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ORIGINAL PAPER

Integrating diet and exercise to effectively reduce fat mass in children with obesity during weight reduction program

Julita Reguła[1], Zbigniew Kasprzak[2]

[1]Department of Human Nutrition and Dietetics, Poznan University of Life Sciences, Poznan, Poland
[2]Department of Hygiene, Poznan University of Physical Education, Poznan, Poland Institute of Health and Physical Education, Jan Amos Komenski State University of Applied Sciences in Leszno, Leszno, Poland

ABSTRACT

Introduction: This study is aimed to evaluate the effects of total daily energy expenditure (TDEE) on fat mass (FM) reduction in children with obesity and to develop nomograms to support the planning of weight reduction programs in children.
Material and methods: A total of 219 children with obesity aged 12–15 years participated in a 4-week summer camp weight reduction program. The intervention combined dietary energy restriction with various activities to increase exercise levels. Total daily energy expenditure was measured using continuous 24/7 HR monitoring. Changes in body weight and body composition – including fat mass, fat-free mass, and total body water – were measured using the bioelectrical impedance analysis.
Results: On average, TDEE exceeded dietary energy intake by approximately 2590 kcal per 24 h, resulting in significant body weight and FM reductions. Fat mass loss was greater in boys (3.3 kg) than in girls (1.8 kg). The prescribed physical exercise lasted 3–4 h per day and accounted for an average of 32% of total daily expenditure. Boys' total energy expenditure was markedly higher than that of girls, which corresponded to their significantly greater FM losses.
Conclusions: The weight reduction program proved effective for reducing FM in obese children. Fat mass loss was significantly affected not only by TDEE but also by the proportion of energy expended during therapeutic exercise, the energy cost of physical activity, and the overall daily energy balance of the participants. Individual engagement in physical activity was dependent on the degree of obesity at the start of the program. The results and the prepared nomogram can be used to develop recommendations for weight loss.

KEY WORDS:

childhood obesity, fat mass reduction, dietary intervention, physical activity, energy balance.

INTRODUCTION

Childhood obesity has risen sharply over the past two decades. According to the World Health Organization, 390 million children and adolescents under the age of 20 were overweight or obese in 2022. The prevalence of excessive body weight (including obesity) among children and adolescents aged 5–19 increased from just 8% in 1990 to 20% in 2022 [1]. Obesity negatively impacts overall health, placing affected children at risk for future complications, such as hypertension, dyslipidaemia, atherosclerosis, cardiovascular disease, and non-insulin-dependent diabetes. Early therapeutic intervention is therefore crucial to prevent metabolic consequences [2]. However, weight reduction in children requires particular caution, as inappropriate management may result in growth retardation, loss of muscle mass, or psychoneurological disorders. Recommended treatments for obesity in children and ado-

ADDRESS FOR CORRESPONDENCE:

Prof. Julita Reguła, MD, PhD, Department of Human Nutrition and Dietetics, Poznan University of Life Sciences, Poznan, Poland, e-mail: julita.regula@up.poznan.pl

lescents include lifestyle modification – comprising diet modifications, increased physical activity, and behavioural modifications [3, 4]. Evidence from Pauls *et al.* [5] and Spiga *et al.* [6] indicates that combined behavioural lifestyle interventions produce significant and clinically meaningful reductions in excess weight in children and adolescents compared to standard care or self-help approaches. Diet combined with physical activity plays a central role, as a balanced regimen can ensure adequate nutrient intake during growth, while maintaining a negative energy balance to promote fat loss. In everyday settings, achieving such a regimen can be challenging. Effective therapy requires a multidisciplinary approach involving physicians, nutritionists and physiotherapists. One persistent challenge is tailoring physical exercise programs to match an individual child's abilities and physical condition, which supports long-term adherence. Implementing such programs can be difficult during the school year due to competing academic demands; establishing appropriate procedures during a summer camp may offer a more feasible alternative. According to Izzicupo *et al.* [7], experiences gained during the camp can significantly influence lifestyle habits at home.

A summer camp dedicated to children with obesity offers unique opportunities for intervention: alongside a low-energy diet, regular therapeutic exercise can be provided, improving not only weight outcomes but also eating habits and psychological well-being. Currently, there is a lack of specific recommendations in the literature regarding the optimal intensity of therapeutic exercise in paediatric weight reduction programs and its proportional contribution to total daily energy expenditure. The present study aimed to address this gap by developing practical recommendations for planning slimming therapies in adolescents aged 12–15 years.

MATERIAL AND METHODS

The study was conducted on 219 adolescents with obesity from Poland, aged 12–15 years, who participated in a 4-week weight reduction program during a summer camp. This was a prospective, single-arm, interventional study without a control group. The program is a traditional, coeducational, residential summer camp held in a rural area of Greater Poland. Participants were children and adolescents aged 9–18 years with obesity defined according to national body mass index (BMI) for age percentile charts (BMI ≥ 95^{th} percentile for age and sex). Written informed consent was obtained from all participants and their parents.

All meals at the camp were served in the dining hall under the supervision of a registered dietitian. Meals were prepared according to the established nutritional plan (as a 1300 kcal low-energy diet); however, final energy intake was calculated based on actual intake. Plate losses were assessed by weighing portions and leftovers after each meal. The difference between the served and unconsumed portions was used to determine actual intake. Participants followed a low-calorie diet (5.47 $MJ24h^{-1}$) providing on average 58.1 g of protein, 37.3 g of fat, 182 g of carboydrates (Table 1). The energy content of all meals prepared during the intervention was calculated using the "Dietetyk" software (JuMaR), considering the plate losses.

TABLE 1. The contents (mean ± SD) of energy and macronutrients in diets of teenagers and average of parameters of energy expenditure during the therapy

Energy and macronutrients in diets	
EI [$MJ.24h^{-1}$]	5,47 ±0.36
Protein [g]	58.1 ±4.43
Animal protein [g]	39.9 ±4.07
Carbohydrates [g]	182 ±21.8
Fat [g]	37.3 ±5.62
Energy from protein (%)	18
Energy from carbohydrates (%)	56
Energy from fat (%)	26
TDEE [$MJ.24h^{-1}$]	13.2 ±1.6
EB [$MJ.24h^{-1}$]	–7.73 ±1.34

EB – energy balance (energy intake – total daily energy expenditure), EI – average energy intake, TDEE – average total daily energy expenditure

Total daily energy expenditure (TDEE) was assessed non-invasively using continuous 24-hour heart rate monitoring (Polar Sport Tester). At the same time, an individual regression was established between oxygen consumption and pulse rate using a Cardiorespiratory Diagnostic System (Medgraphics, USA). Oxygen consumption was measured at rest and during treadmill running [8–10]. From these measurements, the threshold pulse – known as HR-FLEX – was determined as the mean of the highest resting pulse rate and the lowest exercising pulse rate. Total daily energy expenditure was calculated as the sum of partial expenditures during sleep, low activity (pulse rate below HR-Flex, such as reading, watching TV, or attending lectures), moderate activity therapy (pulse rate above HR-Flex but below 140 bpm, typically during therapy-related exercise), and high activity (pulse rate above 139 bpm, associated with more intense physical effort). Therapeutic exercise included a variety of regular activities: brisk walking or running (covering a 7 km route), cycling (14–16 kmh^{-1}), swimming, bowling, dancing, walking (4–5 kmh^{-1}), morning exercises, team sports (basketball, football, volleyball), aerobics, and gym workouts (cycling on a cycloergometer at up to 70% VO2max, or treadmill running at approximately 10 kmh^{-1}). Energy expenditure was calculated from the recorded pulse rate data using the "Energia" software package (JuMaR).

Body composition, including fat mass (FM), fat-free mass (FFM), body cell mass (BCM), and total body water (TBW) was assessed by bioelectrical impedance analysis

TABLE 2. Anthropometric parameters of adolescents with obesity before and after the therapy (mean ± SD)

Parameters	Girls, $n = 114$		Boys, $n = 105$	
	Before therapy	After therapy	Before therapy	After therapy
Weight [kg]	80.6 ±10.5[a]	77.1 ±10.0[b]	87.8 ±16.2[A]	82.8 ±15.2[B]
FM [kg]	34.4 ±7.54[a]	32.6 ±7.39[b]	34.6 ±8.86[A]	31.3 ±8.30[B]
FFM [kg]	46.2 ±5.05[a]	44.5 ±4.26[a]	53.2 ±9.47[A]	51.6 ±8.95[A]
BCM [kg]	25.7 ±2.93[a]	24.7 ±2.68[a]	29.1 ±6.04[A]	27.7 ±5.37[A]
TBW [kg]	33.5 ±3.86[a]	31.6 ±2.68[a]	40.0 ±5.88[A]	39.0 ±5.53[A]

BCM – body cell mass, FFM – fat-free mass, FM – fat mass, TBW – total body water
Mean values with different superscript letters ([a,b] in girls, [A,B] in boys) within a column are significantly different at $p < 0.01$.

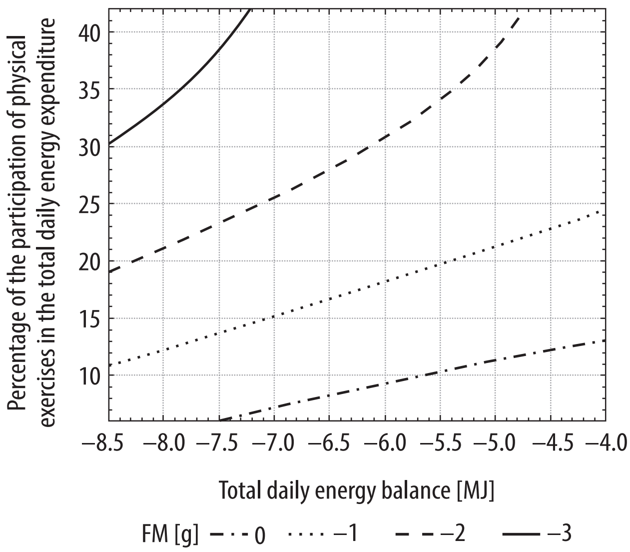

FIGURE 1. Changes in fat mass in children with obesity depending on the percentage of participation in physical exercises, energy expenditure and energy balance

FM – fat mass

using a BIA 101S bioanalyzer (AKERN-RJL). During the measurements, participants were in a supine position and remained at rest. Measurements were taken in the morning at both the beginning and end of the program. Anthropometric parameters of the patients are presented in Table 2.

Statistical analysis was performed using analysis of variance (ANOVA) for factorial designs, the Student *t*-test for dependent samples, and multiple regression analysis. All calculations were conducted using the STATISTICA™ PL software (StatSoft). Intergroup differences at $p < 0.01$ were indicated in the tables by different letters assigned to the columns.

RESULTS

The average TDEE considerably exceeded energy intake from the diet (on average approx. 7.73 $MJ24h^{-1}$) (Table 1). This negative energy balance was reflected in body weight loss, including reductions in FM, with significantly greater FM losses observed in boys (3.3 kg) compared to girls (1.8 kg) (Table 2).

No significant changes were noted during therapy in FFM, BCM, or TBW. Achieving a high negative energy balance during therapy was primarily due to increased physical activity among children with obesity. As part of the slimming program, regular physical exercise of varying intensity was prescribed, up to 70% VO2max. Daily exercise duration was 3–4 h, and on average, accounted for 32% of total daily expenditure.

Among the different forms of physical activity, the highest energy expenditure (approximately 4–5 $kcal.kg^{-1}$body weight) was observed during fitness club exercises (5.01 ±1.62 $kcal.kg^{-1}$ body weight), aerobics (4.52 ±1.41 $kcal.kg^{-1}$ body weight) and cycling (4.35 ±0.10 $kcal.kg^{-1}$ body weight).

Lower energy expenditure was recorded for swimming (3.77 ±0.72 $kcal.kg^{-1}$ body weight) and team sports such as football, basketball, and volleyball (3.37 ±0.81 $kcal.kg^{-1}$ body weight), while the lowest values were observed during evening walking (2.11 ±0.23 $kcal.kg^{-1}$ body weight). Multiple correlation analysis showed that FM loss was strongly associated with energy intake, exercise energy expenditure, and 24-hour energy balance ($Y = -4.55 + 0.0028 \times A + 0.0015 \times B + 0.0022 \times C$, $R = 0.56$, $p < 0.001$), where A represents the dietary energy intake (partial correlation $R = 0.20$ $p < 0.001$), B represents energy cost of exercise therapy (partial correlation $R = 0.23$ $p < 0.01$), and C represents 24-hour energy balance (partial correlation $R = 0.35$ $p < 0.001$).

Fat mass loss was also strongly correlated with the share of physical exercise in TDEE and the energy expended during exercise, with higher proportions of exercise in TDEE and greater energy expenditure during activity resulting in larger FM reductions in adolescents (Figure 1).

Analysis of the energy cost of physical effort during therapy per 1 kg of body weight revealed that girls participated in the exercise program less intensively than boys (Table 3).

Consequently, boys had markedly higher energy expenditures than girls, which corresponded to greater FM losses. Notably, individual engagement in the exercise program, expressed as MJ.kg body $weight^{-1}$, was inversely related to the degree of obesity at the beginning of therapy ($R = -0.47$, $p < 0.001$), indicating that adolescents with higher BMI values were less actively involved in the exercise program.

TABLE 3. Average values of the energy cost of physical effort during the therapy and the activities outside the therapy for children with obesity (mean ± SD)

Parameters	Girls	Boys
Energy cost of physical effort related to the therapy		
[kcal]	1001 ±167	1137 ±201
[MJ]	4.18 ±0.69	4.75 ±0.84
Energy cost of physical effort related to the therapy		
[kcal.kg^{-1} body weight]	12.5 ±2.11	13.7 ±2.38
[MJ.kg^{-1} body weight]	0.052 ±0.009	0.057 ±0.01
Energy cost of activities outside the therapy		
[kcal]	1284 ±296	1516 ±503
[MJ]	5.37 ±0.82	6.34 ±2.10
Total daily energy expenditure		
[kcal]	2919 ±271	3427 ±530
[MJ]	12.2 ±1.13	14.3 ±2.21

DISCUSSION

The summer camp weight reduction program for adolescents with obesity led to significant reductions in both body weight and body fat, but importantly, there was no reduction in FFM or total body water. Weight loss averaged 1–2 kg per week, consistent with the recommendation that this rate is optimal for long-term effectiveness. However, reductions in body weight and FM were significantly greater in boys than in girls. This difference may be explained by lower engagement of girls in prescribed physical activities, reflected in energy expenditure per kg body weight. Boys participated more actively, which may be influenced by psychological factors as well as sex-specific differences in body composition [11]. Additionally, sex differences in obesity may be partially explained by the influence of gonadal steroids on body composition, along with behavioural, socio-cultural, and chromosomal factors [12].

Children with obesity often exhibit low physical fitness and endurance, so the intensity of physical activity should be tailored to individual capabilities to reduce the risk of complications [13]. Numerous authors [14] recommend moderate-intensity exercise (30–70% of maximum workload, heart rate below 150 bpm) that does not overload the knees, hips, or spine. Suitable activities for children with obesity include swimming, cycling, disco dancing, and team sports such as soccer, basketball, and volleyball. These activities are often perceived as enjoyable and can be maintained for longer durations. Different types of exercise also have distinct effects on body composition and physiological processes.

Previous studies [15, 16] indicate that achieving significant energy expenditure during exercise requires the engagement of large muscle groups. Disciplines such as cycling, swimming, and team sports meet this criterion. Moreover, total energy expenditure is often more important than exercise intensity; for example, running one kilometre expends nearly the same energy as walking the same distance. Observations of young people suggest that they may be more willing to engage in these activities than in aerobics or gym exercises. This preference is meaningful in terms of energy expenditure: for instance, a two-hour bike ride or participation in team sports by a 78-kg individual expends approximately 684–694 kcal, whereas 45 minutes of gym exercise expend only 351 kcal.

Therefore, the positive results of weight loss therapy were influenced not only by the magnitude of the negative energy balance but also by the intensity and duration of the therapeutic exercise. A significant aspect of this study is the relatively low dietary energy intake (approximately 1300 kcal/day) compared with the estimated energy requirements of adolescents aged 12–15 years. Considering both age-specific recommendations and the high level of daily physical activity observed in this study, participants' total energy requirements were significantly higher, potentially corresponding to a physical activity level of approximately 1.6–1.8. Consequently, the substantial energy deficit observed in this study was likely a primary driver of the rapid FM reduction. This low-energy diet was proposed based on existing studies that have assessed the effectiveness of weight-loss diets in the range of 1200–1800 kcal/day, depending on gender and individual characteristics [17, 18]. Furthermore, systematic reviews indicate that energy-restricted diets used in childhood obesity interventions typically fall within the range of 1000–2000 kcal/day [19, 20]. The controlled environment of the camp allowed for close monitoring of both intake and physical activity, ensuring participant safety despite the significant energy deficit.

Regular exercise contributed substantially to the negative energy balance, although the role of dietary restriction should also be acknowledged, particularly given the low energy intake applied in this intervention.

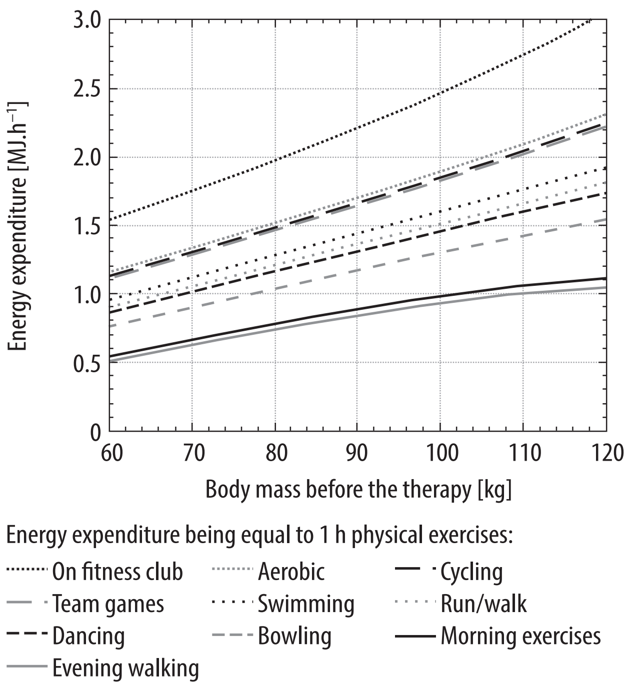

FIGURE 2. Nomogram for planning physical activity

At the summer camp, exercise sessions lasted an average of 3–4 hours per day and accounted for 29–35% of total daily energy expenditure. This is relatively high compared with recommendations of Pyšná *et al.* [21] who suggested that energy expenditure from exercise in young people should constitute 20–30% of total daily expenditure.

The study also clarified the extent to which physical activity contributes to generating a negative energy balance sufficient for effective therapy. It was found that with a TDEE of 11.7–13.8 MJ and an exercise energy cost of 3.77–4.19 MJ, approximately 3–4 hours of varied daily physical activity is sufficient to achieve beneficial results. Therapies may be most effective when the energy cost of exercise accounts for roughly 33% of total daily energy expenditure. Additionally, it was observed that individuals with considerable obesity require special attention when planning therapeutic exercise, as participation levels depend strongly on initial body weight. Therefore, participants should be divided into groups with similar body weight, and detailed exercise schedules should be tailored based on the results of this study, as illustrated in the proposed nomogram (Figure 2). The results are consistent with the observations of Dettlaff-Dunowska *et al.* [22], who found that overweight children, especially boys, are at greater risk of reduced physical fitness. Furthermore, there is a close relationship between the degree of obesity, nutritional status, and the incidence of metabolic complications in children. A study by Koziol-Kozakowska *et al.* [23] showed that high blood pressure, high triglyceride levels, and impaired glucose tolerance are more common in children with severe obesity, increasing the risk of type 2 diabetes and fatty liver disease.

A 4-week body weight reduction program conducted at a summer camp for obese adolescents aged 12–15 years proved to be effective, resulting in significant body weight and FM loss, with substantially greater reductions observed in boys. Changes in body weight were influenced by total daily energy balance and the energy cost of therapeutic exercise. Fat mass loss was significantly affected not only by TDEE but also by the proportion of energy expended during therapeutic exercise, the energy cost of physical activity, and the overall daily energy balance of the participants. Individual engagement in physical activity was dependent on the degree of obesity at the start of the program.

LIMITATIONS

This study has several limitations that should be considered. The study population consisted of participants in a structured summer camp-style weight loss program, which may limit the generalizability of the results to the broader population of children with obesity. Compliance with dietary and physical activity recommendations was closely monitored during the camp, so the results may not reflect real-world conditions, especially outside of a controlled environment. Potential measurement error associated with body composition assessment cannot be ruled out. Bioelectrical impedance analysis results can be influenced by changes in hydration status, particularly during rapid weight loss, potentially affecting the accuracy of body FM measurements. This is particularly important for short-term interventions where rapid water loss may occur. However, it is important to note that in this study, all measurements were performed under standardized conditions (morning, fasting) and no significant changes in total body water were observed. Furthermore, the lack of long-term follow-up limits the assessment of the sustainability of the observed effects.

CONCLUSIONS

It is important to emphasise, however, that the intervention was short-term (4 weeks), so the results should be interpreted cautiously in the context of long-term weight management. Returning to habitual lifestyle patterns after the intervention may be associated with partial regain of body fat. Furthermore, although intensive, short-term interventions can be effective in reducing fat mass, their repeated use may potentially influence metabolic adaptations; therefore, such approaches should be used with caution, especially in growing individuals.

DISCLOSURES

1. Institutional review board statement: This study was approved by the Ethics Committee of the Poznań University of Medical Sciences (approval decision no. 174/14, dated: 13.02.2014).

2. Assistance with the article: None.
3. Financial support and sponsorship: None.
4. Conflicts of interest: None.

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