

Improvements in obesity-related measures among Asian patients with severe obesity following a structured lifestyle intervention

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Background: The rising prevalence of severe obesity among children and adolescents poses a major public health challenge.

Purpose: In this study, we examined the differences in body composition and physical fitness between obese and severely obese Asian youth and evaluated their responses to a customized lifestyle intervention.

Methods: A total of 136 overweight and obese participants (mean age, 11.5±3.0 years) were enrolled in an individualized lifestyle modification program. The participants were stratified by obesity severity, with severe obesity defined as a body mass index (BMI)-for-age ≥120% of the 95th percentile. Body composition and physical fitness were assessed at baseline and after 3 interventional stages. The results were compared between the severely obese group and nonseverely obese group, and the relationships between the changes were analyzed.

Results: Among the obese participants, 46% met the criteria for severe obesity. At baseline, those with severe obesity demonstrated a lower performance percentile in the 1-minute sit-up test (22.1±25.2 vs. 47.9±28.0, $P=0.002$) and the standing long jump (8.5±14.6 vs. 26.8±23.2, $P=0.003$) than their nonseverely obese peers. Participants in both groups showed significant reductions in body fat percentage and preserved skeletal muscle mass after the intervention. Those in the severely obese group achieved greater reductions in weight, BMI, BMI z score, and fat mass, particularly during the first 2 interventional stages, indicating a stronger response to the program.

Conclusion: The severely obese youth showed poorer baseline physical fitness levels but greater improvements in key obesity-related measures following the lifestyle interventions. These findings highlight the potential

benefits of early targeted interventions for this high-risk group.

Key words: Lifestyle, Obesity management, Pediatric obesity, Physical fitness

Key message

Question: How does obesity severity affect baseline fitness and improvements in key obesity-related measures following participation in a structured lifestyle modification program?

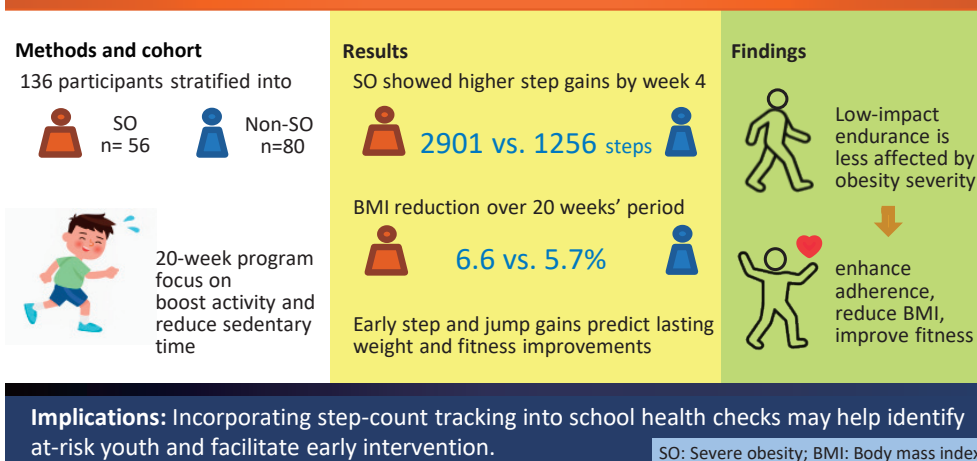
Finding: Severely obese youth showed poorer baseline physical fitness but greater improvements in key obesity-related measures following lifestyle interventions.

Meaning: Early targeted intervention may help prevent progression to more severe obesity and declines in physical fitness in patients with obesity.

Introduction

Childhood obesity represents a profound global public health challenge in the 21st century, with the prevalence of pediatric overweight and obesity escalating at an alarming rate.¹⁾ In Taiwan, more than a quarter of children and adolescents were classified as overweight or obese in 2021.²⁾ Alarming, nearly half of the Taiwanese population is unaware of the definition of obesity, and only 14.7% of individuals attempting to lose weight seek professional assistance.²⁾ This growing epidemic underscores the urgent need for comprehensive strategies to address and reverse childhood obesity, as its impacts extend beyond

BMI reduction in severely obese youth through a step-count strategy



Graphic abstract

individual health, influencing broader societal and economic outcomes.³⁾

The prevailing understanding is that obesity results from a caloric imbalance, where insufficient physical activity combined with excessive calorie intake leads to significant weight gain.¹⁾ It is recommended that children and adolescents engage in at least 60 minutes of moderate-to-vigorous physical activity daily.^{4,5)} However, despite these guidelines, only 24% of high school students meet this standard.^{5,6)} In Taiwan, the situation is similarly concerning, with only 32.8% of junior high school students and 27.4% of high school students reporting adequate physical activity.⁷⁾ This sedentary lifestyle, further compounded by academic pressures, weakens muscle strength and stamina, creating a cycle of inactivity that discourages further physical activity. The coronavirus disease 2019 pandemic has exacerbated this issue, as extended school closures and the shift to online teaching have led to increased sedentary behaviors, contributing to rising rates of childhood obesity and worsening its severity.⁸⁾ The incidence of severe obesity has significantly increased, reflecting a troubling trend.^{9,10)}

Obesity has a profoundly detrimental impact on children's mental health and physical fitness, with obese youth often displaying poorer fitness levels compared to their normal-weight peers.^{1,11,12)} Children and adolescents with obese tend to experience greater weight gain and higher BMI z scores throughout childhood compared to their normal-weight peers.¹³⁾ This underscored the critical need to enhance physical fitness and activity levels in order to slow the decline in metabolic rate and prevent the progression of obesity. Empirical studies have consistently shown that exercise is effective in reducing body fat and mitigating cardiovascular disease risk factors.^{14,15)} However, due to significant academic pressures faced by

Taiwanese youth children and adolescents, a more adaptable intervention model is required to accommodate their lifestyle. In this context, lifestyle modification emerges as a more practical and sustainable approach.¹⁶⁻¹⁸⁾ Most obese children have limited exercise capability,¹⁷⁾ which makes it difficult for them to engage in moderate-to-vigorous intensity exercise or accurately monitor the duration of their exercise. Consequently, our outpatient lifestyle modification programs focus on increase daily steps counts as a strategy to reduce sedentary behavior. Previous research has demonstrated that participation in these programs helps overweight and obese children effectively manage their BMI.^{17,19)}

In Taiwan, lifestyle modification is the only readily available option for individuals under 18. However, evidence on the effectiveness of such interventions in severely obese (SO) youth remains limited.²⁰⁾ Despite the growing recognition of the challenges faced by SO youth, there remains a notable gap in research comparing their physical fitness and body composition to those of less obese peers. Therefore, the present study aims to explore difference in body composition and physical fitness between SO and less obese children and adolescents. Furthermore, this study seeks to assess how the severity of obesity impacts baseline fitness and potential improvement following participating in a structured lifestyle modification program.

Methods

1. Participants

This study involved overweight and obese children and adolescents aged 5 to 18, who attended "The Health and Vitality Clinic" at National Taiwan University Children's

Hospital and participated in the lifestyle modification program that encouraged the participation of their parents or caregivers. The program was personalized, family-centered, delivered by a multidisciplinary team that included pediatricians, physical therapists, dietitians, clinical psychologists, and nursing coordinators. It was structured in 3 sequential stages with distinct goals: knowledge building in the first 4 weeks, habit consolidation from weeks 5 to 12, and self-monitoring from weeks 13 to 20, with visits decreasing from twice a month to once a month to gradually build independence in managing lifestyle changes.^{17,19)} All participants and their parents were thoroughly briefed on the program's structure and objectives. Informed consent, both written and comprehensive, was obtained from the patients and their parents before the commencement of the program. This study was approved by the Institutional Review Board of National Taiwan University Hospital (20180803IRINC).

2. Measurements

Participants were asked to record their diet and daily step count using pedometers. At each visit, their body composition, physical fitness performance and average daily steps of 1 week prior to visit were systematically measured.

Body composition assessment included weight, height, body mass index (BMI), waist and hip circumference, as well as bioelectrical impedance analysis. BMI was calculated by dividing weight in kilograms by the square of the height in meters. To standardize for gender and age differences, height *z* score and BMI *z* score were calculated based on the World Health Organization's (WHO) growth reference.²¹⁾ Overweight was defined as having a BMI *z* score greater than 1 standard deviation (SD), corresponding to BMI-for-age between the 85th and 95th percentiles. Obesity was categorized as a BMI *z* score greater than 2 SDs, corresponding to BMI-for-age above the 95th percentile. Severe pediatric obesity was defined as a BMI *z* score greater than 3 SDs, indicating a BMI-for-age $\geq 120\%$ of the 95th percentile according to WHO standards.²¹⁾ Waist and hip circumferences were measured using a standard circumference tape. Waist circumference, in particular, was noted as an inexpensive and efficient method for evaluating abdominal adiposity, which is a critical indicator of obesity-related health risks.²²⁾

The body fat percentage, body fat mass, and skeletal muscle mass was measured using bioelectrical impedance analysis, which is a reliable, convenient and noninvasive method for estimating body composition and monitoring progress during weight loss or fitness programs. In this study, bioelectrical impedance analysis was performed using the InBodyS10 device (InBody Co., Ltd., Korea) under

standardized conditions and procedures, with the same investigator conducting all assessments to ensure consistency.

Physical fitness was evaluated through multiple dimensions, including flexibility, muscle strength and endurance, explosive power, and cardiopulmonary endurance. For flexibility assessment, the sit-and-reach test was utilized to measure the tightness in the lower back and hamstring muscles. During the test, participants sat on the floor with their legs fully extensive and reached forward as far as possible. Muscle strength and endurance were measured using a 1-minute sit-up test, which gauged the participants' ability to perform repeated abdominal contractions within a set time frame. Explosive power was assessed through the standing long jump, which tests the ability to generate force and propel the body forward. To assess cardiopulmonary endurance, participants performed both an 800-meter run and a 6-minute walking test. The results from all fitness assessments were compared against age- and sex- specific norms established by the Taiwan Ministry of Education and transformed as percentile rank, providing a benchmark for evaluating each participant's physical fitness relative to their peers.

3. Statistical analysis

Comparisons of parameters between the SO and nonseverely obese (non-SO) groups were performed. Data analysis was conducted using IBM SPSS Statistics ver. 22.0 (IBM Co., USA). Categorical variables were expressed as counts and percentages, while continuous variables were reported as means $\pm$ SD. Group comparisons were performed using independent samples *t* test, while comparisons between baseline and the end of each intervention stage were conducted using paired *t* test. Relationships between body composition and fitness were analyzed with bivariate correlation analysis. A 2-tailed *P* value of less than 0.05 was considered statistically significant.

Results

1. Baseline characteristics of the participants

The study involved 136 overweight and obese children and adolescents (74 males, 62 females) with a mean age of 11.5 ± 3.0 years who participated in the lifestyle modification program from March 2018 to October 2024. Among these participants, 107 completed the first stage (4 weeks), 53 completed the second stage (12 weeks), and 36 participants completed all 3 stages (20 weeks), with 10 participants still active in the program followed up to months. At baseline, 13 (10%) were categorized as overweight, while 123 (90%)

were obese, including 56 participants classified as SO. The study compared outcomes between SO (n=56) and non-SO (n=80) subjects.

Table 1 outlines the baseline characteristics of the 82 children (age, 5–11) and 54 adolescents (age, 12–18). When comparing the SO and non-SO groups, body composition analysis revealed that weight, BMI, BMI z score, waist circumference, hip circumference, waist-to-hip ratio, and waist-to height ratio were significantly higher in the SO subgroups for both children and adolescents. However, height z score did not significantly differ between the SO and non-SO groups. When comparing adolescents to children, there were no significant difference in BMI z scores within the SO (3.90 ± 0.61 vs. 3.75 ± 0.57 , $P=0.372$) or non-SO groups (2.47 ± 0.35 vs. 2.31 ± 0.46 , $P=0.088$). As expected, adolescents in both SO and non-SO groups had significantly higher BMI (SO: 38.58 ± 4.14 kg/m² vs. 29.00 ± 3.40 kg/m²; non-SO: 28.79 ± 3.05 kg/m² vs. 23.92 ± 1.94 kg/m²; $P<0.001$ for both) and waist-to height ratios (SO: 0.67 ± 0.06 vs. 0.63 ± 0.05 , $P=0.010$; non-SO: 0.58 ± 0.04 vs. 0.55 ± 0.04 , $P=0.005$) compared to their respective counterparts in the children group. Of note is that the height z scores

were significantly lower in adolescents than in children, regardless of obesity status (SO: 0.24 ± 1.34 vs. 1.22 ± 1.36 , $P=0.007$; non-SO: -0.03 ± 0.93 vs. 0.81 ± 1.04 , $P<0.001$).

Bioelectrical impedance analysis indicated that body fat percentage was significantly higher in the SO groups compared to the non-SO groups- $42.1\% \pm 6.7\%$ vs. $35.8\% \pm 5.3\%$ in children and $45.1\% \pm 5.5\%$ vs. $35.8\% \pm 5.2\%$ in adolescents ($P<0.001$ for both). While skeletal muscle mass did not differ significantly between SO and non-SO groups in children, adolescents in the SO group had significant higher absolute skeletal muscle mass than their non-SO peers (31.5 ± 6.2 kg vs. 25.5 ± 6.2 kg, $P=0.004$). However, despite greater absolute skeleton muscle mass, the proportion of skeletal muscle mass relative to body weight was lower in the SO subgroups across both age groups compared to their non-SO counterparts.

Compared with the non-SO group, SO adolescents had significantly lower overall physical fitness, showing lower percentile rank in the 1-minute sit-up test (22.1 ± 25.2 vs. 47.9 ± 28.0 , $P=0.002$) and standing long jump (8.5 ± 14.6 vs. 26.8 ± 23.2 , $P=0.003$), and more time of 800-m run (478.2 ± 102.6 seconds vs. 408.1 ± 67.3 seconds, $P=0.005$).

Table 1. Participants' baseline characteristics

Variable	Children (age 5–11)		P value	Adolescents (age 12–18)		P value
	SO group (n=37)	Non-SO group (n=45)		SO group (n=19)	Non-SO group (n=35)	
Body composition						
Age (yr)	9.1±1.7	9.8±1.3	0.038	14.6±1.8	14.6±1.8	0.956
Male sex	25 (69)	18 (40)	0.013	14 (74)	17 (54)	0.163
Height (cm)	140.4±12.5	142.4±10.2	0.445	164.4±8.8	161.8±9.0	0.315
Height z score	1.22±1.36	0.81±1.04	0.127	0.24±1.34	-0.03±0.93	0.374
Body weight (kg)	58.4±15.4	49.0±9.8	0.001	104.2±13.4	76.0±14.5	<0.001
BMI (kg/m ²)	29.00±3.40	23.92±1.94	<0.001	38.58±4.14	28.79±3.05	<0.001
BMI z score	3.90±0.61	2.47±0.35	<0.001	3.75±0.57	2.31±0.46	<0.001
Waist circumference (cm)	88.3±10.5	78.6±7.9	<0.001	109.7±11.0	93.5±8.4	<0.001
Hip circumference (cm)	94.2±10.6	87.5±6.9	<0.001	120.2±7.2	104.8±7.5	<0.001
Waist-hip ratio	0.94±0.05	0.90±0.06	0.003	0.91±0.06	0.89±0.07	0.340
Waist-height ratio	0.63±0.05	0.55±0.04	<0.001	0.67±0.06	0.58±0.04	<0.001
Body fat percentage (%)	42.1±6.7	35.8±5.3	<0.001	45.1±5.5	35.8±5.2	<0.001
Body fat mass (kg)	25.5±8.0	17.4±4.6	<0.001	45.7±6.6	27.0±7.4	<0.001
Skeletal muscle proportion (%)	29.7±4.2	33.7±5.0	<0.001	30.9±4.7	33.8±3.9	0.027
Skeletal muscle mass (kg)	17.6±5.4	16.1±3.8	0.186	31.5±6.2	25.5±6.2	0.004
Physical fitness						
Sit-and-reach test (PR)	57.4±30.2	53.8±25.1	0.560	41.3±28.6	50.3±27.8	0.267
Sit-and-reach test (cm)	28.0±9.2	27.9±7.0	0.958	23.6±8.4	28.0±8.8	0.081
1-Min sit-up test (PR)	42.4±30.8	48.7±29.6	0.352	22.1±25.2	47.9±28.0	0.002
1-Min sit-up test (times)	21.1±9.4	24.3±8.7	0.108	23.6±9.8	31.0±7.4	0.003
Standing long jump (PR)	19.3±22.2	19.4±17.6	0.970	8.5±14.6	26.8±23.2	0.003
Standing long jump (cm)	103.1±22.3	105.4±25.9	0.670	118.3±30.7	140.0±26.5	0.009
800-m run (PR)	3.6±6.7	3.6±7.3	0.994	1.0±0.0	2.6±6.0	0.262
800-m run (s)	471.1±87.3	444.2±68.7	0.123	478.2±102.6	408.1±67.3	0.005
6-Min walk test (m)	516.4±81.2	531.1±74.4	0.422	514.3±54.9	552.9±88.7	0.123

Values are presented as mean $\pm$ standard deviation or number (%).

SO, severely obese; non-SO, nonseverely obese; BMI, body mass index; PR, percentile rank.

Boldface indicates a statistically significant difference with $P<0.05$.

No significant differences were found in the 6-minute walking test when compared to normal-weight peers of the same sex and age of Taiwanese.²³⁾

When compared with the normal population of Taiwanese youth, the sit-and-reach and 1-minute sit-up performance were close to the normative medians in both child subgroups and non-SO adolescents, while standing long jump and 800-m run performance were ranked below average in all groups, reflecting deficits in explosive power and cardiopulmonary endurance.

2. Longitudinal dynamic changes of parameters

After the lifestyle modification program, both SO and non-SO groups showed significant reductions in BMI, BMI z score, waist circumference, and body fat percentage at the end of each program stage, while skeletal muscle mass remained stable (Table 2, Fig. 1). In contrast to the non-SO group, the SO group experienced greater reductions in weight, BMI, BMI z score, and fat mass in the first 2 stages, but weight loss plateaued in the final stage. Over the 20 weeks' period, the BMI reduction was 6.6% and 5.7% in SO and non-SO group, respectively. A reduction in BMI of at least 5% occurred in 9 of 13 participants (69.2%) in the SO group and in 13 of 23 participants (56.5%) in the non-SO group ($P=0.452$). By week 20, the attrition rate had risen to approximately 70%. The primary reasons for early program termination included financial constraints, academic demands, lack of family availability for support, unsatisfactory progress, and confidence in the ability to lose weight without professional assistance.

Improvements in physical fitness were observed across both groups during the first 2 stages of the program, particularly in the 1-minute sit-up test and standing long jump. We observed the sit-and-reach test, 800-m run, and 6-minute walking test showed an overall trend of improvement. Furthermore, statistically significant progress

was noted in the 800-m run during the second stage for both groups. Notably, participants in the SO group demonstrated a greater reduction in 800-m runtimes by the week 12 compared to the non-SO group (-65.5 ± 62.8 seconds vs. -20.2 ± 54.2 seconds, $P=0.024$). No significant difference was found between the 2 groups in other physical fitness measures.

Participants were encouraged to wear pedometers after joining the program, with the daily step count recorded starting in the week 2 as the baseline value. Among the 67 participants who tracked their steps regularly, there was a significant increase in the daily step count from the week 2 to the week 4 in both groups. Furthermore, by the week 4, the SO group showed a significantly greater increase in daily step count compared to the non-SO group ($2,901\pm 2,650$ steps vs. $1,256\pm 1,933$ steps, $P=0.021$) (Table 3).

3. Factors contributing to weight loss

Weight loss was most pronounced and sustained during the second stage of the intervention (Supplementary Tables 1-3). To identify the primary factors influencing this weight loss, bivariate correlation analysis was conducted. Findings revealed that weight reduction at week 12 was significantly associated with the daily step count recorded at week 4, as well as improvements in standing long jump distance by week 12. These results underscore the importance of early increases in daily physical activity and enhancements in lower-body strength and explosive power as critical contributors to sustained weight reduction.

Additionally, weight loss at week 4 demonstrated a strong correlation with weight loss at week 12, highlighting the importance of initial weight changes as predictors of long-term outcomes. Similarly, progress in standing long jump and daily step count at week 4 strongly correlated with corresponding improvements at week 12, suggesting that initial gains in both physical activity and functional

Table 2. Changes in body composition from baseline to end of each stage by study group

Variable	Baseline to week 4			Baseline to week 12			Baseline to week 20		
	SO group (n=46)	Non-SO group (n=61)	P value	SO group (n=19)	Non-SO group (n=34)	P value	SO group (n=13)	Non-SO group (n=23)	P value
Weight gain (kg)	-1.54±1.90	-0.59±1.41	0.002	-3.17±3.90	-0.91±1.98	0.004	-2.40±4.50	-1.28±2.73	0.358
Relative change in weight (%)	-2.0±2.2	-0.8±2.3	0.007	-3.5±4.3	-1.1±3.2	0.027	-2.2±6.2	-1.5±3.8	0.345
Change in BMI (kg/m ²)	-0.98±0.82	-0.53±0.71	0.002	-2.21±1.41	-0.93±0.92	<0.001	-2.26±1.95	-1.53±1.11	0.081
Relative change in BMI (%)	-3.0±2.4	-2.0±2.7	0.062	-6.5±4.0	-3.5±3.5	0.005	-6.6±6.2	-5.7±3.9	0.585
BMI reduction of ≥5%	6 (13.0)	6 (9.8)		13 (68.4)	12 (35.3)		9 (69.2)	13 (56.5)	
Change in BMI z score	-0.23±0.15	-0.12±0.14	<0.001	-0.43±0.26	-0.23±0.18	0.002	-0.53±0.34	-0.38±0.20	0.096
Change in BF percentage (%)	-1.72±2.90	-0.97±3.41	0.314	-3.61±3.98	-2.18±3.35	0.245	-3.36±4.56	-2.87±3.94	0.742
Change in BF mass (kg)	-2.01±2.68	-0.62±2.59	0.025	-4.33±4.38	-1.57±3.18	0.034	-2.96±5.87	-2.06±3.78	0.589
Change in skeletal muscle (kg)	0.25±1.37	0.10±1.11	0.603	1.09±2.55	0.46±0.96	0.282	0.14±3.13	0.04±2.52	0.920

Values are presented as mean±standard deviation or number (%).

SO, severely obese; non-SO, nonseverely obese; BMI, body mass index; BF, body fat.

Boldface indicates a statistically significant difference with $P<0.05$.

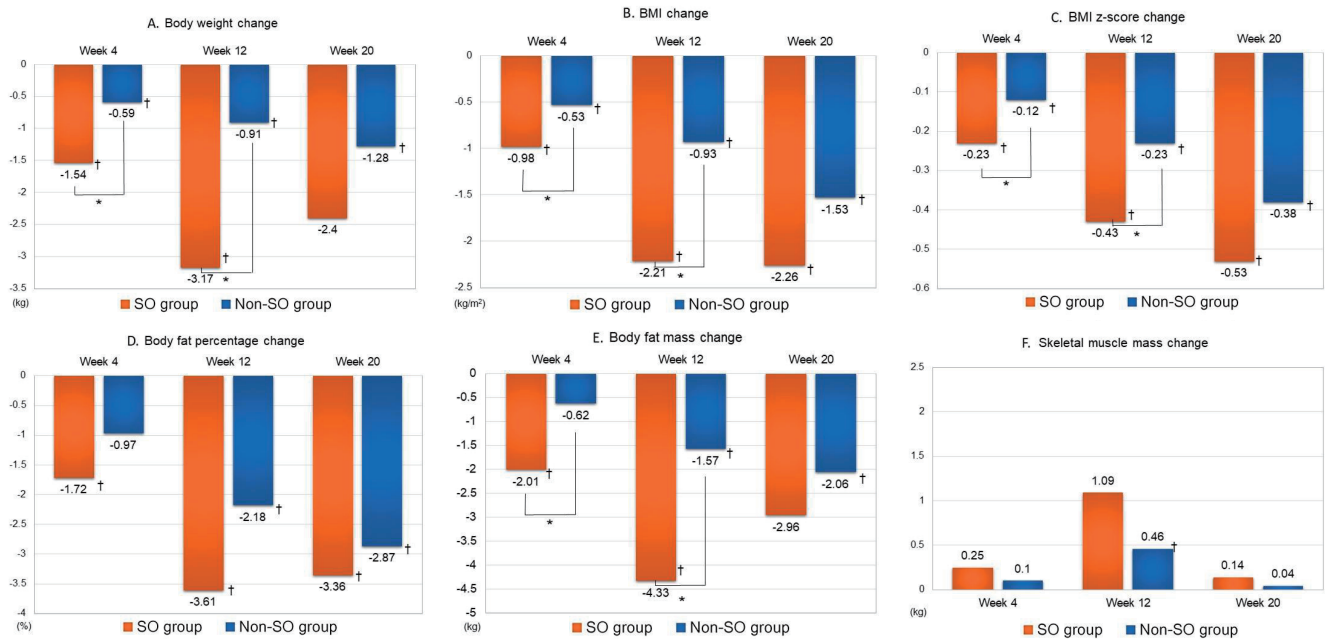


Fig. 1. Body weight change (A), body mass index (BMI) change (B), BMI z score change (C), body fat percentage change (D), body fat mass change (E), and skeletal muscle mass change (F) from baseline to the end of each stage in the severely obese (SO) and nonseverely obese (non-SO) groups. The numbers of SO and non-SO participants at weeks 4, 12, and 20 were 58 versus 40, 36 versus 33, and 16 versus 19, respectively. Data were compared using the *t* test: **P*<0.05 between SO and non-SO groups. †*P*<0.05 from baseline to the end of each stage within group.

Table 3. Physical fitness changes from baseline to end of each interventional stage by study group

Variable	Baseline to week 4			Baseline to week 12			Baseline to week 20		
	SO group (n=43)	Non-SO group (n=57)	<i>P</i> value	SO group (n=17)	Non-SO group (n=31)	<i>P</i> value	SO group (n=11)	Non-SO group (n=21)	<i>P</i> value
Change in sit-and-reach (cm)	3.5±8.5	0.5±3.6	0.019	2.9±7.2	1.5±3.9	0.401	2.8±8.5	1.4±5.5	0.584
Baseline	26.2±9.1	28.3±8.0	0.175	26.3±9.8	27.4±8.1	0.574	25.2±8.4	28.4±8.9	0.171
End of the stage	29.8±8.7	28.8±7.9	0.561	29.1±7.1	28.9±7.2	0.922	28.0±6.2	29.8±9.3	0.568
<i>P</i> value	0.010	0.290		0.120	0.036		0.305	0.253	
Change in sit-ups (number)	5.6±7.2	4.5±6.8	0.441	11.3±13.7	8.0±8.4	0.312	13.8±13.4	10.9±8.3	0.453
Baseline	21.8±9.8	26.8±8.3	0.004	18.9±8.9	26.2±8.2	0.035	16.6±9.6	26.4±8.4	0.001
End of the stage	27.4±11.1	31.3±8.8	0.051	30.2±12.1	34.3±9.8	0.210	30.5±12.1	37.3±9.8	0.091
<i>P</i> value	<0.001	<0.001		0.004	<0.001		0.007	<0.001	
Change in long jump (cm)	4.9±11.3	3.1±11.1	0.430	15.7±17.7	9.4±12.4	0.164	16.3±23.0	12.8±14.1	0.601
Baseline	109.6±27.6	121.1±29.1	0.037	101.6±34.4	120.7±30.0	0.176	95.4±30.8	122.5±31.1	0.010
End of the stage	114.5±28.9	124.2±27.2	0.094	117.3±37.1	130.2±30.8	0.207	111.6±40.8	135.3±29.9	0.074
<i>P</i> value	0.008	0.043		0.003	<0.001		0.052	<0.001	
Change in 800-m run (sec)	-13.1±55.2	-13.3±49.3	0.987	-65.5±62.8	-20.2±54.2	0.024	-20.7±68.0	-3.2±51.3	0.430
Baseline	479.9±102.7	431.8±65.1	0.010	517.8±97.9	428.3±67.5	0.015	522.5±124.6	418.0±62.7	<0.001
End of the stage	466.7±78.8	418.5±50.4	<0.001	452.3±83.3	408.2±60.1	0.060	501.8±100.0	414.8±63.8	0.006
<i>P</i> value	0.175	0.057		0.004	0.046		0.361	0.779	
Change in 6-min walk (m)	12.2±52.6	5.4±54.7	0.573	38.1±76.0	13.2±75.1	0.341	16.4±107.1	20.3±66.2	0.905
Baseline	508.1±79.7	538.3±83.7	0.226	497.1±95.9	537.4±72.4	0.365	501.3±99.3	547.4±85.8	0.079
End of the stage	520.3±69.1	543.6±72.9	0.165	535.2±81.3	550.6±73.7	0.558	517.6±117.1	567.7±79.2	0.114
<i>P</i> value	0.193	0.488		0.110	0.353		0.679	0.175	
Change in daily step (step)	2,901±2,650	1,256±1,933	0.021	476±5,182	280±2,677	0.912	-5,849±5,511	-711±3,427	0.070
Week 2	8,195±3,024	7,459±2,448	0.900	9,949±2,373	8,234±1,935	0.300	12,943±2,114	8,379±2,008	0.371
End of the stage	11,096±3,801	8,751±2,398	0.230	10,424±3,870	8,513±2,185	0.437	7,095±3,520	7,668±2,842	0.164
<i>P</i> value	0.001	<0.001		0.866	0.663		0.207	0.528	

Values are presented as mean±standard deviation or number (%).

SO, severely obese; non-SO, nonseverely obese.

Boldface indicates a statistically significant difference with *P*<0.05.

performance are indicative of consistent advancement throughout the intervention period (Table 4).

Discussion

This study underscores the critical importance of individualized interventions for children and adolescents with different obesity levels. Managing children and adolescents with severe obesity is a great clinical challenge. In our patient cohort, body fat percentages exceeded 40%, approximately 1.5 to 2 times the reference levels,^{24,25} highlighting the difficulties of weight reduction relying solely on individual willpower. Our data showed that structured multidisciplinary lifestyle program resulted in significant improvements in body composition and physical fitness, particularly among those classified as SO, emphasizing the need for personalized strategies in pediatric obesity management. The current study is valuable in providing data on a cohort of children and adolescents with severe obesity in an Asian population, for which limited data are available. In the era of advancing weight reduction interventions, such as weight loss medications and bariatric surgery, lifestyle modification remains the cornerstone and first-line approach.^{20,26} Our

findings support the application of a customized lifestyle modification program for obese children and adolescent with severe obesity.

With regard to body composition and physical fitness, at baseline, SO adolescents demonstrated markedly lower muscular endurance and cardiopulmonary fitness compared to their non-SO peers. Specifically, they performed worse in the 1-minute sit-up test and standing long jump, indicating deficits in core strength and explosive power. These findings align with prior research showing that severe obesity impairs not only physical health but also motor skill development, reducing motivation for physical activity and potentially reinforcing a cycle of inactivity and weight gain.^{27,28} However, both SO and non-SO participants performed comparably to normal-weight peers in the 6-minute walk test, suggesting that low-impact endurance activities are less influenced by obesity severity. Based on this, we replaced moderate-to-vigorous intensity exercise with a step-count-based approach to enhance adherence, increase daily activity, and reduce sedentary behavior. The comprehensive fitness assessments in this study provided critical benchmarks for developing targeted interventions for this vulnerable population.

During the early stages of the intervention, participants in the SO group exhibited greater reductions in weight, BMI, BMI z score, and body fat percentage. The primary goal of pediatric obesity treatment is not merely weight loss, but reduction in BMI to prevent obesity progression. A BMI reduction of over 5% has been proposed as a clinically meaningful outcome, similar to definitions used in adults.²⁹⁻³¹ Our findings indicate that a higher proportion of participants in the SO group achieved this threshold, suggesting greater responsiveness among those with severe obesity. Importantly, BMI reduction was primarily due to fat loss rather than height gain, reflecting the intervention's effectiveness in promoting meaningful body composition changes. This may be attributed to their higher baseline adiposity and lower fitness levels, which allowed for more rapid early improvements. Lifestyle modification therapy—integrating dietary changes, physical activity, and behavioral strategies—remains the cornerstone of pediatric obesity treatment, particularly for managing severe obesity.^{31,32}

Physical fitness improvements were observed across all participants, with significant gains in the 1-minute sit-up test, standing long jump, and 800-m run. The SO group showed a greater reduction in 800-m run times during the second stage, suggesting that sustained engagement in daily activity can lead to substantial fitness gains even among those with initially low capacity. This difference also implies that while the SO group benefits more from early-stage interventions, the non-SO group may require

Table 4. Bivariate correlation between weight loss and fitness variables

Variable	Δ Weight 4	Δ Weight 12	Δ Jump 4	Δ Jump 12	Step 2
Δ Weight 12					
PCC	0.734*				
P value	<0.001				
No. of patients	53				
Δ Jump 4					
PCC	-0.184	-0.253			
P value	0.071	0.077			
No. of patients	97	50			
Δ Jump 12					
PCC	-0.238	0.376*	0.334 [†]		
P value	0.103	0.008	0.023		
No. of patients	48	48	46		
Step 2					
PCC	0.335 [†]	0.193	-0.133	-0.252	
P value	0.011	0.307	0.329	0.196	
No. of patients	57	30	56	28	
Step 4					
PCC	0.435*	0.582*	0.018	-0.529*	0.688*
P value	<0.001	<0.001	0.893	0.003	<0.001
No. of patients	58	32	58	29	47

Δ Weight 4, weight loss in week 4; Δ Weight 12, weight loss in week 12; Δ Jump 4, standing long jump increase in week 4; Δ Jump 12: standing long jump increase in week 12; Step 2, daily step count in week 2; Step 4, daily step count in week 4; PCC, Pearson correlation coefficient.
*Significant correlation at the 0.01 level. [†]Significant correlation at the 0.05 level.

more advanced, progressively challenging goals-such as higher-intensity aerobic activities and strength training to avoid plateaus and optimize outcomes.

However, a weight loss plateau was observed in the final stage of the program, highlighting the need for strategies to sustain long-term progress. This stagnation may result from waning motivation or physiological adaptation to weight loss. One contributing factor could be the reduced frequency of follow-up visits between weeks 12 and 20, which may have impacted adherence.¹⁷⁾ To address this, we extended the program duration and introducing target BMI goals to improve engagement and outcomes. Future interventions should focus on optimizing long-term support and follow-up strategies.

Correlation analysis revealed that early improvements in physical activity, especially increases in daily step count and gains in lower-body strength were strong predictors of long-term success. These physical gains not only reflected reduced sedentary behavior but also improved muscular endurance and mobility, fostering a positive feedback loop of physical engagement. Setting achievable goals, such as increasing daily step count, helped build confidence, motivation, and sustainable habits early in the program. Given its predictive value, we advocate for integrating step-count tracking into routine health monitoring in schools and public health initiatives. Authorities should go beyond simple height and weight screening by including step count to better identify children and adolescents at risk due to insufficient physical activity. Early detection enables timely, targeted interventions that can prevent the progression of obesity-related complications.

The family-based nature of the program was central to its success. By involving parents in education, goal setting, and behavior modeling, the intervention created a supportive environment conducive to sustainable lifestyle changes. Parental involvement has been shown to significantly influence children's adherence to healthy behaviors, reinforcing the value of collaborative, family-centered approaches in managing pediatric obesity.³³⁾

This study has limitations. Attrition over time reduced the sample size, potentially affecting the generalizability of findings. The attrition from the lifestyle modification has been common issues in previous studies.^{34,35)} Nonetheless, those participants who remained in the program may represent a subgroup of cohort who are willing to engage and may benefit more from the program than those who did not continue the program. Additionally, the long-term sustainability of improvements of SO children and adolescents remains uncertain, warranting further follow-up studies. In our previous study, we have shown sustained effects after completion of the 5-month program. Future research should explore the psychological and social

factors influencing adherence and investigate strategies to enhance long-term engagements.

Footnotes

Supplementary materials: Supplementary Tables 1-3 are available at <https://doi.org/10.3345/cep.2025.01774>.

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