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ORIGINAL CONTRIBUTIONS

Pre-surgical Weight Loss Predicts Post-surgical Weight Loss Trajectories in Adolescents Enrolled in a Bariatric Program

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Abstract

Introduction Adolescent obesity is markedly increasing worldwide and bariatric surgery is emerging as an effective treatment option. However, a subset of patients fails to achieve significant weight loss or show post-surgical weight regain. Efforts have been made to identify different post-surgical weight trajectories and their possible predictors. Furthermore, the role of pre-surgical intervention programs in optimizing post-surgical results has been a subject of debate.

Objectives This study aimed to evaluate the impact of a 3-month lifestyle-oriented pre-surgical program for adolescent candidates for bariatric surgery on pre-surgical weight loss (body mass index (BMI) on completion − BMI at admission), and to identify predictors of different post-surgical weight loss trajectories.

Methods Forty-eight adolescent bariatric surgery candidates were enrolled in a lifestyle- and behavior-oriented bariatric program consisting of a 3-month pre-surgical outpatient intervention and a 6-month post-surgical follow-up.

Results Mean BMI decreased by 1.82 points (SD = 1.83) during the program's pre-surgical intervention phase, a 3.8% average drop in participants' BMI; post-surgical weight loss trajectories were significantly associated in a curvilinear model with pre-surgical weight loss; optimal post-surgical results were associated with moderate pre-surgical weight loss, and inversely associated with maternal history of obesity, early-life weight loss attempts, and comorbid learning disorders.

Conclusions Moderate weight loss in a pre-surgical lifestyle-oriented intervention program predicts optimal post-surgical weight loss. Additionally, by assessing risk factors and pre-surgical weight loss patterns, it may be possible to identify sub-populations of adolescents undergoing bariatric surgery at risk of achieving sub-optimal long-term results.

Keywords Bariatric surgery · Laparoscopic sleeve gastrectomy (LSG) · Adolescents · Pre-surgical · Program · Intervention · BMI · Prediction · Trajectory · Obese · Lifestyle

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Introduction

Adolescent obesity has markedly increased worldwide in its extent and prevalence in recent decades, and is associated with many serious comorbid conditions [1, 2]. Unfortunately, conservative treatment options have shown limited efficacy [3]. As a result, bariatric surgery, used to treat adults with severe obesity for many decades, is emerging as an accepted treatment option for adolescents [4].

Although adult populations undergoing bariatric surgery have been extensively studied, studies have only recently focused on short-term follow-up in the adolescent bariatric population [5, 6].

Inge et al., in a 5-year follow-up study, found that adolescent bariatric outcomes (BMI and presence of elevated blood pressure, dyslipidemia, and type 2 diabetes) are positive overall, with maintenance of weight loss and

improved health trajectories [6]. However, a subset of patients demonstrate weight regain on post-surgical follow-up, with some beginning to gain weight as early as 6 months post-surgery [7–11]. Hence, a fraction of adolescents undergoing bariatric surgery ultimately fail to achieve significant weight loss [6]. In order to optimize post-surgical weight loss trajectories, research has focused on identifying possible predictors for these patient subsets and their weight loss trajectories [12].

Results, however, are mixed. Many factors have been implicated as potentially predictive of the degree of weight loss that can be expected following bariatric surgery, but few are strongly and consistently supported in the literature. Furthermore, most have been studied in adults only.

Studies in the adult population identified demographic and pre-surgical factors such as marital status, race, physical activity, [12] dietary adherence, [13] baseline BMI, [13, 14] and personality disorders as possible predictors of post-surgical weight loss [14]. Mitchell et al., in a large cohort of adults undergoing bariatric surgery, found that three modifiable behaviors in the post-surgical period (self-weighing, not eating when full, and lack of eating continuously) were associated with a more favorable weight change 3 years after bariatric surgery [15].

In other studies, however, lifestyle and behavioral factors have not been found to be statistically significant predictors of success in long-term weight loss [16]. A meta-analysis reported that pre-surgical variables, such as previous weight loss attempts, maladaptive eating patterns such as binge eating and consuming sweets, depression, anxiety, history of sexual abuse, low self-esteem, past/current alcohol abuse/use, and other psychiatric disorders do not appear to predict poorer outcomes [14].

The only study addressing predictors in the adolescent population, a study from the Teen-Lab consortium, did not find behavioral factors to be predictors of success in long-term weight loss maintenance [16].

In another attempt to predict post-surgical weight outcomes, studies used early post-surgical weight loss amount to identify long-term weight loss trajectories in adults. Manning et al. found that the percent of weight lost and weight loss velocities during the 6-month period following laparoscopic sleeve gastrectomy (LSG) and Roux-en-Y gastric bypass (RYGB) were strongly associated with maximal weight loss and the weight loss percent at 2 years [17]. Obeidat et al. found a strong correlation between 1-month post-LSG %EWL (excess weight loss) and %EWL at 1 and 2 years post-surgery [18]. Mor et al. found that at 12 months following RYGB, the majority of patients continue to be in the same weight loss quartile to which they were initially classified at 1-month post-operation [19]. Taken together, these studies demonstrate that the amount of weight loss during the first few months following surgery may predict long-term weight loss and can reasonably be used as an indicator of post -surgical weight trajectories.

As opposed to solely identifying characteristics of patients to predict weight loss patterns following bariatric surgery, some research groups attempted to *modify* these trajectories through pre-surgical intervention programs or weight loss regimens. Although the issue of mandatory pre-surgical weight loss in adults is still under debate, the American Society for Metabolic and Bariatric Surgery (ASMBS) currently recommends pre-surgical weight loss for patients at risk [20], and pre-surgical weight loss regimens prior to bariatric surgery have been a routine, common, and sometimes mandatory practice in the USA and around the world [21]. Studies have tried to evaluate the efficacy of such weight loss regimens and pre-surgical intervention programs in improving short- and long-term results, including peri-surgical complications and weight loss following bariatric surgery [21–27].

Some of these studies, conducted in adults, have reinforced the advantages of pre-surgical weight loss programs in improving peri-surgical outcomes, showing improved surgical access and navigation [28, 29], modification of risk factors associated with peri-surgical morbidity [30], significant reductions in liver volume [31], reduced post-surgical complication rates [25, 30], and improved dietary control and weight loss after surgery [32]. A 2012 systematic review has further shown that mandatory pre-surgical weight loss is associated with weight loss after surgery [14].

Other research, however, suggests differently. A study by Kalarchian et al. in 2016 found no favorable effect for their pre-surgical lifestyle intervention in adults on weight loss over the first 2 years following surgery, and no reduction in complication rates [25]. Additional studies have found similar results [24]. A 2017 review by Kim JJ concluded that there is insufficient evidence to support an association between mandatory participation in a pre-surgical weight loss regimen, and achieved weight loss or durable bariatric outcome benefit [21]. In conclusion, current knowledge is affected by an ongoing debate based on mixed results concerning the utility of pre-surgical intervention programs in the adult population.

In adolescents, studies examining pre-surgical intervention programs are scarce. Some studies have evaluated the feasibility of pre-surgical intervention programs [33, 34]. However, to our knowledge, studies have not yet examined the impact of such programs on pre-surgical weight and comorbid conditions, or on post-surgical weight loss.

Study goals: The present study aimed:

1. To evaluate the impact of a lifestyle-oriented behavioral-change intervention program on pre-surgical weight in adolescent candidates for bariatric surgery

2. To identify pre-surgical patient characteristics associated with different weight loss trajectories following bariatric surgery
3. To evaluate the impact of pre-surgical weight changes on post-surgical weight loss, at 6 months post-bariatric surgery

Materials and Methods

The study was conducted in a medical psychiatric ward in Schneider Children's Medical Center of Israel, a tertiary general children's medical center. The department includes a special service for the management of eating disorders and obesity including outpatient, inpatient, and day treatment care. The bariatric program was developed to meet the needs of morbidly obese adolescent candidates for bariatric surgery, using a day treatment format. The multidisciplinary team includes a pediatric surgeon with special expertise in laparoscopic bariatric surgery, pediatric endocrinologist, medical management nurse, and a psychosocial and nutritional team responsible for delivering the pre- and post-surgical bariatric protocols. The latter team is composed of a child and adolescent psychiatrist, psychiatric nurse, physical education teacher, social worker, dieticians, psychotherapists, and social guides/mentors (undergraduate psychology students), all with special expertise in adolescent bariatric surgery.

Description of the Psychosocial and Nutritional Program

Treatment Format and Principles

The Bariatric Adolescent Program is based on a 9-month, day treatment format, beginning with 3 months of pre-surgical weekly assessments and preparation, followed by a multidisciplinary bariatric committee for surgery approval, the bariatric surgery itself, and 6 months of post-surgical day treatment follow-up at a frequency of once a week to once a month. The goals of the program are to educate about bariatric surgery, introduce self-monitoring of food intake and daily activities, induce lifestyle changes, and encourage familial involvement and lifestyle changes. The study was approved by the institution's IRB (Helsinki Committee).

The day treatment program is based on a highly structured format conceptualized as an open group treatment of approximately ten adolescents at a time, who are both pre- and post-bariatric surgeries. Patients attend the unit once a week, arriving at 8:00 am and staying until 14:00 pm. They continue their routine life at home and at school while applying the program recommendations.

The weekly sessions in the pre-surgical phase include:

1. Dietary and activity counseling: Patients and their families receive individual diet and activity counseling sessions, conducted by a bariatric dietician, which implement the following principles: normalization of food intake with no mandatory weight loss (eating three balanced meals and three snacks a day, as prescribed by the National Institute for Food of Israel, and drinking up to 1.5 L of water), encouragement to decrease sedentary activities (e.g., TV time, computer games, internet activities, social networking) during and after school hours, and adherence to an individual moderate physical activity program. Patients are required to record daily food intake and activities, and review the results of their self-monitoring with the dietician while discussing any difficulties. Behavioral home chores are given, including exposure to relevant food cues and reduction of sitting behaviors.
2. Family sessions: Parents and adolescents participate in monthly group sessions that employ interventions based on problem-solving and role-playing techniques. To assist their child in adopting a change in lifestyle and encourage their cooperation and involvement with the treatment program, parents receive psychoeducation focused on the importance of regular family meals, preparation of healthy foods, reduction of sedentary activities, and parental modeling.
3. Individual supportive therapy: Individual therapy, delivered weekly by psychotherapists (social workers and art therapists), is based on cognitive behavioral principles, and provides psychoeducation and support [35]. Therapy is focused on different cognitive, behavioral, and interpersonal aspects such as interpersonal problems and difficulties developing close relationships. A requisite for surgical approval is the achievement and maintenance of basic normal functioning (adequate attendance to school, participation in basic social interactions, and participation in home chores), and candidates receive encouragement and tools for achieving this goal during the program.
4. Group therapy and activities: Group therapy is delivered by a drama therapist and is based on a problem-solving and interpersonal approach—identifying problems, discussing different options to address difficulties, role-playing situations, practicing "homework" to cope with difficulties in real life (e.g., dealing with bullying at school). Other group activities include group supervised planning, preparing and consuming meals, and a physical activity group.
5. Psychiatric assessments are performed at admission and psychiatric interventions are implemented according to the adolescent's needs.

The hospital's IRB approved the program protocol.

Participants

The study group consisted of adolescents aged 13–18 (mean 16.2, SD = 1.23) with a diagnosis of morbid obesity, who were admitted to the pre-surgical intervention program described above.

Participants were referred to the program by the hospital's inpatient or outpatient pediatric units or by a pediatrician in the community (the diagnostic workup was performed by an endocrinologist prior to the referral). Eligibility criteria, as recommended by the Israeli Ministry of Health [36], were body mass index (BMI; weight in kilograms/height in meters squared) > 35 with a serious physical complication amenable to improvement by weight reduction, or BMI > 40 with a less severe medical complication and previous failure to lose weight in intensive outpatient programs. Exclusion criteria were a medical, disease-related etiology for the obesity (e.g., Prader Willi syndrome, genetic syndrome, and brain tumor), intellectual disability or inability to understand or cooperate with the program requirements, and a diagnosis of a severe non-stabilized psychiatric disorder at the initial assessment that required acute intervention outside the scope of the program. Also excluded were patients whose caretakers refused to attend the program.

Forty-eight participants were enrolled in the program (n = 48). Tables 1 and 2 show the patients' characteristics. Three participants dropped out before completing the pre-surgical phase of the program, two participants received a recommendation to not complete the program due to behavioral difficulties that impeded their cooperation, and 43 participants completed the 3-month pre-surgical program.

Table 1 Patient characteristics and comorbidities

Characteristic/comorbidity		Frequency	Percent
Gender	Male	18	37.5
	Female	30	62.5
Ethnicity	Jewish	40	83.3
	Arab	8	16.7
Father overweight		21	71
Mother overweight		25	65.8
Hypertension		9	23.7
Diabetes mellitus type 2		2	5.3
Pre-diabetes		18	47.4
Obstructive sleep apnea		26	66.7
Musculoskeletal pain		28	71.8
ADHD		19	51.4
Learning disorders		18	48.6

Table 2 Patient characteristics

	Mean	Std. deviation
Age at enrollment	16.2	1.23
BMI at enrollment	47.97	5.42
Age of first weight loss attempt	10.6	2.57

Following completion of the program, four participants were not recommended for surgery by the multidisciplinary bariatric committee, due to non-adherence to nutritional recommendations (two participants), inability to adhere to lifestyle changes (one participant), and extreme lack of a supportive system (one participant). One participant chose not to undergo surgery due to satisfactory pre-surgical weight loss. Patients with non-adherence to dietary recommendations and lifestyle changes received a recommendation to repeat the program at a future date. Thirty-eight participants underwent bariatric surgery. During the 3-months period post-surgery, one patient dropped out from follow-up, and two patients have not yet completed the 3-month follow-up at the time of writing this article. Thirty-five participants completed the 3-month post-surgical follow-up. Four participants have not yet completed the 6-month post-surgical follow-up, while 31 participants completed the 6-month post-surgical follow-up.

The clinical investigator provided oral and written explanations of the nature and purpose of the study to the parents and patients. Prior to enrollment, parents of all participants signed a consent form, and patients provided assent to participate.

Description of the Bariatric Surgery Performed

All participants underwent laparoscopic sleeve procedure followed by a 2-day inpatient hospitalization in the surgical ward.

Assessment Protocol

Patients were assessed at four time points throughout the treatment protocol.

Admission assessment (T1) A physician along with a dietician or a nurse conducted the admission assessment. Patients underwent a physical examination consisting of weight and height measurement, vital signs, a general physical exam, and an electrocardiogram. The medical record was reviewed for medical comorbidities, and a full psychiatric assessment was performed (which included an interview assessment, developmental history as reported by parents, and examination of medical records for psychiatric comorbidities). Notably, this medical workup was not designated for surgical assessment

(which was performed elsewhere by a surgical staff). A demographic and lifestyle semi-structured interview, specially developed by the program, was administered at this timepoint to patients, as well as to parents, eliciting information regarding ethnicity and religion, familial eating habits and activity habits (both physical and recreational), and familial weight and dieting history.

Pre-surgical assessment (T2) An assessment was performed at 3 months following enrollment and immediately prior to surgery. Patients underwent a physical examination consisting of weight, height, and vital signs measurement by a physician or a nurse.

Post-surgical assessments (T3, T4) Patients underwent a physical examination consisting of weight, height, and vital signs measurement at 3 and 6 months post-bariatric surgery (T3 and T4, respectively).

In addition to the aforementioned assessments, a battery of questionnaires was administered at each timepoint (T1, T2, T3, T4) in an attempt to receive a more detailed and comprehensive assessment of the participants' characteristics and mental health throughout the duration of the program and follow-up (these questionnaires included BDI-II for assessing depression [37], PBI for assessing parenting and parental bonding [38], EDE for assessing eating disorder psychopathology [39], a bullying assessment questionnaire [40], SDQ, a brief behavioral screening questionnaire [41], PEDSQL to assess health-related quality of life [42], and MDQ to assess mood disorders) [43].

Data Collection and Extraction

BMI data was collected prospectively from the physical examinations conducted at all timepoints. Demographic information (age, sex, ethnicity) was extracted from the psychiatric assessment and from the semi-structured interview (both at T1). Medical and psychiatric comorbidities and pharmacotherapies were obtained from the psychiatric assessment at admission (as reported by parents and by the adolescents) and from medical records. Daily routine information (e.g., physical and sedentary activities, sleeping habits), social functioning information (e.g., social difficulties and bullying), patient and familial weight history, dieting history, and weight goals (i.e., the patient's ideal weight as perceived by the adolescent and by the parents) were obtained primarily from the semi-structured interviews administered to patients and parents (T1). Daily food intake and activity details were obtained from self-monitoring reports (see the "Treatment Format and Principles" section). Program attendance (by adolescents and by parents) was noted prospectively at each visit.

Data Analyses

In order to examine changes in BMI during the intervals between assessments, paired sample *t* tests were used. BMI reduction during the pre-surgical program was calculated as the delta between T1 and T2, BMI reduction during the 3-month postoperative period was calculated as the delta between T2 and T3, and BMI reduction during the 6-month postoperative period was calculated as the delta between T2 and T4.

A preliminary correlation analysis was conducted to screen for correlations between baseline patient characteristics and the amount of weight loss at 6 months post-surgery. The patient characteristics were as follows: age, sex, ethnicity, BMI at enrollment, parental weight, ideal weight, age of first weight loss attempt, medical comorbidities (e.g., HTN, diabetes and pre-diabetes, OSA, musculoskeletal pain, hyperlipidemia, fatty liver, PTC, hirsutism, PCOS), psychiatric comorbidities (ADHD, dysthimia, depression, anxiety), history of psychiatric treatment, psychiatric stimulant use (methylphenidate), learning disorders, social difficulties and bullying, sleeping difficulties, and physical activity. Three characteristics were found to have a significant correlation, and therefore were included as predictors in the multiple regression: age of first weight loss attempt, learning disorders, and maternal overweight status (see Table 3 for the correlation matrix).

Next, hierarchical multiple regression was conducted (Table 4). The dependent variable was BMI reduction during the 6-month postoperative period. Predictors were entered in three steps: [1] age of first weight loss attempt, learning disorders, and maternal overweight status; [2] BMI reduction during the pre-surgical program; and [3] the squared value of BMI reduction during the pre-surgical program. The squared value presented at step 3 allowed us to test the possibility of a quadratic association (in contrast to a linear association examined at step 2) between pre-surgical weight loss and

Table 3 Correlation matrix between the study variables and BMI reduction at 6 months post-surgery

	BMI reduction at 6 months post-surgery
Gender	− 0.093
Age at enrollment	0.287
Ethnicity	0.059
Age of first diet	0.49*
Physical activity	− 0.225
ADHD	− 0.075
Learning disorders	− 0.36*
BMI at enrollment	0.059
Father overweight	− 0.146
Mother overweight	− 0.54**

*$p < 0.05$; **$p < 0.01$ (two-tailed)

Table 4 Results of hierarchical regression analyses predicting BMI reduction at 6 months post-surgery

Predicting variables		Step 1	Step 2	Step 3
Step 1	Maternal overweight status	− 0.47**	− 0.45**	− 0.35**
	Learning disorders	− 0.34*	− 0.34*	− 0.35**
	Age of first weight loss attempt	0.32*	0.3	0.36**
Step 2	Pre-surgical BMI reduction		− 0.2	1.23**
Step 3	Pre-surgical BMI reduction squared			− 1.49**

*$p < 0.05$; **$p < 0.01$ (two-tailed)

weight loss at 6 months. All analyses were performed using SPSS 18.

Data Excluded from Analysis

Data analysis from the aforementioned questionnaire battery was discontinued due to an overt homogeneity of results, which showed a uniform lack of psychopathology or other difficulties whatsoever (presumably, adolescents did not disclose authentic information about their inner personal life due to a belief that they would be denied surgery if they were to disclose psychopathology).

Similarly, analysis of compliance with the formal program requirements (i.e., attendance and food monitoring) was disregarded due to uniform formal compliance—all patients were fully attendant due to the a priori requirement of the surgical approval committee that surgical approval would be conditioned by pre-surgical program compliance (i.e., patients who were to show poor attendance would not be granted surgical approval). Analysis of self-monitoring food reports showed a uniform high compliance with program recommendations (uncorrelated with individual weight changes) and was similarly considered unreliable.

Results

Paired samples *t* test analyses revealed significant changes in BMI at all assessment intervals (see Fig. 1: BMI (mean) at all assessment points). Significant differences ($t_{42} = 6.55$, $p < 0.001$) were found between BMI at T1 ($n = 48$, $M = 47.97$, SD = 5.33) and BMI upon completion of the program (T2; $n = 43$, $M = 45.93$, SD = 5.59). A significant difference ($t_{34} = 24.49$, $p < 0.001$) was also found between BMI at T2 and BMI at 3 months postoperative assessment (T3; $n = 35$, $M = 37.92$, SD = 5.3). Finally, a significant difference ($t_{30} = 26.13$, $p < 0.001$) was found also between BMI at T3 and BMI at 6 months postoperative assessment (T4; $n = 31$, $M = 35.08$, SD = 5.75). The overall BMI change from admission (T1) to 6 months follow-up (T4) was assessed using a paired samples *t* test, and was found to be 12.79 BMI points ($n = 31$, SD = 2.61, $p < 0.001$).

Preliminary correlation analysis revealed a positive correlation between BMI reduction at 6 months post-surgery and age of first diet ($r = 0.49$*). In addition, significant negative correlations were found between BMI reduction at 6 months and learning disorders ($r = -0.36$*), as well as mother overweight ($r = -0.54$**) (see Table 3 for the correlation matrix).

In the hierarchical multiple regression model, the independent variables explained 72.8% of the variance (F1, 18 = 9.88. $p < 0.01$). In step 1, maternal history of obesity was negatively associated with BMI reduction at 6 months (Beta = − 0.474, $p < 0.01$) and so was the presence of a learning disorder (Beta = −0.474, $p < 0.01$). Age of the first attempt to diet was positively associated with BMI reduction at 6 months (Beta = − 0.32, $p < 0.05$), i.e., older age of first lifetime diet was related to a greater BMI reduction at 6 months post-surgery. In step 2, the association between BMI reduction during the program and BMI reduction at 6 months did not reach significance. In step 3, squared BMI reduction during the program was positively associated with BMI reduction at 6 months (Beta = − 1.45, $p < 0.01$), revealing a quadratic association between the variables (see Fig. 2)—i.e., moderate weight loss during the pre-surgical program was associated with the greatest BMI reduction at 6 months post-surgery, whereas both extremes of the quadratic curve (minimal as well as extreme pre-surgical weight loss) were associated with poorer results at 6 months post-surgery.

No significant differences in any baseline characteristics (demographic, medical, psychiatric, etc.) were found between program completers and dropouts.

Discussion

The participants significantly lost weight and reduced BMI during the 3-month intervention in the pre-surgical lifestyle change program, with a mean reduction of 1.75 BMI points. It is important to stress that the program did not directly target weight loss but rather the implementation of lifestyle changes among adolescent candidates for bariatric surgery. Weight loss was not mandatory for surgical approval.

Among adult populations, pre-surgical intervention programs have been assessed in multiple studies [21–27]. To

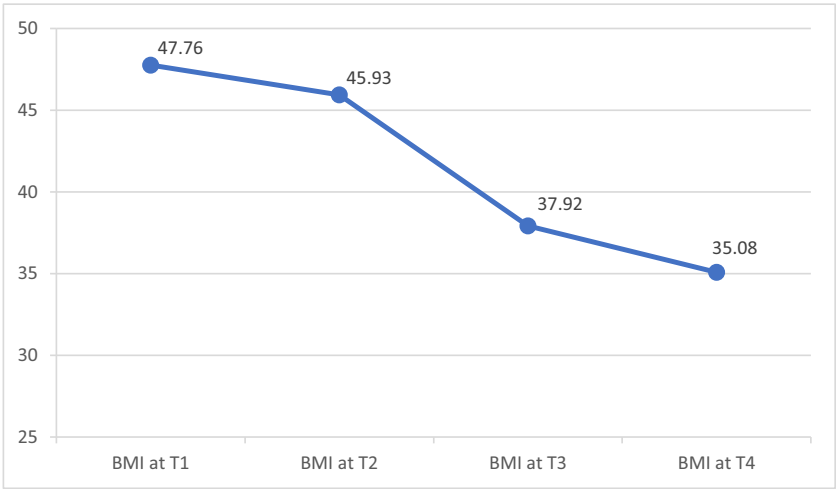

Fig. 1 BMI (mean) at all assessment points

our knowledge, this is the first study to evaluate the impact of a pre-surgical intervention program on pre-surgical weight loss among adolescents.

Despite recommendations for multidisciplinary pre- and post-surgical interventions [3, 36, 44], adolescents seem to be relatively reluctant to stay engaged in pre- and post-surgical bariatric programs. In a study by Cohen et al. evaluating a pre-surgical program, 42 % of participants were non-completers [33]. In contrast, favorable adherence was found in the bariatric program described in the current study. The program had a very low dropout rate, with 85% of participants fully completing it. This finding may be attributed to program attendance being required for surgical approval by the bariatric committee.

A review of the literature concerning the impact of pre-surgical weight loss on post-surgical weight loss among adults showed mixed results. In a 2017 review, Kim JJ did not find sufficient evidence to support a mandatory pre-surgical weight loss regimen prior to bariatric surgery. Such participation was not associated with amount of post-surgical weight loss [21]. However, the heterogeneity in the designs and results of the examined studies limits the validity and applicability of the review's conclusions (e.g., small sample sizes, inconsistencies in study methodologies, omissions of dietary strategy, and different surgical procedures). Contrasting with these results is a 2018 retrospective chart review by Krimpuri et al. that evaluated the predictive value of pre-surgical weight loss on 1-year post-surgical change in BMI in adults. Results showed that pre-surgical weight loss was a significant predictor of 1-year change in post-surgical BMI [45].

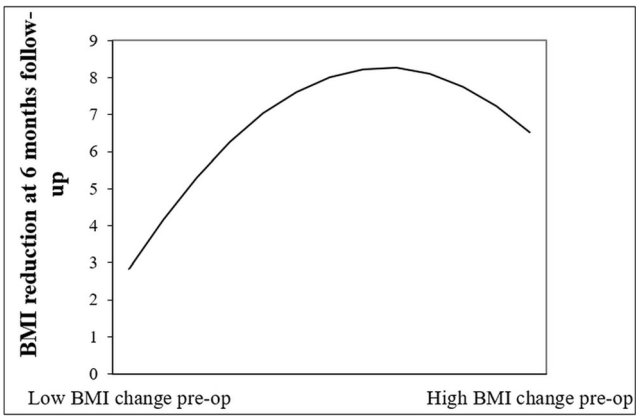

Fig. 2 Estimated pattern of the associations between pre-surgical BMI reduction and BMI reduction at 6 months follow-up: a quadratic effect

All of the above studies were conducted with adult participants. Participants were not enrolled in a pre-surgical program, and weight loss, or lack of, was not achieved through a comprehensive and structured intervention. Furthermore, in some studies, pre-surgical weight loss was a mandatory requirement for surgery.

In the current study, participants were all adolescents within a narrow age range. They were all enrolled in the same highly structured pre-surgical program directed towards lifestyle modification, and underwent the same surgical procedure (LSG). Weight loss was not mandatory for surgery, but rather attendance and compliance with program recommendations.

Results of the current study show that pre-surgical BMI reductions were significantly associated, in a curvilinear model, with BMI reduction at 6 months post-surgery (illustrated in Fig. 2). This finding indicates that the most significant post-surgical reductions in BMI were associated with moderate pre-surgical BMI reductions (pre-surgical BMI reduction of 2.4 points was associated with the most significant post-surgical losses). Moderate pre-surgical weight loss may reflect behavioral and dietary stability at the pre-surgical phase that may continue throughout the post-surgical period. Moderate weight loss should be distinguished from extreme or minimal weight loss during the program, with the latter associated with the poorest post-surgical results.

Post-surgical weight loss may reflect the end-point of multiple physiological, behavioral, cognitive, and environmental factors. Many studies are currently trying to elucidate markers or predictors to understand the different post-bariatric weight trajectories, but most of these works have been unsuccessful—for example, a recent study by Ryder et al. split 50 adolescents under long-term follow-up for post-RYGB (8.1 years mean follow-up time) into two groups post hoc, weight-maintainers and weight regainers, and found no significant differences in weight-related and eating behaviors, health responsibility, physical activity/inactivity, or dietary habits between groups (although maintainers had a better quality of life score after surgery). [16]

As described earlier, formal compliance (attendance and self-reported adherence to program recommendations) must be distinguished from real-life implication of changes (e.g., dietary adherence at home). Formal compliance was mandatory for surgical approval, and consequently, results showed uniform high formal compliance, thus unreliably reflecting real-life changes. (see the "Materials and Methods" section). However, the purpose of assessing the true implication of the program recommendations in the adolescent's personal and family life during the pre-surgical period may be served by an indirect marker—weight change. Thus, we believe that the importance of pre-surgical weight loss lies not in the weight lost per se, but rather in its reflection of actual changes in the adolescent's lifestyle. Such changes, if continued, would arguably have paramount importance during the post-surgical period.

Changes in lifestyle and dietary adherence may be attributed to participation in a highly structured and change-oriented program. They may also relate to the participants' engagement in a social group environment, and/or to the timing of the intervention during the pre-surgical phase, which in itself may be a stage characterized by high motivation for change.

Although the above findings relate to a relatively short post-surgical follow-up, their significance is amplified when considering studies showing weight loss during the first months as predictive of long-term weight loss (as detailed in the "Introduction" section) [17–19, 46].

Additional findings of this study indicate that lower reductions in BMI at 6 months post-surgery were significantly associated with maternal history of obesity and the presence of comorbid learning disorder. Higher reductions in BMI were associated with a later age in which the first attempt for weight loss had taken place. These results may reflect genetic and/or environmental influences on weight and weight reduction that require further investigation, and may signify populations at risk that may require more personalized and/or family-based interventions. Furthermore, the results emphasize the importance of family involvement and education (which is a key component of the program).

No further significant associations were found between reductions in BMI at different time points and patient characteristics.

Although relatively small, the sample used in this study was formed without preliminary selection of the participants and was composed of consecutive referrals to the bariatric program. The Schneider Children Medical Center is a tertiary hospital which admits patients from all over Israel without health care plan restrictions. Thus, the sample used in this study corresponds to the general population in terms of ethnicity and other sociodemographic variables. Notably, no differences were found between dropouts and completers in terms of baseline characteristics.

Strengths and Limitations A strength of this study is that it was based on a structured program which used a standardized multidisciplinary intervention. The program used the hospital setting as a vehicle allowing for a high frequency of clinical encounters within a short-term format. The results of the study are strengthened by its prospective, longitudinal design.

Limitations of the study include (1) the lack of a randomized controlled trial (RCT) design, mainly due to the requirements of the Israeli Ministry of Health (mandatory multidisciplinary preparation of adolescent bariatric candidates); (2) the study being based on LSG surgery only; (3) limitations in the evaluation of lifestyle changes (as described earlier in detail); and (4) relatively short-term follow-up (6 months).

Conclusion

The field of bariatric surgery in adolescents is currently under continuous exploration and research and seems to be the only viable solution for adolescents suffering from morbid obesity. Not all adolescents seem to benefit from bariatric surgery, and indeed, there seems to be a sub-population of adolescents undergoing bariatric surgery who fail to lose and/or maintain weight loss in the long term. As of yet, there are no proposed strategies for their early identification or treatment.

In the present study, we have demonstrated a possibility of predicting post-surgical weight loss trajectories as early as in the pre-surgical period. We also identified factors associated with sub-optimal results during the post-surgical phase. Thus, this study may contribute to recent efforts towards identifying sub-populations that require special attention for achieving optimal results in bariatric procedures.

Furthermore, this study explores the utility and efficacy of a pre-surgical change-oriented intervention program for adolescents. It is generally accepted that adolescents form a population in need of special attention, and a pre-surgical intervention and assessment is universally recommended. Despite this, to our knowledge, there is currently no data on the efficacy of such interventions in adolescents. This study is the

first to document: [1] the feasibility of such a program—as previously shown in an early pilot study and currently in a larger sample, with low dropout rates [34] and [2] the positive impact of a change-oriented bariatric program for adolescents without mandatory weight loss on pre- and post-surgical weight. Future efforts need to be made to find ways to assess lifestyle changes in a direct and reliable manner. In this respect, weight loss patterns throughout the bariatric process may be markers for changes in lifestyle.

We recommend a pre-surgical program oriented towards lifestyle change for adolescent candidates for bariatric surgery in order to induce possible longer-term changes. In addition to acting as an agent of change, such a program may facilitate identification of different weight loss trajectories and associated risk factors in the pre-surgical phase in order to implement early interventions and optimize long-term results.

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Compliance with Ethical Standards

The current study received Institutional Review Board approval.

Conflict of Interest The authors declare that they have no conflict of interest.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Statement of Human and Animal Rights All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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