	Tolerance	VIF	p-value
Constant	18.247	0.571	—	17.114 to 19.381	—	—	<0.001
Physical activity (MET-min/week)	-0.017	0.002	-0.405	-0.022 to -0.013	0.968	1.033	<0.001
Energy intake (kcal/day)	0.003	<0.001	0.633	0.002 to 0.003	0.980	1.021	<0.001
Dietary fiber intake (g/day)	-0.108	0.013	-0.452	-0.134 to -0.083	0.986	1.014	<0.001

Model statistics: R = 0.866; R² = 0.751; Adjusted R² = 0.742; F = 91.299; p < 0.001; Durbin-Watson = 1.458. Standard errors, t-statistics, tolerance, and VIF were recalculated directly from the original dataset to confirm accuracy.

Final Regression Model

The final regression equation is as follows:

$$\text{BMI (kg/m}^2\text{)} = 18.247 - 0.017 \times \text{PA (MET-min/week)} + 0.0027 \times \text{EI (kcal/day)} - 0.108 \times \text{DFI (g/day)}$$

Where:

BMI : Body Mass Index (kg/m²)

PA : Physical Activity (score)

EI : Energy Intake (kcal/day)

DFI : Dietary Fiber Intake (g/day)

Physical activity, energy intake, and dietary fiber intake remained independently associated with BMI in the final model.

Principal Findings

When combined, these results show that among adults in the Minanga Public Health Center working area in Manado City, physical activity, energy intake, and dietary fiber intake were independently associated with BMI; higher energy intake was associated with higher BMI, while sex, employment status, education level, and age group were not. These findings should be interpreted as statistical correlations rather than evidence of temporal or causal order due to the cross-sectional design; reverse causality is still conceivable because BMI itself could influence dietary habits or physical activity as easily as the opposite. Longitudinal follow-up is necessary to clarify this directionality.

The mean BMI of the participants in this study was within the normal range for Asian populations. This baseline characteristic indicates that the mean BMI of the study population was within the normal range. Investigating behavioral factors within this normal-weight cohort is highly valuable for primary prevention, as it suggests that even within physiological boundaries, subtle increases in energy intake and reductions in

physical activity or fiber consumption are associated with differences in BMI. These findings support further investigation of behavior-focused screening and health promotion in primary healthcare.

These findings are consistent with the current understanding that body weight regulation is primarily influenced by the dynamic interaction between energy intake and energy expenditure, which together determine long-term energy balance and adiposity accumulation (Theodorakis & Nikolaou, 2025; Milhem & Komarnytsky, 2023).

Physical Activity and BMI

The inverse, independently significant relationship observed between physical activity and BMI reinforces the established contribution of physical activity to energy balance, chiefly through greater energy expenditure and improved metabolic efficiency. Mechanistically, regular activity enhances fat oxidation, insulin sensitivity, and lean body mass, each of which supports healthier long-term weight regulation (Curran et al., 2023; Strain et al., 2024).

These results align with a broader body of evidence linking physical activity to a lower BMI and reduced adiposity risk relative to sedentary lifestyles. In a pooled analysis of more than five million adults, Strain et al. (2024). documented that insufficient physical activity remains widespread globally and closely tracks adverse outcomes such as excess body weight. Similarly, Curran et al. (2023) found that adults who reported lower activity levels and greater sedentary time were more prone to being overweight and obese, a pattern that mirrors what was observed in the present sample.

This observed relationship may also reflect broader lifestyle patterns. Individuals with higher physical activity levels often engage in other health-promoting behaviors, including healthier dietary choices and reduced sedentary

time, which collectively contribute to more favorable BMI outcomes. In Indonesia, increasing urbanization and sedentary occupations may reduce opportunities for daily physical activity, thereby increasing susceptibility to weight gain (Ministry of Health of the Republic of Indonesia, 2023; Sakir et al., 2024). Therefore, strengthening community-based physical activity promotion remains an important strategy for maintaining a healthy body weight.

Energy Intake and BMI

In the present study, energy intake showed the largest standardized positive association with BMI. This finding is biologically plausible because sustained energy intake exceeding energy expenditure leads to a positive energy balance and progressive accumulation of body fat (Theodorakis & Nikolaou, 2025). Excess energy is stored primarily in the adipose tissue, contributing to increases in body weight and BMI over time (Milhem & Komarnytsky, 2023).

This pattern echoes both experimental and epidemiological evidence, indicating that excessive caloric intake is a central driver of weight gain. In a controlled feeding trial, Hall et al. (2019) showed that higher consumption of ultra-processed foods increased energy intake and, in turn, promoted weight gain, a mechanism corroborated by systematic reviews consistently implicating energy-dense ultra-processed dietary patterns as key contributors to obesity risk and unfavorable cardiometabolic outcomes (Mambrini et al., 2023; Moradi et al., 2022).

This positive association may partly reflect Indonesia's ongoing nutritional transition, wherein greater access to processed foods, growing portion sizes, and a shift toward energy-dense products have been recognized as key drivers of obesity and non-communicable diseases across many middle-income settings (Popkin & Ng, 2022), a pattern echoed within Indonesia itself, where unhealthy dietary habits have similarly been linked to elevated risks of obesity and metabolic disorders (Sakir et al., 2024). Thus, managing energy intake remains a cornerstone of effective weight management strategies.

Dietary Fiber Intake and BMI

The inverse association observed between dietary fiber intake and BMI, with higher fiber consumers tending toward lower BMI, aligns with evidence pointing to fiber's role in appetite

regulation, dietary quality, and sustained weight management.

Several biological mechanisms may underlie this relationship. Fiber-rich foods tend to have lower energy densities and enhance satiety by slowing gastric emptying and prolonging digestion, which may, in turn, curb overall energy consumption and guard against a positive energy balance (Li et al., 2023). Another mechanism involves the fermentation of dietary fiber by gut microbiota into short-chain fatty acids, which help regulate metabolism and appetite, reinforcing healthy weight maintenance (Vinelli et al., 2022).

This fiber-BMI relationship echoes the findings from umbrella reviews, which associate fruit-, vegetable-, legume-, and whole-grain-rich dietary patterns with lower BMI and more favorable cardiometabolic profiles than less plant-based diets (Oussalah et al., 2020; Landry et al., 2024). The reverse also holds: dietary transitions toward refined and ultra-processed foods at the expense of plant-based intake tend to lower fiber consumption and correspond to less favorable weight outcomes (Popkin & Ng, 2022).

Considering that the average dietary fiber intake in many Southeast Asian populations remains below the recommended levels, increasing fiber consumption through nutrition education and the promotion of plant-based foods may represent a practical approach to support a healthy BMI and overall metabolic health (Agustina et al., 2025).

The predictors included in the regression model collectively accounted for 75.1% of the variance in the BMI. Although this proportion of explained variance is relatively high for studies based on self-reported behavioral data, the regression model was re-audited against the original SPSS output, including verification of data coding, duplicate records, residual diagnostics and multicollinearity statistics. No coding inconsistencies or duplicate records were identified, and the diagnostic results indicated no substantial violations of the model assumptions. The relatively high R^2 may reflect the combined contribution of the three behavioral variables within this relatively homogeneous study population rather than indicating a causal relationship. However, BMI remains a multifactorial outcome shaped by biological, environmental, genetic, and psychosocial factors beyond those captured in

the present model, and the cross-sectional design means these associations warrant cautious interpretation rather than being read as evidence of temporal or causal relationships.

Sociodemographic Characteristics and BMI

In the present study, BMI was not significantly associated with sex, employment status, education level, or age group. While demographic and socioeconomic factors are frequently linked to obesity at the population level, such relationships are not always consistently observed across different study settings and populations (Ayuningtyas et al., 2022; Thamrin et al., 2022); therefore, this null result should not be interpreted as evidence that these factors are unimportant. This more plausibly reflects the study's modest sample size, limited population variability, and reliance on broad sociodemographic categories, all of which may have constrained the power to detect statistically significant associations.

One possible explanation is the relative homogeneity of the study population, which was drawn from a single primary healthcare catchment area in the city. Limited variation in socioeconomic and environmental conditions may have reduced the observable differences in BMI across demographic groups. Furthermore, the effects of sociodemographic characteristics on BMI are often mediated through behavioral pathways, particularly dietary intake and exercise. Behavioral factors showed stronger statistical associations with BMI in this sample than the demographic variables assessed.

Previous analyses of Indonesian national data have demonstrated substantial geographic variation in the prevalence of obesity and risk factors, suggesting that local environmental and behavioral determinants may play a more prominent role than demographic characteristics alone (Ayuningtyas et al., 2022; Thamrin et al., 2022). Therefore, interventions targeting modifiable behaviors may be more effective than those based solely on demographic risk profiling.

Implications and Limitations

Taken together, physical activity, energy intake, and dietary fiber intake emerged from this study as behavioral factors linked to BMI among adults in the Minanga Public Health Center catchment area — evidence that could help shape future hypotheses and prioritize behavioral targets for public health research and health promotion.

Given the cross-sectional design, however, these results cannot speak to the effectiveness of any specific intervention or program strategy; establishing whether modifying these behaviors actually improves BMI and related health outcomes will require longitudinal studies and intervention trials.

This study has several limitations. The cross-sectional design rules out causal inference and precludes the assessment of temporal relationships between exposure and BMI. Dietary intake and physical activity relied on self-reported instruments, leaving them susceptible to recall and reporting bias. Purposive sampling from a single public health center catchment area may constrain how well these results generalize to other populations. Nevertheless, this study offers locally grounded evidence on the behavioral factors linked to BMI that may inform targeted obesity prevention strategies within primary healthcare settings.

Conclusion

Among adults in the Minanga Public Health Center catchment area, higher physical activity and dietary fiber intake corresponded to lower BMI, while higher energy intake corresponded to higher BMI — associations that should be read as statistical rather than causal or temporal in nature. Because the study relied on a cross-sectional design and non-probability purposive sampling, these findings may not be generalizable beyond the study population; confirming the associations and clarifying their temporal direction will require future longitudinal research using probability-based sampling.

Acknowledgements

The authors express their gratitude to everyone who helped carry out this research, including the management of the study site and all study participants, for their cooperation and support during data collection.

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