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Examining the Behavioral Processes through which Lifestyle Interventions Promote Weight Loss: Results from the PREMIER Trial

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Abstract

Objective—To examine the behavioral processes through which lifestyle interventions impacted weight loss.

Design and Methods—We limited our analyses to overweight and obese Black and White adults randomized to a PREMIER lifestyle intervention (N = 501). Structural equation modeling was conducted to test the direct and indirect relationships of session attendance, days of self-monitoring diet and exercise, change in diet composition and exercise, and six month weight change.

Results—Greater session attendance was associated with increased self-monitoring, which was in turn significantly related to reduction in percent energy from total fat consumed. Change in percent energy from fat and self-monitoring was associated with six-month percent change in weight. Both a decrease in fat intake and increase in self-monitoring are potential mediators of the relationship between attendance and weight change.

Conclusions—Our findings provide a reasonable model that suggests regular session attendance and use of behavioral strategies like self-monitoring are associated with improved behavioral outcomes that are associated with weight loss.

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Keywords

Lifestyle modification; weight loss; behavior change; self-monitoring

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Lifestyle change interventions are an effective first line treatment for obesity and have demonstrated an average initial weight loss of 8–10% across clinical trials (1,2). However, the processes through which lifestyle interventions lead to weight loss are not well understood. Similar to understanding the underlying mechanisms through which weight loss medications and bariatric surgery lead to weight loss, understanding the processes through which lifestyle interventions are effective treatments for weight loss has implications for intervention refinement as well as implementation and dissemination into clinical practice and community settings.

Regular use and mastery of key cognitive-behavioral skills taught during a lifestyle weight loss intervention are thought to lead to improved self-regulation of eating and exercise related behaviors, thus promoting sustained behavior change resulting in weight loss. These skills include goal-setting, self-monitoring of key behaviors, use of stimulus control techniques, problem-solving, coping skills, cognitive restructuring, and relapse prevention (1,2). Unfortunately, empirical evidence supporting this conceptual model has been limited by the fact that use of these skills is rarely assessed in clinical trials, with the exception of self-monitoring. Previous studies have consistently demonstrated a significant relationship between self-monitoring (of diet, exercise, and/or weight) and weight loss (3–7) as well as weight loss maintenance (8). Self-monitoring has also been associated with improved dietary composition (5,9) and increased physical activity (10). In a recent study, using structural equation modeling (SEM), findings suggested that the effect of a behavioral intervention on weight loss was mediated by increased adherence to self-monitoring of diet and exercise (11). However, a major limitation in previous studies has been that the associations among self-monitoring, actual behavior change, and weight change outcomes were typically not examined in the same model or the act of self-monitoring was treated as a proxy for engagement in healthy behaviors while measures of actual behavior change were not included. These limitations leave a gap in understanding how self-monitoring translates into weight loss.

In this current study, using data from the PREMIER trial (12), we applied structural equation modeling (SEM) to examine the behavioral processes through which the two lifestyle interventions tested in the PREMIER trial led to changes in behavioral and weight outcomes during the active weight loss phase of the trial, i.e., the initial six months. Specifically, we conducted analyses to understand the direct and indirect pathways by which session attendance and use of behavioral strategies (i.e., self-monitoring) promoted dietary and exercise change and subsequent weight change.

Methods

Study design, participants, and intervention procedures of the PREMIER trial have been previously described (12,13). In summary, this multicenter trial was conducted at four different clinical sites to examine the effects of lifestyle modification on blood pressure, weight, and diet, particularly fat and sodium intake, among adults with either prehypertension or stage 1 hypertension.

Participants

PREMIER enrolled 810 adults, ages 25 and older, with pre-hypertension or stage 1 hypertension. We restricted our analyses to the 501 White[1] and Black adults with a BMI ≥ 25 kg/m^2 who were randomized to one of the two active intervention conditions described below.

Randomized Groups

Participants were randomly assigned to one of three groups: 1) an "advice only" group (not included in our analyses); 2) a lifestyle intervention referred to as "Established," that was based on traditional lifestyle recommendations; or 3) "Established plus DASH," a lifestyle intervention that consisted of the Established intervention plus promotion of the DASH (Dietary Approaches to Stop Hypertension) diet (14,15). The advice only group received educational materials and also attended a single 30-minute individual session with an interventionist at randomization to discuss the health behaviors that can impact blood pressure.

The Established and Established plus DASH diet interventions occurred over 18 months, but we focused on the intervention process during the initial 6 months (i.e., the intensive intervention phase) given that is when the most weight loss occurred. Both lifestyle interventions consisted of 18 face-to-face sessions (14 group and 4 individual sessions) over the first 6 months. Sessions were weekly in the first three months, bi-weekly for the next three months, and monthly thereafter up to 18 months. Participants were provided with the same educational materials on physical activity, sodium, and alcohol across the two interventions. Also, both interventions emphasized self-monitoring of diet and exercise as well as goal-setting with action plans, problem-solving, relapse-prevention, and social support through group interactions. The Established plus DASH intervention differed in terms of dietary education (specific to DASH diet recommendations) and specific food groups that were self-monitored. Specifically, participants from both interventions monitored total calories, sodium, and physical activity minutes, whereas the Established plus DASH also monitored fruit and vegetable servings, low-fat/non-fat dairy, and total fat intake.

Based on previous analysis of the PREMIER trial data, participants in the Established plus DASH group had a greater reduction in percent energy from fat and carbohydrates at six months compared to the Established intervention (12,16), likely due to the differences in dietary recommendations. However, there was no significant difference in the amount of weight loss between the two intervention conditions at six months (12). For the current study, we pooled data from the two lifestyle interventions for the analyses, but adjusted for treatment assignment.

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[1] White also included 9 participants who self-reported race/ethnicity as White Hispanic.

Measurements

Weight measurements were obtained at baseline and six months, which were used to calculate six-month percent change in weight. For the behavioral process measures we examined variables that were collected during the initial six months of the trial and are established correlates of weight loss based on previous research including session attendance (4), self-monitoring (3–6), dietary composition (17), and physical activity (18).

Session attendance was equal to the total number of sessions attended over the first six months of PREMIER (maximum 18 sessions). Participants in the Established and Established plus DASH interventions were asked to record food and beverage intake and minutes of physical activity in a food and fitness diary at least three days each week. Frequency of self-monitoring was determined by the total number of days in which participants logged food intake and recorded minutes of exercise since the last intervention session. Two unannounced 24-hour dietary recalls were administered via telephone by trained staff at both baseline and six months to assess dietary intake (12). For the current study, we examined baseline to 6-month change in total caloric intake, percent energy from total fat, percent energy from carbohydrates, and percent energy from protein. Furthermore, a 7-day physical activity recall was administered at baseline and six months and used to calculate change in kilocalories expended per day (kcal/kg/day) (19,20).

Statistical Analysis

We used structural equation modeling (SEM) to examine the processes through which the lifestyle interventions in PREMIER led to weight loss. Use of SEM allowed us to simultaneously model the dietary and exercise behavioral processes involved in weight loss and to include both primary (weight change) and secondary outcomes (diet and exercise change) in the same model. Analyses were conducted using Mplus v7. Model diagnostics were performed using SAS v9.2 to evaluate model assumptions of linearity and homoscedastic errors, outliers, and influential observations. Change scores were created to represent six-month change for each dietary variable (i.e., change in total energy intake, change in percent energy from fat, percent energy from carbohydrates, and percent energy from protein), change in kilocalories expended per day, and percent weight change. Each dietary variable was tested in a separate model. In addition to treatment assignment, we controlled for age, race, and sex in each model. Figure 1 presents all the pathways that were examined in the analyses. Goodness-of-fit of the hypothesized models to the data was determined by several fit indices including a non-significant χ^2 ($p > .05$) (21), comparative fit index (CFI) $\geq .90$ (22), root mean square error approximation (RMSEA) $\leq .08$ (23), and the standardized root mean square residual (SRMR) $< .10$ (21). Missing data were handled using full-information maximum likelihood.

Results

Of the 501 participants, 61% were female, 35% self-reported Black/African American race/ethnicity, 32% were overweight but not obese, and 68% were obese. Mean (SD) age was 50 (8.7) years. Table 1 summarizes session attendance, number of days of self-monitoring, total energy intake, percent energy from fat, carbohydrates, and protein, kilocalories expended per day, and weight over the initial six months of the study. Participants, on average, attended 12 of the 18 sessions (67%) during the initial six months. Furthermore, self-monitoring of diet occurred, on average, a total of 69 days (median = 63) and self-monitoring of physical activity occurred, on average, a total of 57 days (median = 50) of the possible 72 days (maximum of 3 days per week required for self-monitoring over 6 months). Mean (SD) weight loss in percent and kilograms over the initial six months across both lifestyle interventions was 5.5% (5.5), 5.3 kg (5.7). The assumption of homoscedastic errors appeared violated when we examined the association between session attendance and both self-monitoring variables; therefore, we used bootstrapping to estimate the standard errors for all parameter estimates in the structural equation models described below.

Model with diet represented by total energy intake

Fit for the model with change in total energy intake was adequate [$\chi^2(4) = 11.02$, $p = .03$; CFI = .99; RMSEA = .06; SRMR = .01]. Despite a significant reduction in total energy consumed from baseline to 6 months, this change was not significantly associated with six-month percent change in weight ($\beta = .00$, $p = .40$), self-monitoring of diet ($\beta = .21$, $p = .76$), nor was this change associated with session attendance ($\beta = -11.95$, $p = .11$).

Model with diet represented by percent energy from total fat

Model fit for the model with percent energy from total fat (see Figure 2) was excellent [$\chi^2(4) = 8.23$, $p = .07$; CFI = 1.00; RMSEA = .05; SRMR = .01]. Greater session attendance was associated with increased number of days of self-monitoring of both diet [$\beta(SE) = 6.32\ (.37)$, $p < .001$] and exercise [$\beta(SE) = 5.36\ (.31)$, $p < .001$]. A 1-day increase in self-monitoring of diet was associated with an average .03% ($p < .05$) decrease in percent energy from total fat consumed over 6 months. Greater session attendance was also associated with a decrease in fat intake [$\beta(SE) = -.49\ (.13)$, $p = .001$]. Both self-monitoring of diet ($\beta(SE) = .04\ (.01)$, $p < .001$) and physical activity ($\beta(SE) = .03\ (.01)$, $p < .001$) had a significant direct effect on change in weight. Furthermore, a 1% decrease in percent energy from total fat was associated with a .06% ($p < .05$) decrease in weight from baseline to 6 months, while adjusting for 6-month change in kilocalories expended per day [$\beta(SE) = .14\ (.10)$, $p = .19$] and other covariates (i.e., treatment assignment, age, sex, and race). Older age [$\beta(SE) = .09\ (.02)$, $p > .001$] and self-reporting White for race [$\beta(SE) = 1.23\ (.43)$, $p < .01$] was associated with greater session attendance over the initial six months.

Session attendance had a significant indirect effect on change in percent energy from fat through self-monitoring of diet ($\beta_{\text{indirect}} = -.16$, $p < .05$). Also, the indirect effects of session attendance on 6-month percent weight change through self-monitoring of diet ($\beta_{\text{indirect}} = .23$, $p < .001$), self-monitoring of physical activity ($\beta_{\text{indirect}} = .14$, $p < .001$), and change in percent energy from fat ($\beta_{\text{indirect}} = .03$, $p < .05$) were significant. The indirect effects of self-monitoring on percent change in weight through change in percent energy from fat ($\beta_{\text{indirect}} = .002$, $p = .11$) and through change in kilocalories expended per day ($\beta_{\text{indirect}} = .00$, $p = .77$) were not significant.

Model with diet represented by percent energy from carbohydrates

Fit for the model with percent energy from carbohydrates (model not shown) was good [$\chi^2(4) = 9.72$, $p = .05$; CFI = 1.00; RMSEA = .05; SRMR = .01]. Similar to the model with total fat, greater session attendance was associated with increased self-monitoring and a .35% ($p < .05$) increase in energy from carbohydrates over six months. An increase in self-monitoring of diet was not significantly associated with an increase in percent energy from carbohydrates over 6 months [β(*SE*) = .03 (.01), $p = .08$]. Change in percent energy from carbohydrates was not significantly associated with change in weight after adjusting for change in kilocalories expended per day and covariates [β(*SE*) = .03 (.02), $p = .13$]. Furthermore, none of the indirect effects through change in carbohydrate intake were significant.

Model with diet represented by percent energy from protein

Model fit with change in percent energy from protein (model not shown) was adequate [$\chi^2(4) = 11.25$, $p = .02$; CFI = .99; RMSEA = .06; SRMR = .01]. Inconsistent with the previous models, greater session attendance was not significantly associated with 6-month change in protein consumption [β(*SE*) = .06 (.07), $p = .42$], nor was increased self-monitoring of diet (β(*SE*) = .01 (.01), $p = .19$). The 6-month change in percent energy from protein was not significantly associated with 6-month percent weight change [β(*SE*) = .07 (.04), $p = .07$]. Indirect effects through change in percent energy from protein were not significant.

Discussion

Our findings provide a reasonable model to explain some of the pathways through which the PREMIER trial lifestyle interventions led to reductions in weight. Specifically, findings suggest that regular session attendance is associated with increased self-monitoring (of both diet and exercise behaviors), with self-monitoring of diet being associated with reduced percent energy from fat, which in turn was associated with weight loss (adjusting for energy expended and other covariates). Moreover, findings suggest that the association between session attendance and dietary improvement was partially explained by use of self-monitoring and session attendance was indirectly associated with weight loss through decrease in total fat intake.

Typically, the importance of session attendance is only studied in the context of weight outcomes without addressing how greater session attendance translates into weight loss. Our findings provide some insight on the role of session attendance in lifestyle interventions, particularly, greater session attendance influences use of behavioral strategies such as self-monitoring of behaviors. In a recent study, anticipation of a scheduled intervention session as well as exposure to an actual intervention session increased the likelihood of dietary self-monitoring just prior to and immediately after an intervention session, respectively (24). Most likely, the association between session attendance and use of behavioral strategies such as self-monitoring is due to the training, prompting, and reinforcement of strategy use and repeated exposure to other participants successfully using the strategies. In addition, older age and being White was associated with greater session attendance, which is consistent with findings from the Weight Loss Maintenance Trial (7,25).

The significant association between self-monitoring and change in fat intake (9) as well as self-monitoring (of diet and physical activity) and weight change are consistent with previous studies (3–6, 10). Our finding that a decrease in percent energy from fat was significantly associated with weight loss, may be related to the focus on teaching participants in the PREMIER lifestyle interventions strategies to limit fat intake (i.e., ≤ 25% of energy from fat for Established + DASH and ≤ 30 % of energy in Established condition) in order to reduce overall energy consumption, thus promoting weight loss and blood pressure reduction. Furthermore, this association is consistent with findings from the Weight Loss Maintenance Trial (17) as well as the Women's Health Initiative Dietary Modification Trial (25). The associations between energy expended and weight change as well as change in percent energy from carbohydrates and protein and weight change found to be significant in previous studies (17,18) were not supported in the current analyses. Furthermore, although conceptually appropriate, the indirect effect of self-monitoring on 6-month percent weight change through change in diet and/or physical activity was not significant. This lack of findings and the small magnitude of effect for significant findings in the models may be due to issues of measurement error rather than incorrect conceptual modeling (26).

The non-significant relationship between change in total energy intake and percent change in weight over six months was surprising since clinically we know weight loss is a result of negative energy balance, typically achieved through reduced energy intake. Furthermore, in a previous study using PREMIER data, the change in both energy from liquids and energy from solid foods was significantly associated with 6-month and 18-month weight change (27). However, a major distinction between the current analysis and the analysis in Chen et al. (27) is that Chen included all 810 participants in the analysis whereas we limited our analysis to those with a BMI ≥ 25 kg/m^2 at baseline and randomized to one of the two active lifestyle interventions (n = 501). When we included those randomized to the Advice Only condition with BMI ≥ 25 (n = 753) and tested the association between change in total energy and percent change in weight over six months, the association was indeed significant ($\beta = .001$, $p < .01$). Based on these findings, it appears that our exclusion of individuals randomized to the Advice Only condition contributed to our inability to detect the relationship between change in total energy intake and weight change. It should be noted that this relationship in Chen et al. (27), particularly for change in energy from solid food, was also very weak at six months ($\beta = .06$, $p < .04$). The lack of a relationship between change in energy intake and weight in this study may indicate the limitations of reliability and validity when using a 24-hour dietary recall in a lifestyle intervention trial such as PREMIER (28). There are several sources of measurement error that must be considered when measuring dietary intake using a 24-hour recall including recall bias, day-to-day variation in dietary intake, and inaccurate or unavailable nutrition facts for certain foods in a nutrition database (29). A gold standard for measuring energy expenditure is the doubly labeled water approach (30,31), however, this method is not ideal for a large trial such as PREMIER given that the isotope tablets each participant would need to take to conduct this test are very expensive. Thus, further work is needed to develop inexpensive and non-burdensome methods for reliable and valid assessment of dietary intake.

As previously mentioned we adjusted for treatment assignment, age, race, and sex by entering them as predictors of each observed variable in the path models. We also applied multiple group analysis as another method to adjust for covariates given the categorical nature of three of the covariates (i.e., treatment, race, and sex). Models were run grouping by a combination of the three binary variables (i.e., 8 cells) and constraining pathway coefficients/parameters to be equal across the groups. This constrained model produced path coefficients very similar to those found in the primary analysis presented above; however, there were indications of poor model fit. A model not constraining paths across groups had considerably better fit and suggested moderation of weight loss processes by treatment, sex, and/or race. However, the small sample size in each of the 8 cells (< 100 participants in each) limited the ability to study this in depth, but is an interesting finding to explore in future studies.

Our study does have limitations. First, the measures of dietary intake and physical activity were obtained by self-report, thus subject to recall bias. However, unannounced 24-hour dietary recalls were performed by trained personnel who applied the multiple pass method to obtain the most accurate information during the PREMIER trial. Second, diet and physical activity were only measured at baseline and 6-month follow-up, which limits the analyses to use of change scores. Future trials should aim to collect behavioral measures at additional time points (at least 3) in order to improve modeling of behavior change trajectories and the relationship with weight outcomes (32). Third, the PREMIER trial did not collect data on use of additional key behavioral strategies (e.g., goal setting, stimulus control, or problem solving) to be included in the models along with use of self-monitoring. There is a need for brief, but reliable and valid measures of all key behavioral components of behavioral interventions to include as mediators and/or secondary outcome measures in future trials (26). Fourth, despite the significant associations among session attendance and self-monitoring, the rate of attendance (67% on average) and number of days of self-monitoring (69 days on average for diet and 57 for physical activity) over 6 months may appear modest. It should be noted that the 67% attendance rate only reflects attendance at initially scheduled face-to-face sessions. Although participants were encouraged to attend every session in PREMIER, make-up sessions as well as phone sessions were sometimes made available to participants who missed the scheduled session. However, make-up and phone sessions were limited as to not encourage missing consecutive sessions and also because the group social support could not be recreated. If we included the number of make-up and phone sessions in the count then the attendance rate would be much higher; however, we wanted the attendance variable in the structural equation model to reflect attendance to a planned, group session. Participants were required to self-monitor diet and physical activity only three days per week during the program, thus adherence to self-monitoring over the initial 6 months (96% adherence for diet and 79% for physical activity self-monitoring) was actually quite high.

Our study also has several strengths. First, the sample was large and diverse. Second, intervention process data related to diet and physical activity was collected, as well as extensive data on clinically relevant health outcomes, such as weight. Third, intervention goals and procedures used in PREMIER are typical of those used in contemporary weight loss programs. Hence, our results may be generalizable. Fourth, we were able to test associations simultaneously in one model to understand the direct and indirect pathways through which weight loss occurs. Our models provide further evidence that self-monitoring is a key component for regulating the types of macronutrients consumed, particularly fat, and managing weight. Still, replication of our study and analytic methods in other weight loss interventions is clearly warranted.

In conclusion, our study is one of few to apply structural equation modeling to simultaneously model the diet and physical activity behavioral processes related to weight outcomes to understand the underlying mechanisms of a lifestyle intervention. Our findings confirm theoretical assumptions and what is experienced in clinical practice-- training in and use of behavioral strategies like self-monitoring are associated with improved health behaviors, which can lead to significant weight loss. In addition, the models in this study provide a starting point to explore specific intervention components and how they translate into behavior change as well as possible areas to address to prevent behavioral relapses that lead to weight regain.

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What is already known about this subject?

- Lifestyle intervention session attendance is associated with significant weight loss
- Self-monitoring mediates relationship between lifestyle intervention and weight change
- Self-monitoring mediates relationship between lifestyle intervention and health behavior change

What does this study add?

- Structural equation modeling is a useful analytic approach to understand how lifestyle interventions lead to weight loss
- Greater session attendance is associated with increased self-monitoring
- Decrease in consumption of fat mediates relationship between session attendance and weight change

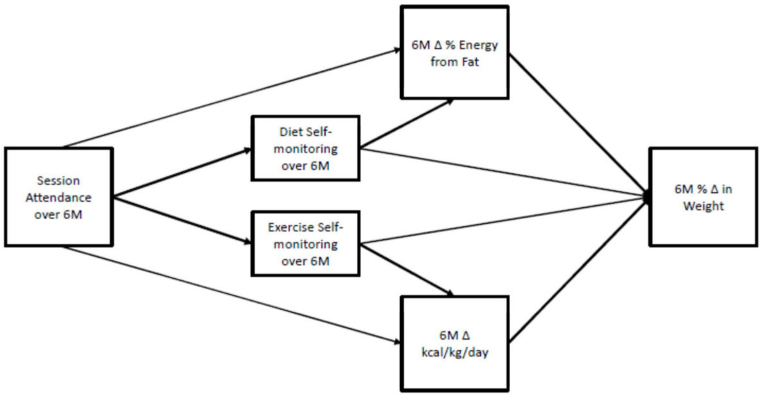

Figure 1.

Path Model of Behavioral Processes for Weight Change in PREMIER.

Note. Models were adjusted for treatment assignment, age, race, and sex by entering each as a predictor of each observed variable in the model.

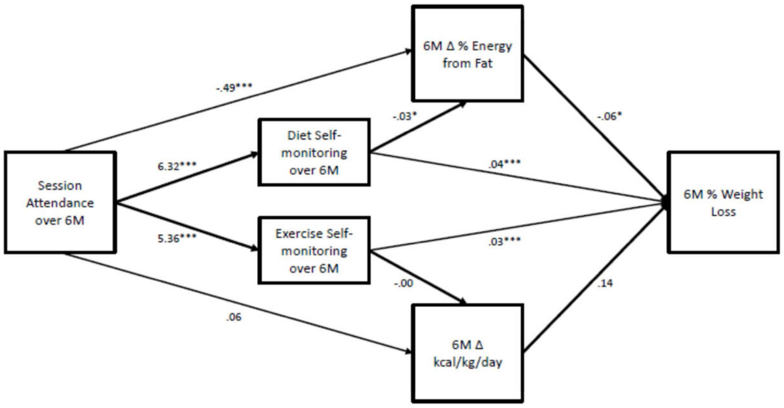

Figure 2.

Path Model for Behavioral Processes for Weight Change in PREMIER: Percent Energy from Fat Model. Parameter estimates are unstandardized regression coefficients. Model is adjusted for treatment assignment, age, race, and sex. Model fit: $\chi^2(4) = 8.83$, $p = .07$; CFI = 1.00; RMSEA = .05; SRMR = .01. ***$p < .001$, ** $p < .01$, * $p < .05$.

Table 1

Sample Characteristics (N = 501)

Characteristics	***M* (*SD*)**
Session Attendance (over 6 months)	12.26 (4.70)
Days of Self-monitoring of Diet (over 6 months)	68.86 (46.29)
Days of Self-monitoring of Physical Activity (over 6 months)	56.69 (39.36)
Total energy (kcal)	
Baseline	1955.49 (639.38)
6-month	1667.35 (530.38)
Percent energy from total fat	
Baseline	33.53 (7.75)
6-month	26.73 (9.04)
Percent energy from carbohydrates	
Baseline	50.62 (9.87)
6-month	56.53 (10.44)
Percent energy from protein	
Baseline	16.05 (4.26)
6-month	17.45 (4.20)
Kilocalories expended per day (kcal/kg/day)	
Baseline	33.78 (3.15)
6-month	34.25 (2.74)
Weight (kg)	
Baseline	97.63 (18.46)
6-month	92.24 (18.53)