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A COM-B-guided lifestyle intervention reduces metabolic syndrome in overweight and obese adolescents: a multiphase study in Vietnam

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Metabolic syndrome (MetS) among adolescents with overweight/obesity (OW/OB) is rising rapidly in low- and middle-income countries (LMICs), yet evidence on theory-driven behavioral interventions remains limited. To estimate the prevalence and risk factors of MetS in Vietnamese adolescents aged 11–14 years with OW/OB, and to evaluate the effectiveness of a 12-month lifestyle intervention grounded in the COM-B model. We conducted a three-phase study: (1) a province-wide cross-sectional survey to determine MetS prevalence; (2) a matched case–control study to identify risk factors; and (3) a school-based COM-B intervention comprising health education, environmental modifications, and motivation enhancement. Adherence was quantified using a six-point scale and categorized as high (≥ 75%), moderate (40–<75%), or low (< 40%). The primary outcome was MetS resolution at 12 months according to International Diabetes Federation (IDF) pediatric criteria; secondary outcomes included anthropometric, biochemical, and behavioral changes. Of 6,009 students screened, 2,055 (34.2%) had OW/OB, among whom 628 (30.6%; 95% CI, 28.6–32.6) had MetS, with hypertriglyceridemia (87.9%) and low HDL-C (84.4%) being most prevalent. Waist-to-height ratio ≥ 0.46 was the strongest independent risk factor (OR = 2.96; 95% CI: 1.76–5.00), while exclusive breastfeeding for 6 months was protective (OR = 0.45; 95% CI: 0.35–0.58). A 12-month COM-B–guided lifestyle intervention in 300 OW/OB adolescents with MetS achieved a 71.7% resolution rate (95% CI: 66.2–76.7), with significant improvements in metabolic parameters (triglycerides − 0.41 mmol/L, HDL-C + 0.12 mmol/L, CAP − 29.6 dB/m; all $p < 0.001$) and health behaviors (sugar-sweetened beverage intake − 4.7 times/week, screen time − 3.6 h/day). High adherence was associated with the greatest cardiometabolic and behavioral gains, supporting a dose–response relationship consistent with the COM-B framework. A school-based COM-B intervention substantially improved MetS and health behaviors among adolescents with OW/OB, with effectiveness varying by adherence level. The model appears feasible and scalable in LMIC settings, although longer-term follow-up is needed to assess sustainability.

Keywords Metabolic syndrome, COM-B, Behavioral intervention, Overweight and obesity, Vietnam

Abbreviations

ALT	Alanine aminotransferase
AST	Aspartate aminotransferase
AUC	Area under the curve
BMI	Body mass index
CAP	Controlled attenuation parameter
CI	Confidence interval
COM-B	Capability, opportunity, motivation – behavior
DBP	Diastolic blood pressure
GEE	Generalized estimating equation

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HbA1c	Hemoglobin A1c
HDL-C	High-density lipoprotein cholesterol
IDF	International Diabetes Federation
LSM	Liver stiffness measurement
MetS	Metabolic syndrome
NPV	Negative predictive value
OR	Odds ratio
OWOB	Overweight and obesity
PPV	Positive predictive value
ROC	Receiver operating characteristic
SBP	Systolic blood pressure
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
TIDieR	Template for Intervention Description and Replication
WHR	Waist-to-hip ratio
WHtR	Waist-to-height ratio
WHO	World Health Organization

The prevalence of overweight and obesity (OW/OB) among children and adolescents is rising rapidly worldwide, with a particularly pronounced burden in low- and middle-income countries (LMICs)[1,2]. This trend is accompanied by early-onset metabolic disturbances, among which metabolic syndrome (MetS) is a strong risk factor for future cardiovascular disease and type 2 diabetes in adulthood[3]. Evidence indicates that youths with OW/OB have a substantially higher risk of MetS than their normal-weight peers, and that metabolic abnormalities often emerge during puberty[4,5].

In Viet Nam, recent epidemiological data show that OW/OB among school-aged children has increased sharply—from 8.5% in 2010 to 19.0% in 2020 among those aged 5–19 years—particularly in urban areas[6–8]. However, studies on MetS prevalence, its risk factors, and theory-driven behavioral interventions in this age group remain limited. Most risk factors for MetS are behaviorally modifiable, including unhealthy dietary patterns, physical inactivity, insufficient sleep, and prolonged screen time[9]. We focused on adolescents aged 11–14 years because this corresponds to early-to-mid puberty—a period marked by rapid physical, hormonal, and behavioral changes—when dietary and activity habits begin to consolidate[4,5].

The COM-B model (Capability, Opportunity, Motivation—Behaviour)[10,11] is a widely used theoretical framework for designing health behavior change interventions. In adolescent settings, COM-B has been applied to co-design school-based physical activity interventions[12], to develop programs enhancing physical activity among children in China[13], and to guide nutrition/physical activity interventions across child and adolescent environments[14,15]. In LMIC contexts, COM-B has likewise informed formative research shaping child nutrition interventions (e.g., Kenya), supporting the generalizability of this framework beyond high-income settings[16]. Building on this evidence, we designed a COM-B–based intervention to concurrently enhance capability (education and skills), opportunity (school and family environments), and motivation (individual goal-setting and feedback) among adolescents aged 11–14 years with OW/OB.

This multi-phase study aimed to: (i) estimate the prevalence and identify risk factors of MetS among adolescents with OW/OB in a Mekong Delta province; (ii) evaluate the effectiveness of a 12-month COM-B–based lifestyle intervention on metabolic and behavioral outcomes; and examine the relationship between intervention adherence and clinical outcomes.

Methods

Study design

We conducted a three-phase sequential study in a province of the Mekong Delta, southern Viet Nam, from October 2023 to May 2025.

Phase 1: a school-based cross-sectional survey to estimate the prevalence of MetS among adolescents with OW/OB.

Phase 2: a matched case–control study to identify behavioral and clinical risk factors for MetS.

Phase 3: a 12-month school-based lifestyle intervention grounded in the COM-B model.

Reporting adhered to the STROBE and TIDieR guidelines[17,18].

Participants

Inclusion criteria: students aged 11–14 years classified as OW/OB according to the WHO 2007 growth reference (body mass index [BMI]-for-age > + 1 SD for overweight; > +2 SD for obesity)[19]; without chronic endocrine, metabolic, or cardiovascular diseases; and free of acute illness during recruitment. For Phase 3, participants were additionally required to meet the 2007 International Diabetes Federation (IDF) consensus definition of MetS for ages 10–16 years (central obesity plus ≥ 2 additional criteria)[20].

Exclusion criteria: refusal to participate, anticipated change of residence, or medical contraindications to physical activity. Written informed consent was obtained from parents/guardians and assent from students.

Sampling strategy

Phase 1: Sample size for prevalence estimation was calculated using a single-proportion formula, assuming an OW/OB prevalence of 27.8%[21], design effect of 2, and a 6.1% margin of error. We used multistage cluster sampling stratified by urban/rural areas, randomly selected schools, and conducted school-wide anthropometric screening.

Phase 2: Each MetS case was matched 1:1 with a non-MetS control by age, sex, school, and nutritional status.

Phase 3: A single-group pre–post intervention required 300 participants, based on an expected improvement rate of 95%. We applied stratified cluster sampling with peer pairing to support group-based behavior change and followed participants for 12 months *(Supplementary Methods Appendix, pp: 1–2)*.

Schools were notified one week in advance (principal and homeroom teachers). Students absent on the data-collection day were contacted again within one week.

Data collection and measurements

Data were collected on school premises by a trained research team. Anthropometry (weight, height, waist and hip circumferences) followed WHO procedures[19]. Blood pressure (BP) was measured three times at ≥ 1-minute intervals; the first reading was discarded and the mean of the second and third readings was used. If the second and third readings differed by > 5 mmHg, a fourth measurement was taken and the mean of the third and fourth readings was recorded.

Fasting venous blood was collected to quantify plasma glucose, triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), alanine aminotransferase (ALT), aspartate aminotransferase (AST), and glycated hemoglobin (HbA1c) using internationally standardized methods. Non-invasive assessment of hepatic steatosis and fibrosis was performed with FibroScan® to obtain the controlled attenuation parameter (CAP) and liver stiffness measurement (LSM)[22].

Diagnostic thresholds and cut-offs followed the IDF pediatric criteria (fasting glucose ≥ 100 mg/dL [5.6 mmol/L]; systolic BP ≥ 130 mmHg and/or diastolic BP ≥ 85 mmHg; HDL-C < 40 mg/dL [1.03 mmol/L]; TG ≥ 150 mg/dL [1.7 mmol/L])[20]; waist-to-hip ratio (WHR): elevated WHR > 0.89[23]; waist-to-height ratio (WHtR): at-risk WHtR ≥ 0.46[24]; American Diabetes Association (HbA1c)[25]; and CAP ≥ 248 dB/m and LSM ≥ 5.5 kPa on FibroScan®[26,27].

Behavioral and lifestyle assessment

A structured questionnaire captured dietary habits, physical activity, screen time, and sleep. Students aged 11–12 years received assistance from teachers or parents to ensure comprehension; older students self-completed the questionnaire.

Intervention activities were coordinated across schools and families with collaboration among school staff, the research team, and parents.

- Health education was delivered monthly through interactive classes, small-group discussions, and media videos. Content emphasized risks of obesity-related chronic diseases and the role of healthy lifestyles. Parent workshops were held quarterly to strengthen knowledge and home supervision.
- Dietary guidance was provided via a nutrition handbook, sample menus, and evidence-based rules (reducing sugar, salt, and saturated fat, increasing vegetables and fiber) to improve diet quality while meeting developmental energy needs. No absolute calorie-restriction (weight-loss) diet was prescribed; the focus was on meal quality and eating behaviors. Parents were trained to support dietary adjustments at home.
- Physical activity was encouraged for ≥60 min/day on ≥5 days/week, including school sports, walking, cycling, or home-based exercise. Students maintained activity logs and participated in peer-pair competitions to enhance motivation. Process data were collected periodically to assess behavior change.

Intervention design (COM-B framework)

The 12-month intervention targeted three components[10,11]:

Capability: health education on nutrition and physical activity, with skills training for meal planning and exercise scheduling.

Opportunity: improvements to the school environment, provision of healthier food options, and active engagement of parents.

Motivation: goal setting, individualized feedback, peer support, and recognition of progress.

Intervention reporting followed the TIDieR checklist[18].

Adherence assessment

Adherence was quantified on a six-point scale derived from WHO and CDC recommendations for pediatric obesity management[9,28], encompassing three domains (maximum 2 points each):

Health education & family participation: attendance at ≥ 80% of sessions with ≥ 1 family member participating in counseling.

Dietary behavior: sugar-sweetened beverages < 1 time/day and ≤ 3 times/week; avoidance of eating out > 3 times/week or eating while using screens.

Physical activity & sedentary behavior: ≥60 min/day of moderate-to-vigorous activity on ≥ 5 days/week; recreational screen time < 2 h/day on ≥ 5 days/week.

Scores were recorded quarterly; the maximum cumulative score was 24 over 12 months. Categories were defined as low (< 40%; mean score < 2.5), moderate (40–<75%; mean 2.5–<4.5), and high (≥ 75%; mean ≥ 4.5). Scoring was based on student self-reports, corroborated by teachers/school health staff and parent logs; discrepancies were resolved by consensus.

The primary outcome was MetS remission at 12 months (no longer meeting IDF criteria). Secondary outcomes included changes in anthropometric, biochemical, hepatic, and behavioral indicators (diet, physical activity, screen time, sleep). The adherence score served both as an exposure (for subgroup analyses) and as a process measure *(Supplementary Methods Appendix, pp: 3–66)*.

Statistical analysis

Descriptive statistics summarized baseline characteristics and pre–post changes. Paired t-tests or Wilcoxon signed-rank tests were used for continuous variables; McNemar's test for categorical variables. Logistic regression identified baseline risk factors for MetS. Generalized estimating equations (GEE) evaluated time × adherence interactions for continuous outcomes. Receiver operating characteristic (ROC) analysis assessed predictive models. Missing data were handled by multiple imputation under a missing-at-random assumption[24]. Analyses were conducted in Stata, with two-sided $p < 0.05$ considered statistically significant *(Supplementary Methods Appendix, pp: 67–76).*

Ethics statement

This study was approved by the Ethics Committee of the University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam (Approval No. 505/HĐĐ-ĐHYD, dated May 4, 2023; ID: 23387-DHYD). All methods were carried out in accordance with relevant guidelines and regulations. Written informed consent was obtained from all participants and their legal guardians prior to enrollment. All personal data were anonymized and kept strictly confidential.

Results

Between October 2023 and May 2025, a three-phase sequential study was conducted in a representative province of the Mekong Delta region in southern Vietnam, including a cross-sectional survey of 6,009 children to assess the prevalence of MetS among OWOB children (October 2023–February 2024); a case–control study involving 1,192 children (February–May 2024); and a 12-month community-based intervention for 300 children diagnosed with MetS (May 2024–May 2025), implemented across rural, peri-urban, and urban areas.

Prevalence of MetS and risk factors

Among 6,009 screened students aged 11–14 years, 2,055 (34.2%) were classified as OW/OB according to the WHO 2007 (Table 1). Within this subgroup, 628 adolescents (30.6%; 95% CI, 28.6–32.6) met the IDF criteria for MetS[20] (*Supplementary Table* S1). The most prevalent MetS components were elevated triglycerides (87.9%) and low HDL-C (84.4%). Notably, 96.5% of those with MetS had a WHtR ≥ 0.46 (Table 2).

Based on univariable and multivariable logistic regression, several anthropometric, behavioral, and environmental factors independently predicted MetS among OW/OB adolescents. WHtR ≥ 0.46 emerged as the strongest risk factor (adjusted odds ratio [OR] 3.90; 95% CI, 2.29–6.65), followed by dislike of participating in physical activity (OR 2.28; 95% CI, 1.74–2.98) and sleep duration < 8 h/night (OR 2.43; 95% CI, 1.85–3.20) (*Supplementary Tables S2*, *S4*). Unhealthy eating behaviors were also contributory: eating out ≥ 3 times/week (OR 1.56; 95% CI, 1.23–1.99), eating while using screens (OR 1.71; 95% CI, 1.28–2.28), frequent availability of snack foods at home (OR 1.56; 95% CI, 1.22–2.01), frequent consumption of fried/stir-fried foods (OR 1.30;

Characteristic		Undernutrition (n = 288)	Normal weight (n = 3,666)	Overweight (n = 1,157)	Obese (n = 898)	p value
Residence	Rural	74 (25.7%)	831 (22.7%)	243 (21.0%)	158 (17.6%)	0.001
	Peri-urban	101 (35.1%)	1170 (31.9%)	414 (35.8%)	335 (37.3%)	
	Urban	113 (39.2%)	1665 (45.4%)	500 (43.2%)	405 (45.1%)	
Sex	Male	187 (64.9%)	1699 (46.3%)	619 (53.5%)	607 (67.6%)	< 0.001
	Female	101 (35.1%)	1967 (53.7%)	538 (46.5%)	291 (32.4%)	
Age group (years)	11–12	129 (44.8%)	1771 (48.3%)	653 (56.4%)	598 (66.6%)	< 0.001
	13–14	159 (55.2%)	1895 (51.7%)	504 (43.6%)	300 (33.4%)	
Weight (kg)		30.6 ± 4.9	41.1 ± 6.9	52.2 ± 8.0	64.4 ± 11.9	< 0.001
Height (cm)		147.9 ± 9.3	151.5 ± 8.4	152.7 ± 8.2	153.7 ± 8.1	< 0.001
Waist circumference (cm)		55.0 ± 4.2	62.9 ± 5.5	74.1 ± 6.3	85.2 ± 8.6	< 0.001
Hip circumference (cm)		71.6 ± 5.1	80.0 ± 6.0	88.5 ± 5.8	96.7 ± 7.4	< 0.001
Systolic BP (mmHg)		107.9 ± 5.2	108.9 ± 4.6	109.3 ± 7.4	112.1 ± 10.8	< 0.001
Diastolic BP (mmHg)		68.3 ± 4.2	69.1 ± 3.8	68.9 ± 5.6	70.9 ± 7.7	< 0.001
BMI (kg/m²)		13.9 ± 0.9	17.8 ± 1.8	22.2 ± 1.8	27.1 ± 3.1	< 0.001
WHR		0.77 ± 0.05	0.79 ± 0.05	0.84 ± 0.06	0.88 ± 0.06	< 0.001
WHtR		0.37 ± 0.03	0.42 ± 0.03	0.49 ± 0.04	0.55 ± 0.05	< 0.001

Table 1. Baseline nutritional status and physical characteristics of school-aged children (11–14 years) by BMI category (N = 6,009). Data are n (%) for categorical variables and mean ± SD for continuous variables. p values test differences across BMI categories using χ^2 tests (categorical) and one-way ANOVA (continuous). BMI categories follow the WHO 2007 BMI-for-age reference: undernutrition (thinness) < − 2 SD; normal weight − 2 to < + 1 SD; overweight ≥ + 1 to < + 2 SD; obesity ≥ + 2 SD[19]. BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

MetS component	Total (n = 628)	Overweight (n = 230)	Obese (n = 398)	p value
WHtR ≥ 0.46	606 (96.5%)	211 (91.7%)	395 (99.2%)	< 0.001
Fasting glucose ≥ 5.6 mmol/L	171 (27.2%)	52 (22.6%)	119 (29.9%)	0.048
HDL-C < 1.03 mmol/L	530 (84.4%)	199 (86.5%)	331 (83.2%)	0.264
Triglycerides ≥ 1.7 mmol/L	552 (87.9%)	210 (91.3%)	342 (85.9%)	0.047
Systolic BP ≥ 130 mmHg	96 (15.3%)	13 (5.7%)	83 (20.9%)	< 0.001
Diastolic BP ≥ 85 mmHg	36 (5.7%)	5 (2.2%)	31 (7.8%)	0.004
≥ 3 of 5 MetS components	107 (17.0%)	18 (7.8%)	89 (22.4%)	< 0.001
HbA1c ≥ 5.7%	199 (31.7%)	58 (25.2%)	141 (35.4%)	0.008
CAP ≥ 248 dB/m	379 (60.3%)	92 (40.0%)	287 (72.1%)	< 0.001

Table 2. Metabolic and physiological abnormalities in OW/OB children with MetS (n = 628). Data are n (%). p values compare overweight vs. obese groups using two-sided χ^2 tests. MetS was defined by IDF 2007 pediatric criteria[20]. Cut-offs: fasting glucose ≥ 5.6 mmol/L; HDL-C < 1.03 mmol/L; triglycerides ≥ 1.7 mmol/L; systolic BP ≥ 130 mmHg and/or diastolic BP ≥ 85 mmHg[20]; HbA1c ≥ 5.7% (ADA)[25]; WHtR ≥ 0.46 indicates increased central adiposity[24]; CAP ≥ 248 dB/m indicates hepatic steatosis on FibroScan[*26,27]. "≥3 of 5 MetS components" counts the number of IDF components present (central obesity, elevated TG, reduced HDL-C, elevated BP, elevated fasting glucose). WHtR, waist-to-height ratio; HDL-C, high-density lipoprotein cholesterol; TG, triglycerides; SBP, systolic blood pressure; DBP, diastolic blood pressure; HbA1c, glycated hemoglobin; CAP, controlled attenuation parameter.

95% CI, 1.01–1.67), and drinking bubble tea (OR 1.72; 95% CI, 1.34–2.21) (*Supplementary Table* S3). Sedentary behaviors—including watching TV > 2 h/day (OR 1.61; 95% CI, 1.17–2.21) and playing electronic games > 2 h/day (OR 1.41; 95% CI, 1.00–1.97)—were independently associated with MetS risk (*Supplementary Table S4*). Exclusive breastfeeding for the first six months was the only statistically significant protective factor (OR 0.58; 95% CI, 0.44–0.75) (*Supplementary Table* S2). A predictive model combining these 10 factors demonstrated good discrimination (AUC 0.77; optimal threshold 0.481), with sensitivity 70.3%, specificity 70.1%, positive predictive value 70.0%, and negative predictive value 70.1% (Fig. 1).

Intervention adherence and behavior change by adherence level
The mean 12-month adherence score was 4.9 ± 0.9 points; 225 participants (75.0%) were classified as high adherence (≥ 4.5 points), 69 (23.0%) as moderate (2.5–<4.5), and 6 (2.0%) as low (< 2.5). High adherence was achieved across all three domains: health education/family participation (81.3%), dietary improvement (76.0%), and physical activity/reduction of sedentary behavior (78.7%). Compared with baseline, the high-adherence group showed marked improvements: eating out decreased by − 2.5 times/week (95% CI, − 2.8 to − 2.2), sugar-sweetened beverage intake by − 4.7 times/week (95% CI, − 5.0 to − 4.4), fried-food consumption by − 2.4 times/week (95% CI, − 2.7 to − 2.1), and recreational screen time by − 3.6 h/day (95% CI, − 3.9 to − 3.3). Sleep duration increased by + 1.5 h/night (95% CI, + 1.3 to + 1.7), and days/week with ≥ 60 min of activity increased by + 3.2 (95% CI, + 3.0 to + 3.4). All changes were significantly greater than in the moderate- and low-adherence groups (p < 0.001), reflecting behavior change aligned with COM-B target components (Table 3).

MetS resolution and clinical improvements
At 12 months, 215/300 participants (71.7%; 95% CI, 66.2–76.7) no longer met the IDF MetS criteria, alongside improvements in systolic blood pressure (− 3.67 mmHg), diastolic blood pressure (− 3.22 mmHg), fasting glucose (− 0.36 mmol/L), triglycerides (− 0.41 mmol/L), HDL-C (+ 0.12 mmol/L), HbA1c (− 0.15%), and hepatic steatosis (CAP: −29.6 dB/m); all p < 0.001. Mean WHtR decreased by 0.02 units (p < 0.001) (*Supplementary Table S5*). In GEE models, high adherence was associated with reductions in weight (β=−2.01), BMI (β=−1.04), waist circumference (β=−1.74), CAP (β=−7.65), and triglycerides (β=−0.42), all p < 0.001; HDL-C and height also improved (Table 4). Most associations remained significant after adjustment, indicating consistent intervention effects across cardiometabolic parameters. These findings highlight the comprehensive effectiveness of an intervention targeting capability, opportunity, and motivation—particularly in improving diet and physical activity in line with the COM-B model.

Discussion
This multi-phase study provides new evidence on the prevalence, risk factors, and modifiable behavioral correlates of MetS among adolescents with OW/OB in a LMIC and evaluates the effectiveness of a COM-B–based lifestyle intervention in improving both biomarkers and behaviors. We found that 30.6% of OW/OB adolescents aged 11–14 years met the IDF criteria for MetS[20], indicating early metabolic risk in preadolescents—an age group that is seldom prioritized in school screening programs. This prevalence is comparable to reports from other LMICs[29,30]. Dyslipidemia—particularly hypertriglyceridemia and low HDL-C—was the most frequent abnormality, consistent with pediatric metabolic profiles described previously[29,31].

The COM-B framework guided an intervention targeting (1) capability (nutrition education and physical-activity skills), (2) opportunity (supportive school and family environments), and (3) motivation (feedback,

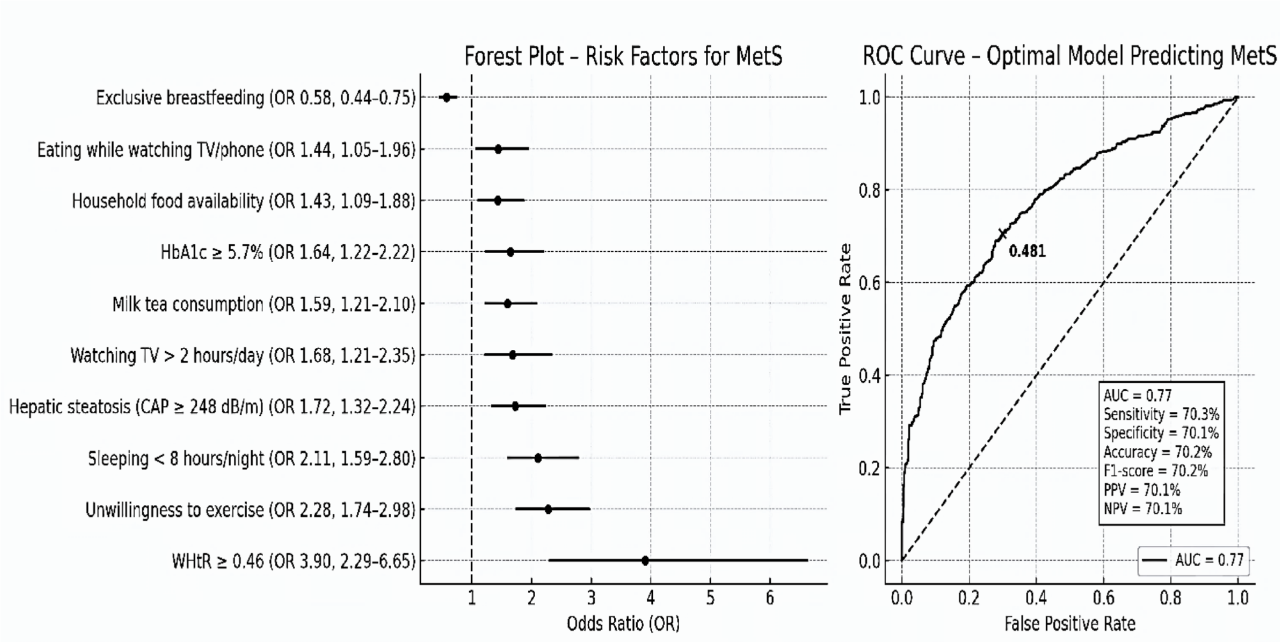

Fig. 1. Adjusted risk estimates and model performance for predicting MetS among OW/OB adolescents. (**A**) Forest plot of adjusted odds ratios (ORs) with 95% confidence intervals (CIs) from the final multivariable logistic regression model predicting MetS among adolescents with OW/OB. The vertical dashed line denotes OR = 1; dots indicate point estimates and horizontal bars the 95% CIs. Variables retained in the final model included: WHtR ≥ 0.46, unwillingness to exercise, sleep < 8 h/night, CAP ≥ 248 dB/m, watching TV > 2 h/day, milk-tea consumption, HbA1c ≥ 5.7%, household snack availability, eating while watching TV/phone, and eating out ≥ 3 times/week; exclusive breastfeeding for 6 months was protective. (**B**) Receiver-operating-characteristic (ROC) curve for the 10-variable model. Model performance: AUC = 0.77; optimal probability threshold = 0.481, sensitivity = 70.3%, specificity = 70.1%, PPV = 70.0%, NPV = 70.1%. The ORs shown in the figure were derived from the adjusted ORs (aORs) reported in Supplementary Tables S2, S3, and S4; variables with statistically significant associations were entered into a final multivariable logistic regression model to predict MetS. All ORs were adjusted for covariates as described in the Methods section. See Methods for details on variable coding and multiple-imputation procedures. Two-sided tests were used for all analyses. ROC, receiver operating characteristic; AUC, area under the curve; PPV, positive predictive value; NPV, negative predictive value; WHtR, waist-to-height ratio; CAP, controlled attenuation parameter; HbA1c, glycated hemoglobin.

group goals, positive reinforcement). The intervention achieved a 12-month MetS remission rate of 71.7%, with the greatest improvements among participants with high adherence. Stratification by adherence revealed a clear dose–response pattern: higher adherence was associated with larger gains in health outcomes. Compared with lower-adherence peers, highly adherent students showed clinically meaningful improvements in BMI, blood pressure, hepatic steatosis indices, fasting glucose, and linear growth, together with behavioral changes—less eating out, reduced sugar-sweetened beverage intake, more physical activity, less screen time, and longer sleep duration. These findings align with prior work indicating that full engagement with health-education and lifestyle components is a prerequisite for reducing MetS risk[32,33].

Our results are broadly consistent with COM-B–informed interventions among adolescents in LMIC settings. In China, Wang et al. (2021) applied the Behaviour Change Wheel/Theoretical Domains Framework to enhance capability for physical activity—mirroring our emphasis on skills for healthy meal planning and activity, and accompanying reductions in sugar-sweetened beverages and eating out[34]. In Kenya, formative research by McClintic et al. underscored the importance of opportunity in designing child-nutrition programs, including mobilizing family and environmental support—consonant with our integration of school setting and parental engagement to sustain positive behaviors[16]. Furthermore, as tested by Willmott et al. (2021), motivation can mediate the effects of capability and opportunity on behavior change, supporting our observation that goal-setting, feedback, and peer recognition helped sustain change[15].

Generalized estimating equation (GEE) models using change scores (Δ) highlighted adherence as a central driver of anthropometric and metabolic improvements among OW/OB students. After adjusting for age, sex, grade, site, and household income, each one-unit increase in adherence (0–6 scale) was associated with a mean decrease of 1.04 BMI units (β = –1.04; 95% CI, − 1.19 to − 0.90; p < 0.001), corresponding to − 2.01 kg of body weight and − 1.74 cm in waist circumference over 12 months. These statistically significant effects are also practically meaningful and meet WHO definitions of "useful response" in community interventions[35,36]. Notably, mean height increased by 0.96 cm in the high-adherence group, indicating that the program did not impede physical growth and may support holistic development. This is salient given persistent concerns about growth

Measure	Baseline	Post-intervention—low	Post-intervention—moderate	Post-intervention—high	*p*
BMI (kg/m²)	25.7 ± 3.8	29.7 ± 3.4	26.7 ± 4.3	24.4 ± 3.8	< 0.001
Waist circumference (cm)	84.1 ± 9.7	93.5 ± 5.7	88.1 ± 10.1	83.2 ± 9.8	< 0.001
Hip circumference (cm)	94.3 ± 8.1	105.5 ± 8.8	98.3 ± 8.9	94.4 ± 8.2	< 0.001
Systolic BP (mmHg)	112.4 ± 13.6	121.7 ± 13.3	113.5 ± 10.8	106.9 ± 10.2	< 0.001
Diastolic BP (mmHg)	68.5 ± 7.2	75.0 ± 8.4	71.2 ± 7.0	67.5 ± 6.9	< 0.001
Fasting glucose (mmol/L)	4.7 ± 0.5	4.7 ± 0.3	4.8 ± 0.5	4.6 ± 0.5	0.109
AST (U/L)	29.4 ± 14.1	29.0 ± 4.4	36.3 ± 19.1	27.3 ± 11.5	< 0.001
ALT (U/L)	34.7 ± 27.8	38.5 ± 18.2	52.2 ± 49.9	29.2 ± 27.0	< 0.001
HbA1c (%)	5.4 ± 0.2	5.6 ± 0.3	5.4 ± 0.6	5.3 ± 0.4	0.367
HDL-C (mmol/L)	1.0 ± 0.2	1.0 ± 0.2	1.1 ± 0.3	1.2 ± 0.2	0.001
Triglycerides (mmol/L)	2.4 ± 1.1	3.0 ± 1.5	2.7 ± 1.1	1.7 ± 0.8	< 0.001
CAP (dB/m)	262.5 ± 52.8	281.0 ± 47.5	259.1 ± 58.6	223.6 ± 60.9	< 0.001
Eating out (times/week)	5.8 ± 2.1	5.2 ± 1.8	4.2 ± 1.4	3.3 ± 1.1	< 0.001
Sugar-sweetened beverages (times/week)	8.1 ± 1.6	7.2 ± 1.5	5.4 ± 1.3	3.4 ± 1.0	< 0.001
Fried/stir-fried dishes (times/week)	5.6 ± 1.7	5.1 ± 1.7	4.6 ± 1.4	3.2 ± 1.3	< 0.001
Recreational screen time (h/day)	7.1 ± 2.8	5.5 ± 2.1	4.4 ± 1.5	3.5 ± 0.9	< 0.001
Sleep duration (h/night)	6.7 ± 1.2	7.2 ± 0.9	7.8 ± 0.9	8.2 ± 0.7	< 0.001
Days/week with ≥ 60 min PA	1.8 ± 0.9	2.5 ± 0.8	3.9 ± 0.7	5.0 ± 0.6	< 0.001

Table 3. Twelve-month pre–post changes by adherence level among OW/OB children with MetS ($n = 300$). Values are mean ± SD. Baseline values refer to the 300 adolescents with metabolic syndrome (MetS) enrolled in the intervention; post-intervention values are stratified by adherence category. P values are from one-way ANOVA comparing the three adherence categories (low, moderate, high) at 12 months. BMI, body mass index; BP, blood pressure; HbA1c, glycated hemoglobin; HDL-C, high-density lipoprotein cholesterol; CAP, controlled attenuation parameter; PA, physical activity.

compromise in pediatric weight-management programs, particularly in high-income settings where stringent energy-restriction models have sometimes been associated with unintended effects on stature[37,38]. In adjusted analyses, some indices—such as fasting glucose, ALT, and diastolic blood pressure—did not reach statistical significance, possibly reflecting the limited intervention duration or the need for more intensive family-based components, consistent with Meng (2025) on NAFLD risk stratification in pediatric obesity[39]. Similar patterns have been reported in long-term European programs (e.g., IDEFICS, STOPP), where deeper metabolic changes often require ≥ 18 months of exposure and adherence > 75% to yield stable improvements[40,41].

The sample was drawn from a single province in southern Viet Nam, which may limit generalizability to regions with different ethnic compositions or socioeconomic contexts. Dietary habits and family engagement characteristic of the Mekong Delta could have enhanced responsiveness. The 12-month follow-up may be insufficient to assess long-term maintenance of behavior and metabolic improvements; future research should extend follow-up duration in line with adolescent intervention literature. Early-life covariates—including pubertal stage, birthweight, and maternal gestational diabetes—were unavailable, raising the possibility of residual confounding.

These findings support integrating theory-driven behavioral interventions—particularly COM-B—into school-based obesity prevention and management. A combined emphasis on capability, opportunity, and motivation can concurrently improve cardiometabolic and behavioral outcomes, especially when adherence is high. Scaling this model to other provinces in Viet Nam and to comparable LMICs contexts may represent a cost-effective strategy to reduce early MetS risk and its long-term sequelae.

Conclusion

In this multi-phase study, we show that MetS affects a substantial proportion of adolescents with OW/OB in southern Viet Nam, and that a school-based lifestyle intervention designed using the COM-B framework can significantly improve both cardiometabolic risk and health behaviors within 12 months. Intervention effectiveness was strongly adherence-dependent, with the most favorable outcomes observed among participants achieving high adherence.

These findings highlight the importance of embedding theory-driven behavior-change frameworks, such as COM-B, into adolescent obesity prevention and management programs—particularly in low- and middle-income countries where resources must be optimized. Concurrently targeting capability, opportunity, and motivation provides a feasible, scalable, and locally adaptable model to mitigate early cardiometabolic risk.

Δ Indicator	Effect size (β)	95% CI	*p*-value
Δ Weight (kg)	−2.01	−2.45 to − 1.56	< 0.001
Δ Height (cm)	+ 0.96	+ 0.55 to + 1.37	< 0.001
Δ BMI (kg/m²)	−1.04	−1.19 to − 0.90	< 0.001
Δ Waist circumference (cm)	−1.74	−2.27 to − 1.20	< 0.001
Δ Hip circumference (cm)	−0.71	−1.06 to − 0.36	< 0.001
Δ Systolic BP (mmHg)	−1.29	−2.35 to − 0.24	0.017
Δ Diastolic BP (mmHg)	−0.55	−1.31 to + 0.22	0.163
Δ WHR	−0.01	−0.02 to − 0.01	< 0.001
Δ WHtR	−0.01	−0.02 to − 0.01	< 0.001
Δ Fasting glucose (mg/dL)	−0.07	−0.16 to + 0.02	0.143
Δ ALT (U/L)	−1.24	−3.36 to + 0.89	0.254
Δ AST (U/L)	−0.89	−1.88 to + 0.10	0.079
Δ HbA1c (%)	−0.08	−0.14 to − 0.02	0.010
Δ CAP (dB/m)	−7.65	−13.10 to − 2.20	0.006
Δ Triglycerides (mmol/L)	−0.42	−0.55 to − 0.29	< 0.001
Δ HDL-C (mmol/L)	+ 0.06	+ 0.03 to + 0.09	< 0.001

Table 4. Effect of adherence on 12-month changes (Δ) in anthropometric, hepatic, and cardiometabolic indicators among children with MetS (GEE model; $n = 300$). Δ indicates post-intervention minus baseline. Regression coefficients (β) represent the mean change in Δ per 1-point increase in the adherence score (0–6); negative β denotes a greater reduction with higher adherence, positive β denotes an increase. Estimates were obtained from generalized estimating equations (GEE) with robust standard errors and clustering at the school level, adjusted for age, sex, grade, study site (rural/peri-urban/urban), and household income; missing data were handled by multiple imputation under a missing-at-random assumption (see Methods). Two-sided $p < 0.05$ was considered statistically significant. BMI, body mass index; BP, blood pressure; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; ALT, alanine aminotransferase; AST, aspartate aminotransferase; HbA1c, glycated hemoglobin; CAP, controlled attenuation parameter; HDL-C, high-density lipoprotein cholesterol.

Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to privacy and ethical restrictions but are available from the corresponding author on reasonable request.

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Author contributions

Nguyen Thanh Nam: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing – original draft. Ta Van Tram: Methodology, Validation, Resources, Writing – review & editing. Phung Nguyen The Nguyen: Conceptualization, methodology, supervision, project administration, funding acquisition, writing – review & editingAll the authors have read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam (Approval No. 505/HĐĐĐ-ĐHYD, dated May 4, 2023). Written informed consent was obtained from all participants and their legal guardians prior to data collection.

Competing interests

The authors declare no competing interests.

Additional information

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