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Effect of a Multicomponent Intervention Program on Metabolic Syndrome Risk Factors and Health-Related Fitness in Omani Male Adolescents with Obesity

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Abstract

Background: Metabolic Syndrome (MetS) in adolescence is a growing public health concern. This study aimed to evaluate the effects of an eight-week multicomponent intervention program (MIP) on MetS criteria and health-related fitness (HRF) components among adolescents with obesity aged 13–16 years in Al Batinah South Governorate, Sultanate of Oman. **Methods***:* Thirty-two adolescents diagnosed with MetS were randomly assigned to either the MIP group or a control group. The MIP included nutritional counseling, parental involvement, and a structured physical activity regimen over eight weeks. Anthropometric data, blood pressure, fasting glucose, lipid profiles, and HRF parameters were assessed pre- and post-intervention. **Results***:* Post-intervention, the MIP group showed significant improvements in BMI, waist circumference, systolic and diastolic blood pressure, fasting glucose, and HDL-C. Cardiorespiratory fitness and muscular endurance also improved significantly, while flexibility and triglycerides showed no significant change. Large effect sizes were observed for BMI ($\eta^2 = 0.921$), systolic BP ($\eta^2 = 0.941$), and fasting glucose ($\eta^2 = 0.848$), indicating substantial clinical relevance. No significant improvements were noted in the control group. **Conclusion***:* An eight-week school-based MIP led to significant improvements in metabolic health and physical fitness among male adolescents with obesity. Incorporating such programs into the school curriculum may offer an effective strategy for managing obesity.

Keywords: Pediatric Obesity, Metabolic Syndrome, Physical Fitness, Health Promotion, Exercise

Introduction

Non-communicable diseases (NCDs) have become the predominant health challenge of the 21st century, responsible for over 71% of global deaths annually (Budreviciute et al., 2020). Among the most common NCDs are cardiovascular diseases, type 2 diabetes, cancers, and chronic respiratory conditions, many of which are linked to modifiable lifestyle factors such as poor diet, physical inactivity, and obesity (Uddin, Lee, Khan, Tremblay, & Khan, 2020). Obesity during adolescence is a rising public health concern globally, with its prevalence increasing markedly over the past few decades (Jebeile, Kelly, O'Malley, & Baur, 2022). Alarmingly, these conditions are increasingly manifesting during adolescence, driven by early-onset obesity and related metabolic disturbances.

Metabolic syndrome (MetS) is a cluster of risk factors, including abdominal obesity, hypertension, dyslipidemia, and insulin resistance, and is now recognized as a major predictor of chronic disease in youth (Chung & Rhie, 2022; Codazzi, Frontino, Galimberti, Giustina, & Petrelli, 2024). From 1990 to 2021, the rates of overweight and obesity among children and adolescents increased twofold, while the cases of obesity alone tripled. By 2021, there were an estimated 93.1 million individuals aged 5 to 14 years and 80.6 million aged 15 to 24 years who were diagnosed with obesity. The regions with the highest rates of overweight and obesity were North Africa and the Middle East, along with notable increases in Southeast Asia, East Asia, and Oceania. Projections for 2050 indicate that 15.6% (approximately 186 million) of those aged 5 to 14 years and 14.2% (around 175 million) of those aged 15 to 24 years will be diagnosed with obesity. It is anticipated that boys aged 5 to 14 years will have a higher prevalence of obesity (16.5%) than overweight (12.9%), while among females and older males, overweight will continue to be more common than obesity. Regions expected to shift toward obesity as the predominant concern by 2041-2050 include North Africa, the Middle East, and certain parts of Latin America and Asia (Kerr et al., 2025).

This study is of paramount importance in the Sultanate of Oman, where society is undergoing rapid economic and social transformations that have led the Sultanate to have one of the highest obesity rates in the region, reaching 67.81% (Okati-Aliabad, Ansari-Moghaddam, Kargar, & Jabbari, 2022). Beside that, among children and adolescents aged 5–19, 34.2% of boys and 30.2% of girls are overweight, while 16.1% and 13.3%, respectively, are obese. MetS currently affects about 23.6% of the adult Omani population, with risk factors such as central obesity and elevated blood pressure becoming increasingly prevalent (Salim, Abadi, Abdullah, Mahfoodha, & Rahim, 2025). Studying this age group (13-16 years) in the South Al Batinah Governorate is not merely an academic exercise, but an absolute necessity. Adolescence represents the last physiological window through which metabolic disorders can be reversed before they develop into chronic diseases that are difficult to treat in adulthood. The urgent need here is to bridge the gap between the current school reality, which is often limited to 40 minutes of physical education per week—and the actual physical needs required to combat this silent epidemic (AL-Sinani, 2014).

Recent data from northern Oman (2023–2024) revealed that 10.7% of adolescents with obesity were also diagnosed with MetS. Statistically significant correlations were found between MetS components and various health-related fitness (HRF) indicators, particularly muscular strength and blood pressure. However, regression analyses revealed weak predictive power, indicating the need for more targeted interventions (Salim et al., 2025).

The strength of this study lies in its practical utility. It does not simply increase physical activity, but adopts a multi-component model that combines programmed physical activity (PA) with enhanced nutritional knowledge (NK), based on the Health Belief Model (HBM). The effectiveness of this approach is evident in its ability to empower individuals by equipping students with the knowledge and skills necessary to make sustainable health decisions. This leads to behavioral change that goes beyond temporary solutions to a shift in health beliefs, ensuring lasting impact even after the program concludes (Orji, Vassileva, & Mandryk, 2012).

Internationally, multicomponent intervention programs—integrating physical activity, nutritional education, and behavioral strategies have shown considerable success in improving metabolic health in youth with overweight. Meta-analyses and empirical studies from countries such as Brazil and Italy have demonstrated that such programs reduce BMI, waist circumference, and blood pressure, while enhancing cardiorespiratory fitness and overall health outcomes (Abrignani, 2018; Brand et al., 2020; Elvsaas, Giske, Fure, & Juvet, 2017). Moreover, multicomponent approaches have consistently outperformed single-focus interventions in managing and preventing childhood obesity (Denova-Gutierrez et al., 2023).

Despite the strength of this global evidence base, Oman lacks comprehensive, culturally appropriate intervention models modified for adolescents with obesity. A critical gap remains in local data regarding the prevalence of MetS in this population and the effectiveness of structured, school-based health programs. Therefore, this study aimed to examine the effects of an eight-week multicomponent intervention program that combined supervised physical activity (PA) with a nutrition knowledge (NK) educational program focusing on metabolic syndrome (MetS) criteria and health-related fitness (HRF) component levels among adolescents aged 13–16 years diagnosed with obesity and MetS in the Al Batinah South Governorate. The primary aims were to enhance metabolic health, promote healthy behaviors, and support sustainable lifestyle modifications among at-risk and community populations. This integrated approach is intended to empower individuals to improve overall well-being and establish long-term healthy habits.

The findings of this research extend beyond the sample studied to encompass a strategic impact on several levels. It begins with adolescents and their families, as the program provides a "second chance" to restore biological balance and reduce the risk of chronic diseases, thereby improving the quality of family life. It also benefits educational institutions by presenting a scientifically applicable (Plug-and-Play) model that physical education curricula in Oman can adopt, replacing inadequate traditional models. Finally, it benefits the national health system, as the study directly contributes to achieving the goals of "Oman Vision 2040", which aims to build a sustainable and healthy society by reducing the future economic burden associated with treating the complications of obesity and metabolic syndrome.

This study evaluates both metabolic parameters (e.g., fasting blood glucose, HDL cholesterol, triglycerides, waist circumference, blood pressure) and physical fitness indicators (e.g., cardiorespiratory endurance, muscular strength, and flexibility). this study, by focusing on a vulnerable group and under scrutiny, not only seeks to identify the problem, but also provides an effective practical framework that can be used as a cornerstone for school health policies in the Sultanate of Oman, making it a study of high added value to the scientific library and to Omani society alike.

Methods

Study Design

This study employed a quasi-experimental design with two parallel groups: a multicomponent intervention program (MIP) group and a control group (CG). Eligible participants were identified through baseline cross-sectional screening of MetS markers and HRF components. Participants were then randomly allocated to either the MIP or CG using a computer-generated random sequence, with stratification by BMI to ensure baseline comparability between groups. The control group did not receive any intervention during the study.

Ethical Considerations

Ethics approval was obtained from the Ethics Unit at Sultan Idris Education University (UPSI/PPPI/PYK/ETIKA(M)/2024-0262-01). In addition, written informed consent was secured from the participants' parents, along with assent from all adolescent participants.

Sample Size

Sample size was calculated using G*Power software (Faul, Erdfelder, Buchner, & Lang, 2009), assuming a moderate effect size ($f = 0.30$), power ($1–\beta$) = 0.80, and $\alpha = 0.05$, yielding a minimum of 11 participants per group. To accommodate multiple outcome variables and potential attrition, the sample was expanded to 16 participants per group, totaling 32 adolescents (16 MIP; 16 CG). Eligible participants were Omani adolescents (32 boys) aged 13–16 years with obesity (BMI ≥ 95th percentile), and attending school. Inclusion required parental consent and the absence of any diagnosed medical conditions or medications affecting weight or metabolism. Adolescents with genetic obesity syndromes, cognitive impairments, or unwilling to continue participation were excluded.

Multicomponent Intervention Protocol

Following baseline assessments, participants diagnosed with MetS according to International Diabetes Federation (IDF) criteria and presenting low HRF levels were enrolled in the MIP. Participants completed an eight-week multicomponent intervention integrating supervised physical activity (PA) and a nutritional knowledge (NK) education program. The intervention was delivered by trained health professionals and certified physical education (PE) teachers, with programme fidelity monitored through standardized protocols and session adherence. MetS was identified using clinical and anthropometric criteria, and HRF was evaluated using standardized fitness tests (Salim et al., 2025).

Physical Activity Component

The physical activity program included an-eight week, consisting of four 40-minute sessions per week, with each session structured into a 5-minute warm-up, 30 minutes of moderate-intensity circuit training and recreational games, followed by a 5-minute cool-down involving light activities. Exercise intensity was monitored using the Borg Rating of Perceived Exertion (RPE) scale, targeting 60–65% of the participants' maximum heart rate. Based on participants' reports, the average RPE score during the initial weeks was 13.7 score, which gradually increased to 16.2 score in subsequent sessions. Activities included aerobic exercises, resistance training, brisk walking/jogging, and ball games, structured to promote a daily caloric deficit of approximately 600 kcal alongside dietary adjustments (Schneiders et al., 2021).

Educational Program of Nutritional Knowledge Component

The NK program involved weekly 20-minute sessions over the same eight-week period. Content was delivered in Arabic through interactive activities such as food-label reading, visual aids, and games. Topics focused on promoting fruit and vegetable consumption, reducing intake of sugary beverages, junk food and fast food, and understanding calorie balance. Parental involvement was encouraged through shared food diaries and reinforcement strategies discussed during the sessions. The intervention approach was informed by prior research demonstrating the effectiveness of multicomponent strategies in adolescent populations. The educational content of the NK program was developed based on evidence-based nutrition guidelines and aligned with national dietary recommendations for adolescents. To ensure cultural relevance, scientific accuracy, and age-appropriate messaging, the materials were reviewed and validated by a multidisciplinary team comprising registered dietitians, public health experts, and Arabic-speaking educators with experience in adolescent health. Additionally, a pilot test of the curriculum was conducted with a small group of adolescents and parents from the target population to refine language, clarity, and engagement strategies before full implementation. To assess changes in nutrition knowledge among participants, identical knowledge assessments were conducted before and after the intervention. The assessment instrument comprised 20 multiple-choice and true/false questions addressing key topics of the program, including the advantages of consuming fruits and vegetables, the interpretation of food labels, the identification of added sugars, the concept of calorie balance, and the health implications of consuming junk and fast foods. This questionnaire was developed in Arabic and underwent pilot testing to ensure comprehension and reliability, yielding a Cronbach's alpha of 0.78. It was administered at baseline (Week 0) and right after the final session (Week 8).

Measures and Instruments

Anthropometric assessments included weight and height measured using calibrated digital scales (±0.1 kg) and stadiometers (±0.1 cm), waist circumference (WC) measured at the midpoint between the iliac crest and the 10^{th} rib using a non-elastic tape, and BMI calculated as weight (kg)/height² (m²) with age- and sex-adjusted z-scores based on WHO standards.

Metabolic syndrome (MetS) was defined according to IDF criteria as central obesity or waist circumference (WC ≥ 90^{th} percentile) plus at least two of the following: triglycerides ≥ 150 mg/dL, high-density lipoprotein cholesterol (HDL-C: < 40 mg/dL, blood pressure ≥ 130/85 mmHg, or fasting glucose ≥ 5.6 mmol/L; fasting venous blood samples were collected in the morning and analyzed for glucose and lipid profiles using enzymatic assays and laboratory-grade analyzers. Health-related fitness (HRF) was evaluated through validated protocols, including cardiorespiratory fitness assessed via the 20-meter shuttle run test (estimating VO_{2max}), muscular strength measured using a Smedley-type handgrip dynamometer (best of two trials per hand), muscular endurance via a 30-second curl-up test, and flexibility assessed using the sit-and-reach test and a trunk flexion meter (Nevill et al., 2021).

Data Collection Procedures

All assessments were conducted by trained health professionals in school settings. Baseline data were collected one week prior to the intervention, and post-intervention measurements were taken within two days after completion of the eight-week program.

Statistical Analysis

Data normality was assessed using the Shapiro–Wilk test in IBM SPSS version 27, which is appropriate for small sample sizes (<50). Two-way ANOVA was conducted using GraphPad Prism 9.01 to examine group-by-time differences between the multicomponent intervention program (MIP) and the control group (CG) from pre- to post-intervention. To further account for baseline variability, relevant covariates and isolate intervention effects on MetS markers and HRF outcomes, ANCOVA was subsequently applied. To minimize the influence of pre-test values as a potential confounding factor, post-intervention outcomes were analyzed using ANCOVA. The assumptions underlying ANCOVA, including linearity and homogeneity of regression slopes, were evaluated prior to analysis using diagnostic procedures in SPSS. Homogeneity of regression slopes was assessed by fitting a general linear model with a group-by-covariate interaction term; a significant interaction ($p < 0.05$) indicated violation of the assumption. Linearity was examined through group-specific scatterplots of covariates against dependent variables, visually inspected for approximate linear relationships. Levene's test confirmed homogeneity of variances ($p > 0.05$). Effect sizes of the multicomponent intervention were estimated using eta squared (η^2).

Results

Descriptive features of participants and normality

According to descriptive analyses, the multicomponent intervention program (MIP) and control groups were comparable at baseline across demographic, anthropometric, and metabolic characteristics (Table 1; Fig. 1). All 32 participants completed the eight-week study, with a mean attendance rate of 96% in the MIP group. The Shapiro–Wilk test indicated that most variables were normally distributed ($p > 0.05$), supporting the use of parametric analyses. Expected deviations from normality were observed for age and BMI percentile in both groups and for post-test weight in the control group due to obesity- and age-based selection criteria. No significant baseline differences were detected between groups, except for triglyceride levels ($p < 0.05$).

Table 1
Analysis of the normal distribution of pre-test data in MIP and control groups (N=32)

Variables*	Group	Shapiro-Wilk test (Sig.)	
		Pre-test	Post-test
Age (years)	MIP	0.022	-
	CG	0.173	-
Height (cm)	MIP	0.149	-
	CG	0.052	-
Weight (kg)	MIP	0.01	0.012
	CG	0.47	0.322
BMI (kg/m^2)	MIP	0.056	0.059
	CG	0.182	0.103
BMI% ile (%)	MIP	0.114	0.107
	CG	0.006	0.023
WC (cm)	MIP	0.042	0.09
	CG	0.962	0.245
Systolic BP (mmHg)	MIP	0.161	0.142
	CG	0.606	0.405
Diastolic BP (mmHg)	MIP	0.068	0.799
	CG	0.053	0.055
FBG (mmol/L)	MIP	0.424	0.255
	CG	0.272	0.265
HDL (mmol/L)	MIP	0.406	0.066
	CG	0.339	0.339
TG (mmol/L)	MIP	0.754	0.812
	CG	0.409	0.422
CRF (ml/kg/min)	MIP	0.123	0.045
	CG	0.152	0.775
MS (kg)	MIP	0.445	0.056
	CG	0.531	0.495
ME (rep)	MIP	0.483	0.054
	CG	0.11	0.621
Flexibility (cm)	MIP	0.135	0.32
	CG	0.681	0.805
Body composition; WC (cm)	MIP	0.042	0.09
	CG	0.962	0.245

*Cardiorespiratory fitness (CRF), muscular strength (MS), muscular endurance (ME); waist circumference (WC), body mass index (BMI), fasting blood glucose (FBG), high density lipoprotein (HDL), triglycerides (TG).

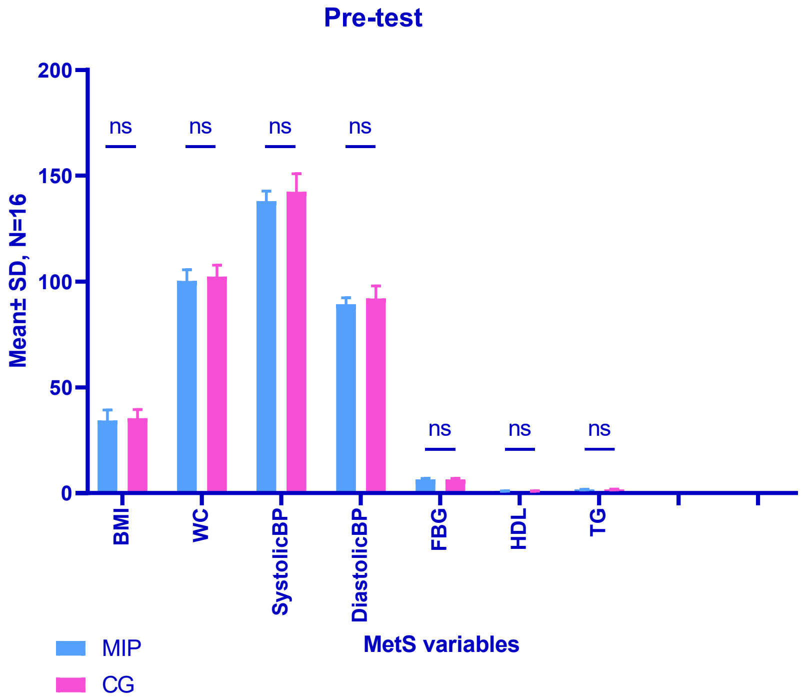
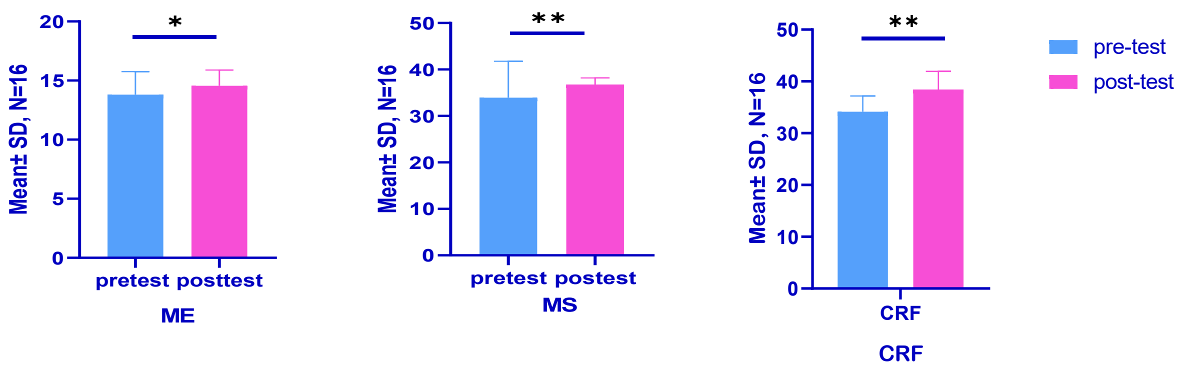


Figure 1: Comparison of MetS variables' means in the CG and MIP groups; *p-value <0.05 and ns p-value >0.05.

Changes in HRF variables between groups

The two-way ANOVA indicated that the MIP group demonstrated significant improvements in muscular endurance (ME: p = 0.028), muscular strength (MS: p = 0.041), and cardiorespiratory fitness (CRF: p < 0.001), whereas flexibility did not change significantly (p = 0.108) (Fig. 2A–D). Significant reductions were also observed in all MetS components, including waist circumference, BMI, blood pressure, fasting glucose, triglycerides, and HDL (p < 0.001) (Fig. 2E–H). In contrast, the control group showed no significant changes in HRF or MetS variables over the same period (Table 2). Post-intervention between-group comparisons confirmed significantly greater improvements in most HRF variables, except flexibility (p > 0.05), and in all MetS parameters in the MIP group compared with controls (p < 0.05) (Figs. 3–4). Intervention effects were further examined using ANCOVA.

A B C



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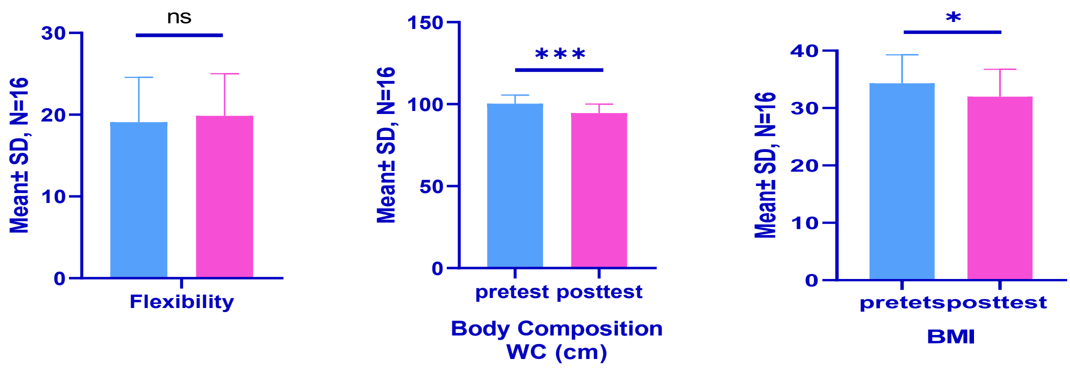

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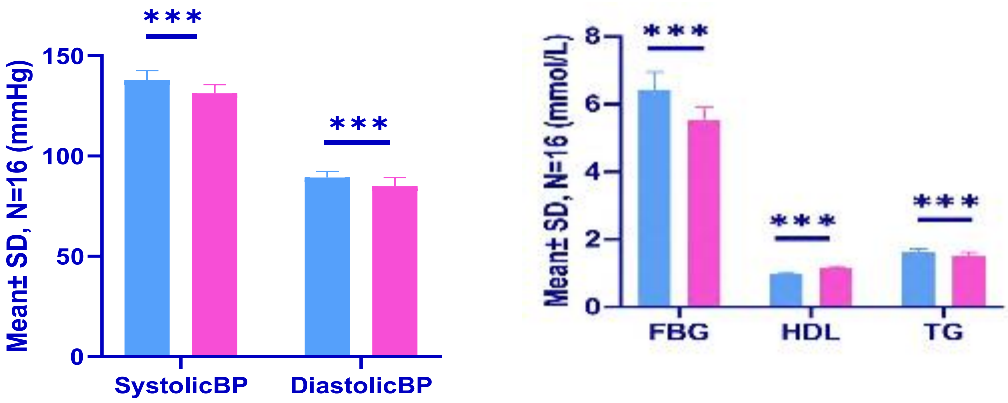
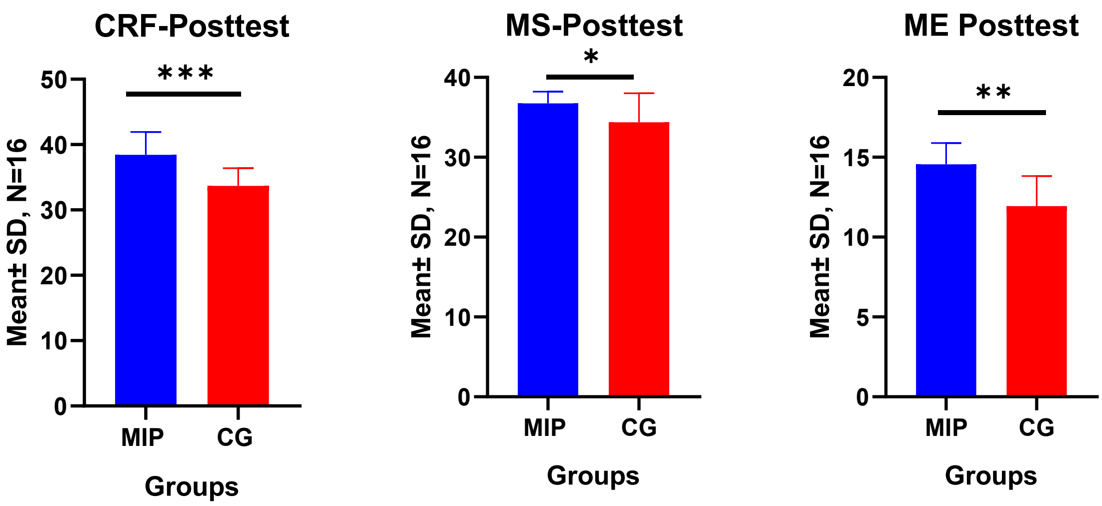


Figure 2: Comparison of (A) HRF variables' mean in the pre and post-test of the MIP group; muscular endurance (ME) (A); muscular strength (MS) (B), Cardiorespiratory factor (CRF) (C), Flexibility (D) and body composition (WC). MetS variables before and after MIP, including body mass index (BMI) (F), blood pressures (G) and biochemical components (H) including fasting blood glucose (FBG), high density lipoprotein (HDL), triglycerides (TG). *p-value <0.05, **p-value <0.01, ***p-value <0.001, ns p-value >0.05.

A B C



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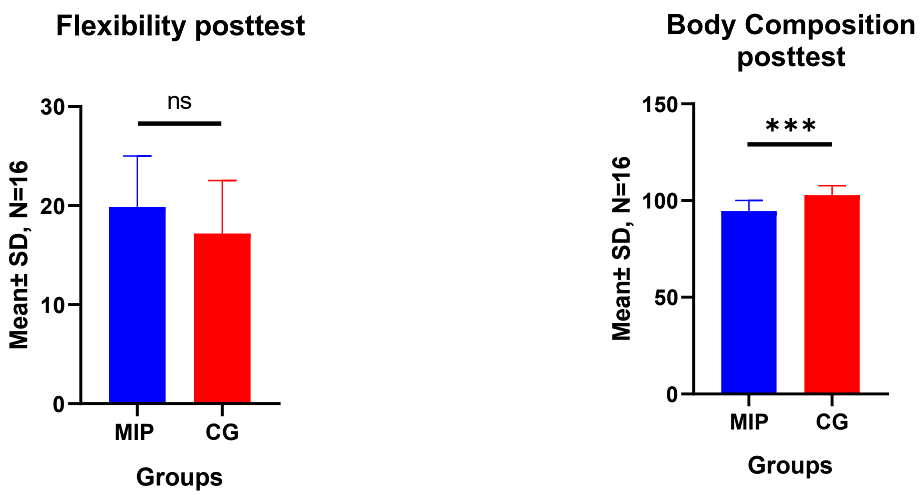

Figure 3: Comparison of HRF variables' mean in post-test of control and MIP groups; Cardiorespiratory factor (CRF) (A), muscular strength (MS) (B), muscular endurance (ME) (C), and Flexibility (D) and Body composition (WC) (E); ns p-value> 0.05, *p-value<0.05, **p-value<0.01, ***p-value<0.001, ns p-value>0.05.

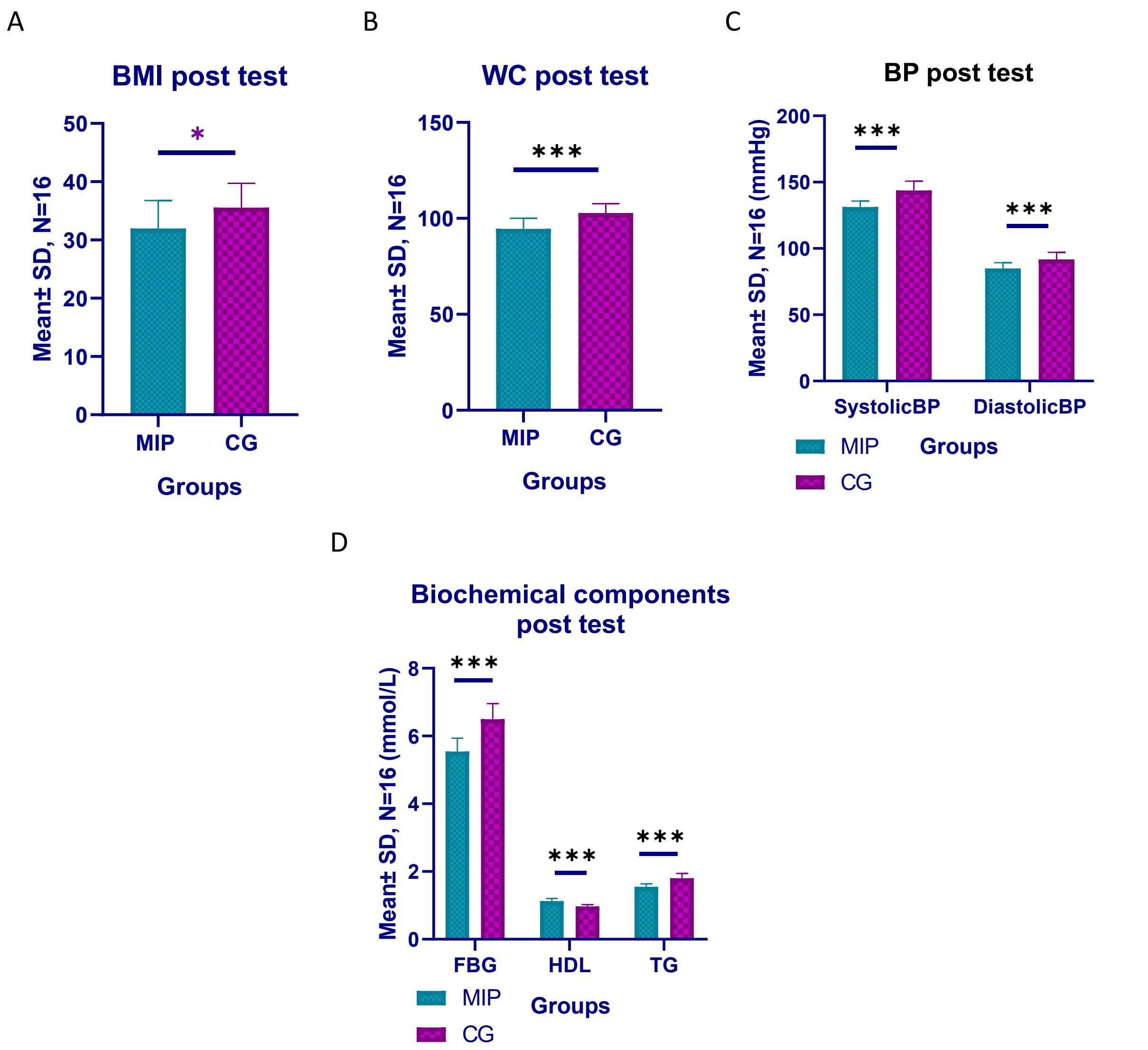

Figure 4: Comparison of MetS variables means before and after MIP. Components evaluated included body mass index (BMI) (A), waist circumference (WC) (B), Blood Pressures (BP) (C) and Biochemical components including fasting blood glucose (FBG), high-density lipoprotein (HDL), and triglycerides (TG) (D). *p-value<0.05, **p-value<0.01, ***p-value<0.001, ns p-value>0.05.

Effect Sizes of the Intervention on MetS and HRF Outcomes

To further validate the findings, ANCOVA demonstrated consistent improvements in MetS markers ($p < 0.0001$) and CRF ($p < 0.0001$), with smaller but significant gains in MS and ME ($p < 0.05$). ANCOVA adjusting for baseline values, age, and BMI confirmed large effect sizes for key MetS variables including BMI ($\eta^2 = 0.921$), waist circumference ($\eta^2 = 0.804$), and fasting glucose ($\eta^2 = 0.848$), while CRF also showed a large effect ($\eta^2 = 0.842$). Flexibility exhibited the smallest effect size ($\eta^2 = 0.441$), indicating minimal intervention impact (Table 2). Since partial η^2 values above 0.80 are extremely rare in behavioral or clinical interventions, especially for complex physiological outcomes such as BMI or fasting glucose, this might raise suspicion of model misspecification, data anomalies, or statistical artifacts due to the small sample size. Continued further studies with larger, well-randomized samples may reduce the risk of inflated effects due to sampling variability or confounding. These results highlight the efficacy of the multicomponent intervention in significantly reducing the risk of metabolic syndrome and improving key health-related fitness components in adolescents with obesity.

Table 2

Comparison of the variables' means between pre- and post-test analysis of the MIP group

ANOVA			ACNOVA		Levene's Test	
Paired variables pre-post-test comparison*	F	Sig.	Partial Eta square (η^2)	Sig.	F	Sig.[a]
BMI (kg/m^2)	4.789	0.037	0.921	0.000	0.520	0.476
WC (cm)	18.17	0.000	0.804	0.000	0.065	0.800
Systolic BP (mmHg)	33.737	0.000	0.941	0.000	1.206	0.281
Diastolic BP (mmHg)	15.356	0.000	0.643	0.000	0.739	0.397
FBG (mmol/L)	37.712	0.000	0.848	0.000	0.051	0.822
HDL (mmol/L)	51.998	0.000	0.647	0.000	0.325	0.573
TG (mmol/L)	34.704	0.000	0.766	0.000	6.180	0.019
CRF (mmHg)	17.609	0.000	0.842	0.000	0.114	0.738
MS (kg)	0.003	0.053	0.294	0.051	2.264	0.143
ME (rep)	5.908	0.021	0.113	0.159	0.005	0.943
Flexibility (cm)	1.928	0.175	0.441	0.002	0.155	0.697
Body composition (WC (cm))	18.17	0.000	0.804	0.000	0.039	0.844

*Cardiorespiratory fitness (CRF), muscular strength (MS), muscular endurance (ME); waist circumference (WC), body mass index (BMI), fasting blood glucose (FBG), high density lipoprotein (HDL), triglycerides (TG).

Discussion

This study evaluated the effects of an eight-week multicomponent intervention program (MIP) on metabolic syndrome (MetS) criteria and health-related fitness (HRF) components among adolescents aged 13–16 years with obesity in Al Batinah South, Oman. Although, the small size of the studied group might introduce some bias in the extrapolation of results, the intervention resulted in significant improvements across several MetS markers, particularly BMI, waist circumference, blood pressure, fasting glucose, and HDL cholesterol, and moderate gains in HRF components, including cardiorespiratory fitness, muscular strength, and muscular endurance.

Multicomponent interventions (MIPs) have been shown to be effective for addressing MetS risk and improving HRF in at-risk populations, producing clinically meaningful changes in adiposity and fitness, and potential but variable improvements in metabolic biomarkers (Jiménez-Peláez, Fernández-Aparicio, Montero-Alonso, & González-Jiménez, 2025; Poli et al., 2025). The statistically significant reduction in BMI and waist circumference among MIP participants is aligned with findings from previous studies (Brand et al., 2020; Kelley, Kelley, & Pate, 2019), who found that multicomponent interventions combining aerobic, resistance, and educational strategies lead to substantial improvements in body composition in youth with overweight or obesity. In the current study, the use of shared food diaries and parental engagement likely contributed to participant adherence to the intervention program.

These reductions are clinically meaningful, as central adiposity is a strong predictor of cardiovascular and metabolic disease risk in adolescents, and decreases in waist circumference and BMI shifted several participants closer to recommended diagnostic thresholds. Furthermore, the intervention significantly reduced systolic and diastolic blood pressure, with reductions sufficient in some cases to approach normotensive ranges. This is particularly relevant given the established association between elevated blood pressure and cardiovascular morbidity. Similar effects have been shown by previous studies, where multicomponent programs resulted in significant reductions in blood pressure and improvements in lipid and glucose profiles (Brand et al., 2020; Zguira et al., 2019).

Improvements in fasting blood glucose and HDL-C levels further suggest enhanced metabolic regulation, with post-intervention values approaching healthier clinical ranges. These findings align with previous studies in which they observed improved metabolic outcomes following short-term PA-based interventions in youth (Eather, Morgan, & Lubans, 2013; Li et al., 2014).

Improvements in cardiorespiratory fitness and muscular endurance indicate that structured, progressive training can enhance aerobic capacity and core strength even over a relatively short intervention period. In contrast, flexibility did not improve significantly, likely due to the limited inclusion of dedicated stretching or mobility exercises, consistent with evidence that flexibility adaptations require specific and regular training stimuli (Eather, Morgan, & Lubans, 2016). Therefore, future interventions should therefore incorporate structured flexibility training with defined frequency, duration, and progression, such as static or dynamic stretching protocols or yoga-based sessions, to elicit measurable improvements.

The large effect sizes observed for BMI ($\eta^2 = 0.921$), systolic blood pressure ($\eta^2 = 0.941$), and fasting glucose ($\eta^2 = 0.743$) suggest a substantial intervention effect and indicate meaningful physiological adaptations following the program. However, these unusually high η^2 values should be interpreted with caution. Given the small sample size, effect size estimates may be inflated and susceptible to overfitting or sampling variability. Therefore, replication in larger and more diverse cohorts is necessary to confirm the magnitude and stability of these effects.

Consistent with previous literature (Borfe et al., 2021; van de Kop, van Kernebeek, Otten, Toussaint, & Verhoeff, 2019), the results of this study reinforce the value of multicomponent interventions, especially those that combine physical activity with nutritional education and behavioral support. These programs offer a structured, sustainable approach to addressing adolescents with obesity and its associated comorbidities. Moreover, the inclusion of parental involvement appeared to strengthen engagement and compliance, consistent with recommendations for family-centered intervention strategies (García-Hermoso, Ramírez-Vélez, Ramírez-Campillo, Peterson, & Martínez-Vizcaíno, 2018). It is therefore recommended that future interventions include sustained parental and community engagement to encourage long-term adherence.
Several limitations should be considered when interpreting the findings. First, participants were aware of the intervention objectives, which may have introduced a Hawthorne effect, whereby behavioral changes occurred partly due to increased attention and monitoring rather than the intervention itself (Jeon et al., 2023). This potential response bias may have contributed to the observed improvements.

Second, the sociocultural environment may have influenced adolescent adherence and outcomes. Previous research has demonstrated that exercise behaviours in adolescence are shaped by peers, family norms, media exposure, and technology use. Social expectations, parental modeling, peer influence, and pressures associated with socially endorsed body ideals or fitness-tracking standards can affect motivation and engagement (Reynolds, Haycraft, & Plateau, 2022). Although these factors were not directly assessed in the present study, their influence may have moderated intervention adherence and behavioural responses. Future research should incorporate measures of sociocultural determinants to better understand their interaction with structured physical activity interventions, particularly within the Omani context.

Finally, the eight-week duration may limit conclusions regarding the sustainability of the observed benefits. While short-term improvements were evident, longer intervention and follow-up periods are necessary to determine whether these metabolic and fitness adaptations can be maintained over time. Extending the program to a full academic semester or implementing longer-term assessments would strengthen the evidence for sustained health effects.

In light of the present findings, several directions for future practice and research are suggested. These include scaling the intervention to larger and more diverse populations to verify gender-specific or contextual differences, integrating such programs into school curricula to expand their reach, and implementing longitudinal follow-up to assess the durability of benefits. Additionally, encouraging adolescents to adopt and maintain healthy lifestyle habits beyond the intervention period is essential for sustained risk reduction.

Conclusion

This study demonstrates that a short-term, school-based multicomponent intervention significantly improves metabolic and health-related fitness profiles in adolescents diagnosed with obesity and MetS. Over the eight-week period, participants in the intervention group showed notable improvements in weight, BMI, waist circumference, blood pressure, fasting glucose, HDL-C, and cardiorespiratory fitness. These findings support integrating such interventions into national education and health strategies in the Persian Gulf region. The analysis confirmed a large effect size for key metabolic indicators, while moderate improvements were observed in muscular strength and endurance. These results underscore the critical role of structured, school-based intervention programs in reducing MetS risk factors and promoting healthier lifestyles among adolescents. While flexibility improvements were minimal, the overall effectiveness of the intervention highlights its potential for broader application in public health strategies targeting adolescents with obesity in Oman and similar contexts. To enhance future outcomes, multicomponent programs should be expanded to larger samples, embedded in school health policy, tailored to include flexibility-specific training, and supported through community and family-based reinforcement. Promoting long-term adherence to healthy lifestyle behaviors will be essential to ensuring the sustainability of the observed benefits.

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