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ORIGINAL ARTICLES

Effectiveness of a Weight Loss Program Using Digital Health in Adolescents and Preadolescents

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Abstract

Objective: To identify an efficacious intervention on treating adolescents with overweight and obesity, this might result in health benefits.

Methods: Adolescents with overweight or obesity aged 10–17 years with BMI percentile ≥85th were included in this historical observational analysis. Subjects used an entirely remote weight loss program combining mobile applications, frequent self-weighing, and calorie restriction with meal replacement. Body weight changes were evaluated at 42, 60, 90, and 120 days using different metrics including absolute body weight, BMI, and BMI z-score. Chi-square or Fisher exact tests (categorical variables) and Student's *t*-test (continuous variables) were used to compare subjects.

Results: In total, 2,825 participants, mean age 14.4 ± 2.2 years, (54.8% girls), were included from October 27, 2016, to December 31, 2017, in mainland China; 1355 (48.0%) had a baseline BMI percentile ≥97th. Mean BMI and BMI z-score were 29.20 ± 4.44 kg/m^2 and 1.89 ± 0.42, respectively. At day 120, mean reduction in body weight, BMI, and BMI z-score was 8.6 ± 0.63 kg, 3.13 ± 0.21 kg/m^2, and 0.42 ± 0.03; 71.4% had lost ≥5% body weight, 69.4% of boys and 73.2% of girls, respectively. Compared with boys, girls achieved greater reduction on BMI z-score at all intervals ($p < 0.004$ for all comparisons). Higher BMI percentile at baseline and increased frequency of use of the mobile application were directly associated with more significant weight loss.

Conclusions: An entirely remote digital weight loss program is effective in facilitating weight loss in adolescents with overweight or obesity in the short term and mid term.

Keywords: adolescents; BMI; digital health; digital intervention; obesity; weight loss

Introduction

The prevalence of overweight and obesity among adolescents has increased rapidly in both developed and developing countries, giving rise to serious global public health concern.[1–3] Growing evidence indicates that adolescents with overweight or obesity face psychosocial and physical challenges as a consequence of their excess weight,[4–7] and are more likely to suffer from mental disorders, bullying, and discrimination than normal weight

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Correction added on May 3, 2021 after first online publication of April 6, 2021: The article reflects Open Access, with copyright transferring to the author(s), and a Creative Commons Attribution Noncommercial License (CC-BY-NC) added (http://creativecommons.org/licenses/by-nc/4.0/).

peers.[4,6] Importantly, overweight and obesity are associated with chronic health consequences such as type 2 diabetes mellitus, dyslipidemia, hypertension, asthma, and other comorbidities.[5,8,9] In addition, adolescents with overweight or obesity are more likely to face increased health risks in adulthood than individuals of healthy weight in their youth.[10–12] Most of the aforementioned factors increase the risk of cardiovascular diseases, contributing to population burden of disease by impacting morbidity and all-cause mortality.[2,13,14]

Because modest weight loss can significantly reduce cardiovascular risk,[15–17] several effective lifestyle intervention programs have been developed to combat obesity among adolescents.[18–20] Protocols focusing on achieving changes in diet and physical activity appear to be effective methods of weight reduction and behavior management in adolescents with overweight or obesity.[18–20] However, those contemporary lifestyle interventions have proven to be ineffective in weight loss or long-term maintenance,[19,21] creating the need to supplement traditional strategies with evidence-based programs that yielded greater efficacy. The application of remote technology for weight management is an area of great innovation and potential that would likely be particularly attractive for youth who are already so well connected with mobile devices and social media platforms. Use of remote technology such as cell phones is pervasive among adolescents and have been examined in several weight loss programs for this population.[21]

Limited work has shown promising results using these technologies to promote and achieve weight loss,[22,23] as digital approaches can overcome barriers such as access, location, and cost in weight management programs among the preadolescent and adolescent-age groups. Considering that the majority of studies using digital technology were conducted in adults and were limited by small sample sizes and heterogeneity of methods, further research in adolescents using promising intervention and large populations is required to determine the effect of these tools on obesity control.

The aim of this study was to evaluate the efficacy of a digital health platform for weight loss utilizing a mobile application, a wireless scale and calorie restriction with nutritional supplementation in a large retrospective observational study in adolescents.

Methods

The MetaWell remote weight loss program ($770; Weijian Technologies, Inc., Hangzhou, China) is an entirely remote program, without any type of face-to-face interaction. The program consists of a free mobile application available on both Apple® and Google Play® app stores combined with a wireless home scale (Senhe Industrial, Co., Ltd., Shenzhen, China) as well as a nutrition program. Upon download of the mobile application, users were prompted to register, provide age, gender, and other basic demographic information (Supplementary Appendix SA1). Participants were also prompted to purchase the associated wireless ($45) scale that captured body weight.

The nutrition program was tailored based on each participant's basal metabolic requirements (BMRs) estimated by Schofield's predictive equation (kcal/day) as suggested by FAO/WHO/UNU[24]: For boys aged 10–18 years: $BMR = 650 + 17.5W$, whereas for girls: $BMR = 743 + 12.2W$, where W represents body weight in kilograms. The recommendation was to focus on consuming a diet of all food groups while recommending a negative calorie balance of 30%, meaning a calorie intake equivalent to 70% of their estimated daily calorie expenditure. Participants were provided individualized low-calorie meal plans that consisted of healthy recipes delivered through the mobile application, supplemented with up to three daily Yufit® biscuits (low calorie 416 kcal/100 g, 11.2 g of protein/100 g, and noncaffeinated meal replacements with a low glycemic index). Participants were given nutritional information as well as sample nutritional plans (Supplementary Appendix SA2). Direct measures of supplement usage during the time period studied were unavailable.

Once participants had achieved target weight (*i.e.,* either a 10% loss of baseline weight or a weight percentile <85th percentile), a transition diet plan was recommended. Participants and their parents were instructed to measure urinary concentration of ketones each morning, with ketones reported on a scale from 0 (0 mg/dL) meaning no ketosis to 4 (160 mg/dL) meaning potentially unsafe ketosis, with a goal of 2 (40 mg/dL) to 3 (80 mg/dL) levels. An increase in carbohydrate intake was recommended if ketone measurement was at level 4 at any time point. If three consecutive measurements of level 4 were observed, the user was recommended to stop the plan and consume a higher carbohydrate diet.

Physical activity was encouraged during the program, but no specific exercise recommendations were provided. Users were prompted by the application to weigh themselves on a daily basis through the wireless scale. In the application, participants had access to a record of their weight loss progress, as well as a ''Health Status Overview'' that provided a snapshot of their current health data as well as optimal measures of BMI. Screen captures of the application are presented in Supplementary Appendix SA1.

Study Protocol

We included subjects aged 10 to 17 years who completed the commercial MetaWell program in mainland China from October 27, 2016, to December 31, 2017, and subjects were expected to have a minimum of recorded participations including measurements at baseline weight and at 35 days or beyond (comparison of those who had <35 days, Supplementary Appendix SA3), as well as a baseline gender- and age-specific BMI ≥85th percentile using the BMI tables from the Center of Disease Control.[24]

Exclusion criteria were secondary causes of obesity (*e.g.,* endocrine abnormality), participants on pharmacologic intervention for weight reduction, participants who had prior or planned bariatric surgery, and logistic problems that might interfere with successful participation in the study. We also excluded those with weight values at baseline at the top and bottom 1% to reduce error and to improve the reliability of the analysis. Subjects were divided into three subgroups according to age- and gender-specific BMI percentile: ≥85th–<95th BMI percentile, ≥95th–<97th BMI percentile, and ≥97th BMI percentile.

Data collection. For the purpose of this study, a complete deidentified data set of program users collected by Weijian Technologies, Inc., was provided for research purposes. Baseline information including demographic characteristics, height, and weight were self-reported by participants through MetaWell application. As participants required their parents to register them in the program, the parents' registration was considered consent to have their children follow this weight loss program, they also provided electronic consent for their data to be used for research purposes. The study design, strategy to analyze the data, and analysis were carried out at Mayo Clinic independently and without any company input.

IRB exception was obtained through Mayo Clinic Institutional Review Board based on the deidentified and retrospective observational nature of the analysis.

Study outcomes. The primary outcome of the study was weight loss, defined as any negative change in body weight during follow-up. Secondary outcomes included the proportion of subjects achieving at least 5% weight loss and 10% weight loss at 120 days, change in BMI and BMI z-score (defined as standardized BMI using age and gender normative data from the Centers for Disease Control and Prevention) at different time points during follow-up.[25,26]

Given the large proportion of subjects with a very high BMI limiting the discriminatory value of Z scores, we also calculated the change in BMI expressed as a percentage of the BMI value at the 95th percentile for age and gender, referred as %BMIp95.[27] This was calculated as baseline BMI–BMI at 95th percentile)/BMI at 95th percentile * 100. The delta at follow-up (Δ%BMIp95) was defined as follow-up %BMIp95 minus baseline %BMIp95.

Additional outcomes explored as sensitivity analyses included absolute body weight loss and percentage of weight loss (WL%, calculated as baseline weight–follow-up weight/baseline weight *100) changes.

Statistical Analysis

Means and standard deviations were used to describe continuous variables; counts and percentages were used to summarize categorical variables, both across strata and within stratum. Weight at baseline was defined as the median weight within a 3-day period of first user observation. The program directs users to start an initial 6-week weight loss program, but was commonly continued for longer duration. All users who had weight recorded both at baseline and at ≥35 days were included in the analysis. Weights at the end of each time interval were constructed in a similar manner, but extending the end window to 7 (or 14 in the case of the 120 stratum) days before or after the end-date mark. For those with weights available beyond 35 days, weight recorded in 14-day intervals centered on 42-, 60-, 90-, and a 28-day interval ∼120 days. The sets of users in each time window were not identical (Supplementary Appendix SA4).

Subgroups were evaluated based on age, gender, baseline weight status, and frequency of use.

Although significant linear growth is not expected in this age group during such a short time period (120 days), because we did not have height information at follow-up, the assumption of no linear growth could underestimate the change in parameters that use height at follow-up such as BMI, BMI z-score, and others. To assess this, we created and compared subgroups wherein linear growth was expected vs. subgroups assuming they had achieved their adult heights, namely girls <15 years vs. girls ≥15 years of age, and boys <16 years vs. boys ≥16 years.[28] The frequency of use was defined by the number of weight measurements recorded for each person during each time interval studied divided by the number of days a person was in that time period. Tertiles of these frequencies were then made within time period to create high, medium, and low frequency of use categories. Outcomes were compared between groups using analysis of variance tests. Significance of changes between time points was evaluated using paired *t*-tests. R version 3.6.2 was used for analyses and two-sided $p<0.05$ was considered statistically significant.

Results

We included 2825 individuals of whom 54.8% (1547) were girls and had a mean age of 14.4 ± 2.2 years. Of these, 1355 (48.0%) had a baseline BMI percentile ≥97th, and 38.2% (1078) had a baseline BMI z-score of >2 (Table 1). The mean follow-up duration of use was 123.91 ± 9.20 days based on the last available weight recorded. At 120 days, mean weight loss was 8.6 ± 0.63 kg, mean BMI drop was 3.13 ± 0.21 kg/m^2, and mean BMI z-score reduction was 0.42 ± 0.03, the proportion of individuals analyzed at each time point is outlined in Supplementary Appendix SA4. Overall, statistically significant differences in weight reduction by all metrics were observed at each time point (42, 60, 90, and 120 days) compared with baseline ($p<0.001$, respectively). In addition, greater weight reduction for all metrics was successively achieved at each interval compared with last investigated interval (baseline vs. 42, 42 vs. 60, 60 vs. 90, and 90 vs. 120) ($p<0.001$ for all) (Table 2).

Table 2 also shows weight loss at each time interval by different measures. Mean weight loss, BMI drop, BMI z-score reduction,%BMIp95 change, and WL% for the group with age ≥13 years were significantly different when compared with those <13 years of age at each investigated interval ($p<0.05$, respectively). No statistically significant difference in weight reduction by any metric was observed between genders in any tested interval, except for BMI z-score where boys achieved a greater reduction than girls at each interval ($p<0.02$ for all), and WL% where girls had more WL% than boys at 42-, 60-, and 90-day intervals

Table 1. Baseline Characteristics in All Participants and Across Gender and Age Groups

	Overall	Girls	Boys	Age <13	Age 13+
	(*n* = 2825)	(*n* = 1547)	(*n* = 1278)	(*n* = 649)	(*n* = 2176)
Age, mean (SD); years	14.4 (2.2)	14.5 (2.1)	14.2 (2.3)	11.1 (0.8)	15.3 (1.4)
Weight, kg, mean (SD)	80.8 (18.4)	75.8 (14.2)	86.9 (20.9)	64.7 (13.6)	85.7 (16.8)
BMI, kg/m^2, mean (SD)	29.2 (4.4)	28.6 (4.1)	29.9 (4.7)	26.4 (3.8)	30.0 (4.3)
BMI percentile, *n* (%)					
85th–<95th percentile	941 (33.3)	710 (45.9)	231 (18.1)	178 (27.4)	763 (35.1)
>95th–< 97th percentile	529 (18.7)	340 (22.0)	189 (14.8)	120 (18.5)	409 (18.8)
≥97th percentile	1355 (48.0)	497 (32.1)	858 (67.1)	351 (54.1)	1004 (46.1)
BMI z-score, *n* (%)					
≤ 2 (SD)	1747 (61.8)	1198 (77.4)	549 (43.0)	364 (56.1)	1383 (63.6)
> 2 (SD)	1078 (38.2)	349 (22.6)	729 (57.0)	285 (33.9)	793 (36.4)

SD, standard deviation.

($p < 0.02$ for all). At 120 days, 71.4% had lost at least 5% of baseline weight, whereas 47.9% had lost at least 10% of baseline weight (Table 2).

As shown in Figure 1, the highest baseline BMI percentile group achieved greatest weight loss, BMI drop, and %BMIp95 reduction at each interval ($p < 0.001$). Interestingly, in the ≥85th–< 95th percentile group, reduction in body weight, BMI, and %BMIp95 at 120 days was smaller than that at the 90-day interval. Inversely, all weight outcomes were slightly attenuated at 120 days in the ≥85th–<95th percentile group.

The group with higher BMI percentile at baseline was more likely to achieve ≥5% weight loss and ≥10% weight loss (all $p < 0.001$). In the BMI percentile ≥97th group, the largest proportion of subjects achieved ≥5% weight loss (81.6%) and ≥10% weight loss (60.2%) at 90 days (all $p < 0.05$).

A higher frequency of weight recording was associated with greater reduction on weight, BMI, %BMIp95, and WL% when comparing high, medium, and low tertile use groups at each time interval (respectively, $p < 0.001$). The top tertile group had the most weight loss (Fig. 2).

Discussion

In this large study of ~3000 adolescents with overweight or obesity in mainland China, we observed significant weight loss achieved through a commercially available weight loss program utilizing several interventions, including mobile applications, frequent self-weighing using a wireless scale, and calorie restriction through meal replacement. No adverse reactions were observed during the program period. However, no statistically significant difference was observed between genders across weight outcomes, except for BMI z-score wherein boys achieved a greater reduction than girls at all intervals, and WL% wherein girls had more WL% than boys at most intervals. The study demonstrated that almost three out of four participants lost >5% of their initial body weight with even greater weight loss observed in participants who had elevated BMI at baseline, were older, and who weighed themselves more frequently.

With the expansion of digital technology, adolescents are becoming more proficient and engaged in mobile device usage, providing an opportunity to develop effective weight management programs that exploit remote technology. To date, only a few studies have been conducted to test effectiveness of digital remote weight loss interventions for adolescents, and most publications have focused on identifying the benefit of self-monitoring and/or behavioral changes.[21]

To our knowledge, this is the first study to assess the effectiveness of a mobile phone-based intervention in adolescents and preadolescents integrating an individualized nutrition program, a wireless weighing scale with frequent weight measurement, and meal supplements, having weight loss as the primary outcome. Furthermore, our results demonstrated remarkable effectiveness consistent with the limited previous studies that have aimed at weight loss in children and adolescents with overweight or obesity through digital strategies.[22,23]

The program described herein is totally remote without face-to-face interaction and has several potential advantages: (1) is widely scalable in large populations; (2) aids in overcoming known barriers of other interventions such as access, scheduling, and location; (3) delivers remote and individualized meal plans, which have been described as effective interventions in supporting weight loss and subsequent metabolic benefits in adolescents with overweight or obesity.[29]

Many factors can mediate weight loss in adolescents with overweight or obesity.[16,22] Danielsson et al. concluded that boys showed significantly greater weight loss than girls,[30] whereas our study did not provide sufficient evidence to support major gender differences in weight loss.

Table 2. Weight-Related Outcomes at Follow-Up in All Participants and Stratified by Gender and Age Group

Follow-up	Total	Girls	Boys	*p*	Age <13	Age 13+	*p*
Weight change, kg, mean (MOE)							
42 days	–5.5 (0.19)[a]	5.4 (0.23)	–5.8 (0.33)	0.058	–4.1 (0.42)	–6.0 (0.22)	<0.001
60 days	–6.9 (0.27)[b]	–6.7 (0.30)	–7.2 (0.47)	0.074	–4.8 (0.63)	–7.5 (0.29)	<0.001
90 days*	–8.2 (0.46)[c]	–7.9 (0.52)	–8.5 (0.81)	0.265	–5.0 (1.00)	–9.0 (0.51)	<0.001
120 days	–8.6 (0.63)[d]	–8.4 (0.79)	–9.0 (1.01)	0.352	–5.7 (1.20)	–9.4 (0.72)	<0.001
BMI change, kg/m^2, mean (MOE)							
42 days	–2.01 (0.07)[a]	–2.03 (0.08)	–1.98 (0.11)	0.420	–1.64 (0.16)	–2.12 (0.07)	<0.001
60 days	–2.51 (0.09)[b]	–2.52 (0.11)	–2.49 (0.15)	0.786	–1.91 (0.22)	–2.67 (0.10)	<0.001
90 days	–2.98 (0.16)[c]	–3.03 (0.19)	–2.91 (0.26)	0.457	–2.00 (0.41)	–3.23 (0.16)	<0.001
120 days	–3.13 (0.21)[d]	–3.14 (0.28)	–3.12 (0.31)	0.914	–2.21 (0.41)	–3.37 (0.23)	<0.001
BMI z-score change, mean (MOE)							
42 days	–0.26 (0.01)[a]	–0.23 (0.01)	–0.28 (0.01)	<0.001	–0.22 (0.02)	–0.27 (0.01)	<0.001
60 days	–0.32 (0.01)[b]	–0.30 (0.02)	–0.35 (0.02)	<0.001	–0.26 (0.03)	–0.34 (0.01)	<0.001
90 days	–0.39 (0.02)[c]	–0.35 (0.03)	–0.42 (0.03)	<0.001	–0.30 (0.05)	–0.41 (0.02)	<0.001
120 days	–0.42 (0.03)[d]	–0.37 (0.04)	–0.45 (0.04)	0.003	–0.33 (0.06)	–0.44 (0.03)	0.003
%BMIp95 change, mean (MOE)							
42 days	–7.45 (0.26)[a]	–7.38 (0.31)	–7.54 (0.43)	0.537	–6.90 (0.70)	–7.61 (0.26)	0.023
60 days	–9.24 (0.34)[b]	–9.07 (0.39)	–9.45 (0.34)	0.286	–8.02 (0.94)	–9.57 (0.35)	<0.001
90 days	–10.91 (0.60)[c]	–10.87 (0.67)	–10.96 (1.03)	0.894	–8.38 (1.79)	–11.57 (0.58)	<0.001
120 days	–11.51 (0.77)[d]	–11.28 (1.00)	–11.78 (1.18)	0.524	–9.31 (1.75)	–12.08 (0.85)	0.004
WL%, mean (MOE)							
42 days	6.65 (0.24)[a]	6.98 (0.30)	6.23 (0.38)	0.002	6.09 (0.63)	6.81 (0.25)	0.013
60 days	8.13 (0.32)[b]	8.55 (0.36)	7.61 (0.55)	0.004	6.92 (0.91)	8.45 (0.32)	<0.001
90 days	9.31 (0.57)[c]	9.97 (0.61)	8.52 (1.02)	0.014	6.94 (1.63)	9.92 (0.58)	<0.001
120 days	9.55 (0.72)[d]	10.12 (0.91)	8.88 (1.14)	0.091	7.82 (1.61)	10.00 (0.80)	0.017
>5% total body weight loss, *n* (%)							
42 days	1647 (68.2)	948 (71.0)	699 (64.8)	0.001	338 (62.1)	1309 (70.0)	<0.001
60 days	1235 (73.2)	708 (76.5)	527 (69.1)	<0.001	232 (65.0)	1003 (75.4)	<0.001
90 days	745 (74.6)	422 (78.0)	323 (70.7)	0.008	134 (65.4)	611 (77.0)	<0.001
120 days	610 (71.4)	338 (73.2)	272 (69.4)	0.224	105 (60.0)	505 (74.4)	<0.001
>10% total body weight loss, *n* (%)							
42 days	523 (21.7)	283 (21.2)	240 (22.3)	0.522	114 (21.0)	409 (21.9)	0.648
60 days	661 (39.2)	358 (38.7)	303 (39.7)	0.673	118 (33.1)	543 (40.8)	0.008
90 days	493 (49.4)	265 (49.0)	228 (49.9)	0.775	80 (39.0)	413 (52.1)	<0.001
120 days	409 (47.9)	228 (49.4)	181 (46.2)	0.354	70 (40.0)	339 (49.9)	0.019

[a] $p < 0.001$ for 42 days compared with baseline.

[b] $p < 0.001$ for 60 days compared with 42 days.

[c] $p < 0.001$ for 60 days compared with 90 days.

[d] $p < 0.001$ for 90 days compared with 120 days.

%BMIp95, BMI as percentage of the 95th percentile; MOE, margin of error; WL%, percentage of weight loss.

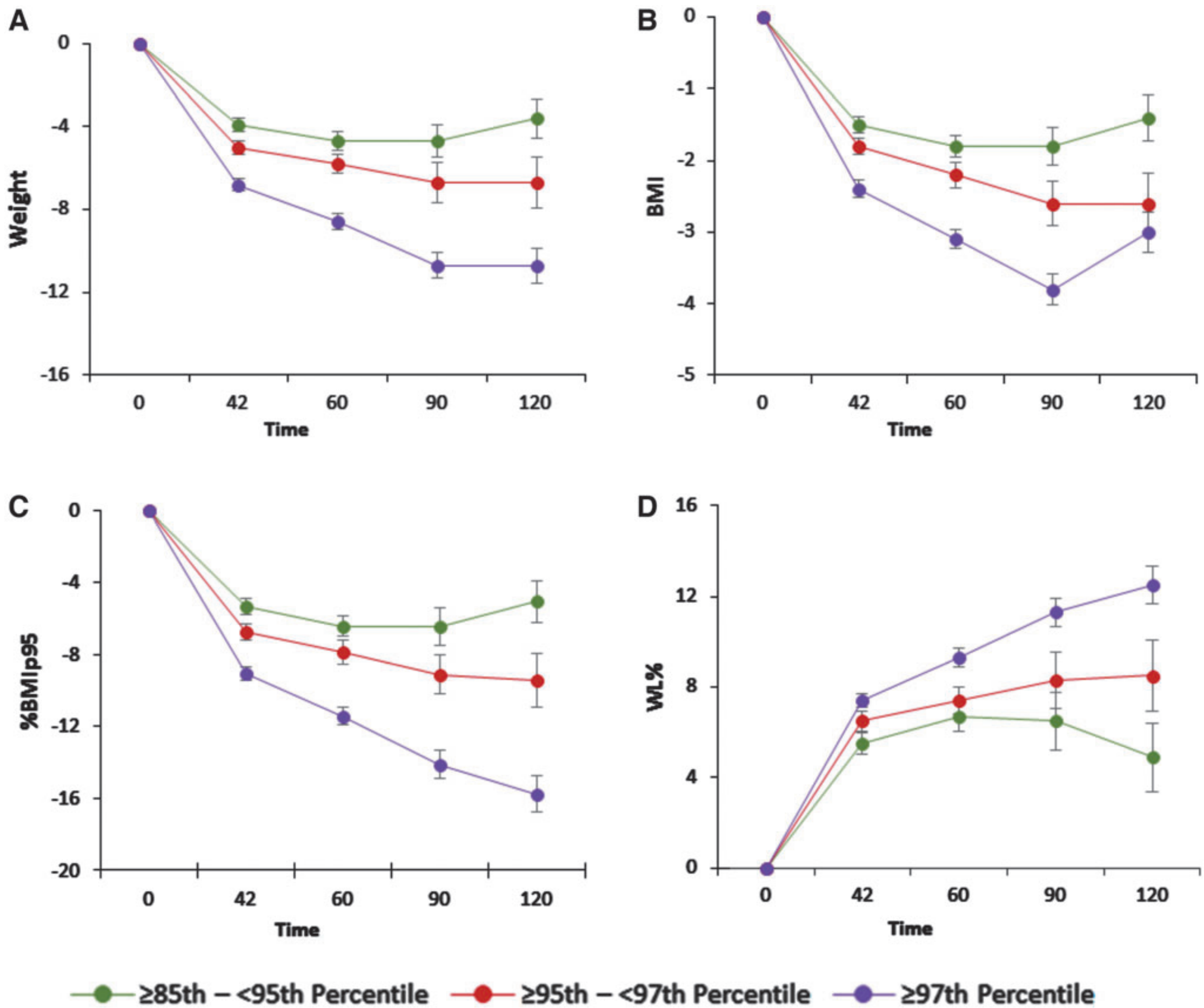

Figure 1. Changes on weight-related outcomes through 120 days based on BMI percentile. Mean change over time in primary outcomes based on BMI percentile subgroups through 120 days. (A) Change in weight (kg). (B) Change in BMI (kg/m^2). (C) Change in %BMIp95 (percentage kg/m^2 for BMI). (D) Change in WL% (percentage kg for weight). $p < 0.001$ for all comparisons. %BMIp95, BMI as percentage of the 95th percentile; WL%, percentage of weight loss.

Although we observed that girls were more likely to achieve the outcome of >5% weight loss than boys, there were no major gender-based differences in weight loss, BMI reduction, or %BMIp95 change. Because inclusion in our study depended inherently on socioeconomic factors (*i.e.,* owning a smartphone and affording the program), technological savvy, and a certain level of health literacy, this might have resulted in older adolescents being more compliant with the weight loss program than younger peers.

As suggested by our results, and comparable with a previous study,[30] the degree of obesity is an important predictor of the outcome. It is noteworthy that in this study, adolescents with overweight did not experience weight regain in the midterm, as their body weight was similar at 120 days vs. 90 days. Not surprisingly, as systematic reviews have shown, the efficacy of both technology-based and traditional weight loss programs was greatest in the early stages, and did not always translate into sustained long-term reductions in weight.[31–34] Decline in participant engagement was cited to be the cause of the lack of long-term effects.[35,36]

We have demonstrated and confirmed what prior studies using mobile device interventions have shown in adults that frequent self-recording of body weight was strongly associated with more significant weight loss.[37,38] This relationship could be explained by the motivational level and not necessarily a causal factor, as those with greater desire to lose weight likely weighed themselves more frequently. Alternatively, high frequency of self-weighing may have driven a feedback loop of more frequently reminder about current weight, thereby increasing motivation and preventing relapses. In this population we also found that adolescents who continued in the program for >120 days also had the greatest results.

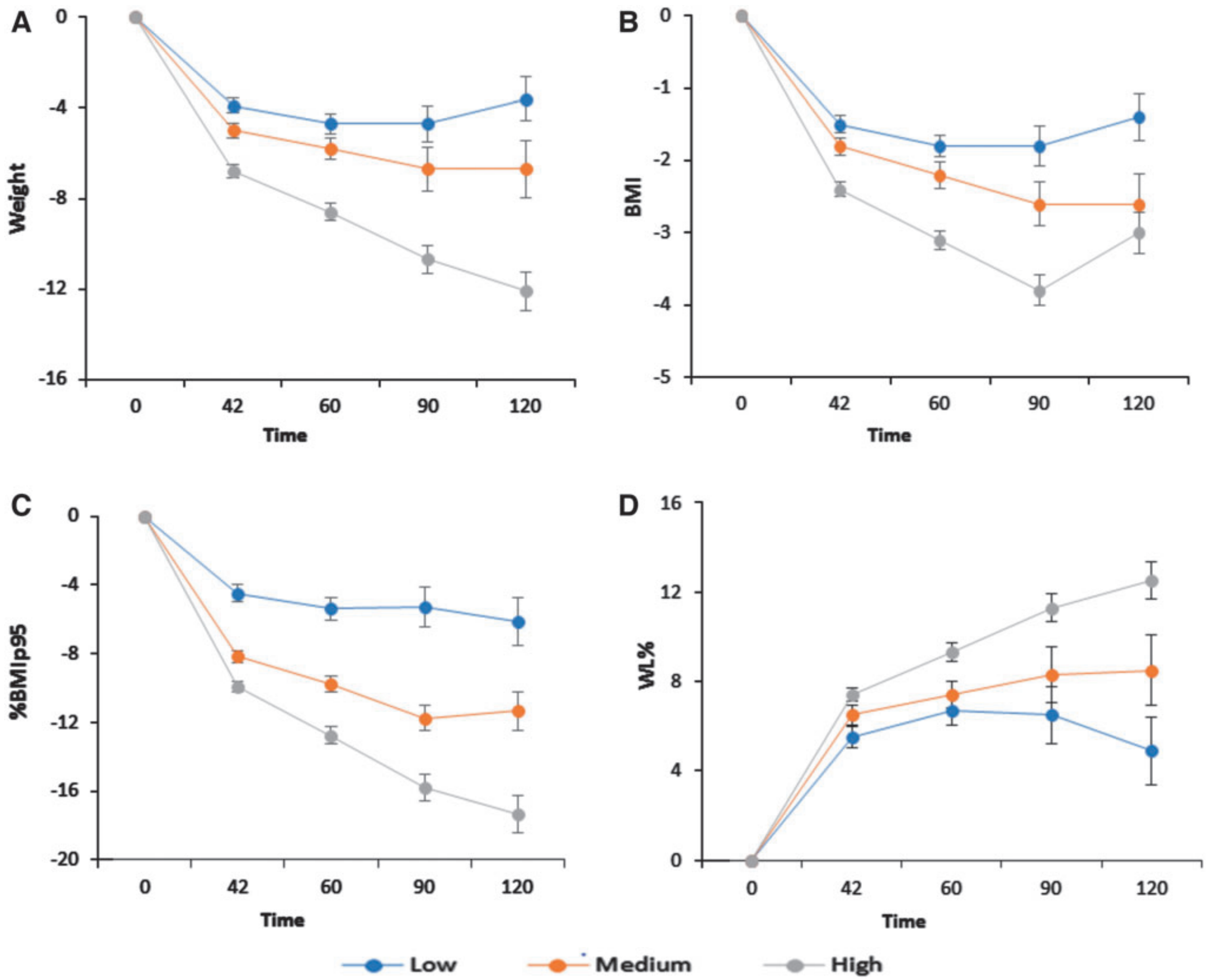

Figure 2. Changes on weight-related outcomes through 120 days based on self-weighing frequency. Mean change over time in primary outcomes based on frequency of self-weighing, categorized as low-, medium-, and high-frequency weighing, through 120 days. (A) Change in weight (kg). (B) Change in BMI (kg/m^2). (C) Change in %BMIp95 (percentage kg/m^2 for BMI). (D) Change in WL% (percentage kg for weight). $p < 0.001$ for all comparisons.

This large retrospective study shows significant short- and midterm weight loss among adolescents, and it was more significant among those with more severe obesity or those who were actively engaged in this totally remote weight loss program. Most participants achieved significant reduction on body weight, BMI, BMI z-score, and %BMIp95 using a digital health program in our study, with an effectiveness that was comparable or even more significant to a pharmacologic weight loss treatment using liraglutide, as it was recently reported.[39] It was reported that participants achieved reduction on body weight of 4.5 kg, BMI of 3.13 kg/m^2, and BMI z-score of 0.22 at 56 weeks using liraglutide.[39]

In addition, decreases on body weight of 7.1 kg, BMI of 2.6 kg/m^2, and BMI z-score of 0.35 at 36 days were observed in another study conducted with electronic health technology[22] compared with those who had reduction on body weight of 8.6 kg, BMI of 3.13 kg/m^2, and BMI z-score of 0.42 at 120 days in our study. Given the innovative phone-based weight loss interventions are highly accepted by adolescents,[22] smart phones may be a promising way to fill a gap in providing adolescents with acceptable and attractive ways to promote weight management. Further long-term studies are encouraged to identify factors that influence weight loss and to explore further inexpensive and accessible strategies to promote successful weight loss.

Limitations

Several limitations warrant mentioning, given the observational nature of this study. First, the lack of a control group prevents us from determining the effect size of the intervention relative to other strategies or methods, or even compared with natural history. However, obesity in adolescents rarely improves without interventions aimed at weight control.[12] Second, follow-up was limited to 120 days, thus the study is unable to determine the long-term effect on

Table 3. Weight-Related Outcomes at Follow-Up Stratified by Combinations of Gender and Age Subgroups

	Girls			Boys		
Follow-up	<15	15+	*p*	<16	16+	*p*
Weight change, kg, mean (MOE)						
42 days	−4.9 (0.42)	−5.7 (0.25)	<0.001	−5.0 (0.41)	−7.2 (0.53)	<0.001
60 days	−6.0 (0.50)	−7.1 (0.37)	<0.001	−6.1 (0.60)	−8.9 (0.72)	<0.001
90 days	−6.8 (0.81)	−8.6 (0.66)	0.001	−7.0 (1.09)	−10.8 (1.09)	<0.001
120 days	−6.9 (1.21)	−9.4 (1.02)	0.002	−7.2 (1.33)	−11.9 (1.41)	<0.001
BMI change, kg/m^2, mean (MOE)						
42 days	−1.9 (0.15)	−2.1 (0.09)	0.003	−1.8 (0.14)	−2.3 (0.17)	<0.001
60 days	−2.3 (0.18)	−2.7 (0.13)	<0.001	−2.2 (0.20)	−3.0 (0.23)	<0.001
90 days	−2.7 (0.30)	−3.2 (0.24)	0.004	−2.5 (0.37)	−3.5 (0.33)	<0.001
120 days	−2.6 (0.43)	−3.5 (0.35)	0.003	−2.7 (0.41)	−3.9 (0.45)	<0.001
BMI z-score change, mean (MOE)						
42 days	−0.28 (0.02)	−0.27 (0.02)	0.744	−0.20 (0.02)	−0.29 (0.02)	<0.001
60 days	−0.34 (0.03)	−0.35 (0.02)	0.979	−0.24 (0.02)	−0.38 (0.04)	<0.001
90 days	−0.41 (0.05)	−0.43 (0.04)	0.162	−0.29 (0.04)	−0.46 (0.05)	<0.001
120 days	−0.41 (0.06)	−0.48 (0.05)	0.108	−0.31 (0.05)	−0.48 (0.06)	<0.001
%BMIp95 change, mean (MOE)						
42 days	−7.35 (0.60)	−7.40 (0.31)	0.879	−7.10 (0.58)	−8.31 (0.60)	0.008
60 days	−8.93 (0.68)	−9.18 (0.45)	0.534	−8.73 (0.82)	−10.58 (0.81)	0.003
90 days	−10.37 (1.16)	−11.17 (0.82)	0.259	−9.94 (1.50)	−12.56 (1.19)	0.015
120 days	−10.22 (1.70)	−12.02 (1.22)	0.083	−10.54 (1.61)	−13.83 (1.59)	0.008
WL%, mean (MOE)						
42 days	6.83 (0.57)	7.09 (0.30)	0.389	5.78 (0.51)	7.03 (0.57)	0.002
60 days	8.29 (0.62)	8.73 (0.42)	0.232	6.95 (0.77)	8.66 (0.72)	0.003
90 days	9.28 (1.04)	10.37 (0.75)	0.089	7.32 (1.51)	10.43 (1.05)	0.003
120 days	8.79 (1.62)	11.05 (1.05)	0.017	7.48 (1.65)	11.17 (1.27)	0.002
>5% total body weight loss, *n* (%)						
42 days	390 (68.7)	558 (72.7)	0.112	422 (61.3)	277 (71.0)	0.001
60 days	280 (73.5)	428 (78.7)	0.067	308 (65.8)	219 (74.2)	0.014
90 days	150 (75.0)	272 (79.8)	0.196	187 (66.8)	136 (76.8)	0.022
120 days	129 (68.3)	209 (76.6)	0.048	157 (64.3)	115 (77.7)	0.005
>10% total body weight loss, *n* (%)						
42 days	129 (22.7)	154 (20.1)	0.24	136 (19.8)	104 (26.7)	0.009
60 days	138 (36.2)	220 (40.4)	0.195	175 (37.4)	128 (43.4)	0.099
90 days	92 (46.0)	173 (50.7)	0.288	131 (46.8)	97 (54.8)	0.095
120 days	81 (42.9)	147 (53.8)	0.020	108 (44.3)	73 (49.3)	0.330

weight loss. However, although weight loss plateau after 90 days, it was encouraging to see no weight regain from 90 to 120 days of follow-up.[40] Third, although the weight loss program included a detailed plan on monitoring ketosis, unfortunately the data on the self-monitoring of ketosis were not comprehensive enough to be analyzed. In addition, we may not be able to detect any effects of ketosis on their developmental growth. However, low-carbohydrate diets have been tested in children and adolescents in other studies with no major side effects detected.[41] Fourth, lack of information on dietary habits, duration of comorbidities, and physical activity limit the ability to rule out effects of comorbidities, concomitant lifestyle changes besides the intervention. Meanwhile, we did not capture information on implementation of the individualized meal plan. Fifth, as suggested by earlier research, obesity is highly associated with family history and, therefore, family engagement and modeling of appropriate behaviors may have influenced the results,[30,42] considering that, to be enrolled in the program, children and adolescents had to have their parents interested in the program. Sixth, as socioeconomic status and education level were not recorded, the role of these constructs or program cost as a barrier to participation or study outcome could not be evaluated. Seventh, we could not evaluate levels of baseline physical activity or changes in measures of central obesity. Lastly, we could not capture height information after baseline, and all BMI values at follow-up were calculated using initial height.

Although significant linear growth is not expected in this age group during 120 days, this could have underestimated the change in parameters that use height such as BMI, BMI z–score, and others. Our sub-group analysis in adolescents assumed that older participants have met their adult height (i.e. girls ages ≥15 years and boys ages ≥16 years) and compared to younger participants who may have to grow during the duration of the study, actually proved that. We found that BMI loss was indeed more significant in those believed to have achieved adult height (Table 3), so the findings in younger individuals surely underestimate the actual reduction in BMI and other metrics using height at 120 days.

Conclusion

This study shows clinically significant weight loss achieved among adolescents with overweight or obesity achieved using a remote weight loss program. Greater weight loss was observed in participants who were older, weighed themselves more frequently, or who had elevated initial BMI percentiles. Although the pilot data are promising, further studies using an experimental design with a control group as well as capturing physical activity and sleep outcomes are needed, also longer follow-up is warranted to establish the causal effect of this remote strategy on weight loss in children and adolescents.

Authors' Contributions

Dr. S.L. drafted the initial article, completed data collection, conducted analysis, and interpretation of data; Drs. M.I., P.C., A.L., and L.O.L. assisted with interpretation of the data and reviewed and revised the article; Dr. S.K. provided expert consultation and assisted with interpretation of the data, and reviewed and revised the article; Dr. C.G.S., Mr. W.L., and Mr. X.Z. completed data collection; Ms. A.T.L. and Ms. C.G.S. conducted statistical analyses and reviewed and revised the article; and Dr. F.L.-J. coordinated and supervised data collection and critically reviewed the article for important intellectual content. All authors conceptualized and designed the study, and agree to be accountable for all aspects of the study.

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Author Disclosure Statement

S.K. reports personal fees outside the submitted study (Rhythm Pharmaceuticals); L.L. reports personal fees from Weijian Technologies, Inc., personal fees and grants outside the submitted study (Novo Nordisk and AstraZeneca); Dr. A.L. reports personal fees from Weijian Technologies, Inc., personal fees outside the submitted study (Itamar medical and Shahal); W.H.L. and X.Y.Z. report grants from Weijian Technologies, Inc; and P.C. reports personal fees from Weijian Technologies, Inc. The other authors declare no conflict of interest.

Supplementary Material

Supplementary Appendix SA1
Supplementary Appendix SA2
Supplementary Appendix SA3
Supplementary Appendix SA4

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