Impact of 5-Year Weight Change on Blood Pressure: Results From the Weight Loss Maintenance Trial

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In this secondary analysis of the Weight Loss Maintenance trial, the authors assessed the relationship between blood pressure (BP) change and weight change in overweight and obese adults with hypertension and/or dyslipidemia who were randomized to 1 of 3 weight loss maintenance strategies for 5 years. The participants were grouped (N=741) based on weight change from randomization to 60 months as: (1) weight loss, (2) weight stable, or (3) weight gain. A significant positive correlation between weight change and systolic BP (SBP) change at 12, 30, and 60 months and between weight change and diastolic BP (DBP) change at 30 months was observed. From randomization to 60 months, mean SBP increased to a similar degree for the weight gain group (4.2±standard error=0.6 mm Hg; $P<.001$) and weight stable group (4.6±1.1 mm Hg; $P<.001$), but SBP did not rise in the weight loss group (1.0±1.7 mm Hg, $P=.53$). DBP was unchanged for all groups at 60 months. Although aging may have contributed to rise in BP at 60 months, it does not appear to fully account for observed BP changes. These results suggest that continued modest weight loss may be sufficient for long-term BP lowering. *J Clin Hypertens (Greenwich).* 2013;15:458–464. © 2013 Wiley Periodicals, Inc

Weight loss is recommended as an effective nonpharmacologic method for lowering blood pressure (BP).[1,2] Short-term studies have demonstrated that weight loss reduces systolic BP (SBP) and diastolic BP (DBP),[3,4] yet long-term studies suggest an attenuated effect over time. Trials of Hypertension Prevention, a prospective randomized trial that evaluated the impact of weight loss on BP and incident hypertension, demonstrated that the BP-lowering effect of weight loss at 6 months declined over a 3- to 4-year follow-up period.[5] Long-term relapse in BP was also observed in the Swedish Obesity Study (SOS), a prospective controlled trial that assessed the impact of weight loss on BP in severely obese adults who underwent gastric surgery.[6] We previously documented that long-term behavioral weight loss is feasible for a substantial proportion of clinical trial participants,[7] providing an opportunity to gain knowledge about long-term BP changes associated with nonpharmacologic, nonsurgical weight loss. In this report, we evaluate the relationship between weight change and BP change during a 5-year period following initial weight loss in the Weight Loss Maintenance (WLM) trial.[8]

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METHODS

WLM is a multicenter randomized trial that compared weight maintenance strategies in overweight and obese adults at risk for cardiovascular disease.[8] Detailed description of the WLM trial methods and the main results from phases 1 and 2 have been previously published.[8–11] Phase 3 results have also been reported.[7] An institutional review board at each participating clinical site approved the research protocol. All participants provided written informed consent and a data and safety monitoring board provided trial oversight.

Participants

WLM participants were overweight or obese (body mass index 25–45 kg/m^2) adults 25 years and older with medication-treated hypertension and/or dyslipidemia and without active cardiovascular disease. Exclusion criteria were medication-treated diabetes mellitus, recent cardiovascular event, weight loss >9 kg in the 3 months prior to study entry, recent use of weight loss medications or prior weight loss surgery, and medical or psychiatric illness that prevented full participation in the study. Three of 4 clinical sites participated in all 3 phases (66 months) of the WLM trial. All participants who enrolled in phase 2 of the WLM trial at these 3 sites were included in this analysis.

Study Design

During phase 1, all participants underwent the same intensive 6-month behavioral weight loss intervention consisting of weekly group counseling on diet and physical activity. During phase 2, which was 30 months

in duration, participants who successfully achieved ≥ 4 kg weight loss in phase 1 were randomized to either a personal contact (PC) weight loss maintenance program, an internet-based interactive technology (IT) weight maintenance program, or a no-further-treatment, self-directed control condition. During phase 3, to test the value of continued maintenance intervention beyond 30 months, the PC and IT participants were re-randomized to either continue or to discontinue intervention for an additional 30 months. Data collection continued for participants who declined re-randomization but were agreeable to ongoing observation. Because of a lack of funding partway through phase 3, the internet-based interactive technology intervention was stopped. Data collection continued for IT participants as observation only. The self-directed control group continued through phase 3 without intervention.

Measurements

Data collection was performed at study entry, the beginning of phase 2 (prior to randomization), and every 6 months thereafter for 30 months. During phase 3, data collection was performed on 2 occasions, at months 42 and 60 following initial randomization. Measurements were obtained by trained certified staff who were blinded to treatment assignment.

Weight was measured in duplicate using a high-quality, calibrated digital scale with participants wearing light indoor clothes without shoes. Weight measurements were collected on 2 separate days at the beginning of phases 1 and 2 and at 12 and 30 months after initial randomization. Duplicate weight measurements were collected at one visit at 60 months post-randomization. Height was measured once at entry using a calibrated, wall-mounted stadiometer.

An ambulatory BP monitor was used as an automated in-clinic device to measure BP. Arm circumference was measured at every visit to determine appropriate cuff size. A 30-minute time lapse was required if participants had engaged in vigorous exercise, ingested food or caffeine, or smoked before BP was measured. Prior to BP measurement, participants rested comfortably in a seated position for 5 minutes in a quiet room free from activity. BP was collected in duplicate on 2 separate visits and averaged at the beginning of phase 2 and at 12 and 30 months after initial randomization. Duplicate BP measurements were collected in one visit at 60 months post-randomization. BP was not measured at the start of phase 1. The first BP measurement was performed at the beginning of phase 2 (after the 6-month weight loss intervention).

Outcomes

We assessed correlations between weight change and BP change for all participants 12, 30, and 60 months after initial (phase 2) randomization. Irrespective of their weight maintenance intervention assignments, participants were categorized into 3 groups based on change in weight from the beginning of phase 2 to the end of phase 3, a 60-month period. Less than a 3% change in weight has been previously recommended to define weight maintenance because it is low enough not to carry clinical relevance, yet high enough to exceed measurement error and body fluid fluctuations.[12] Accordingly, participants were categorized as having (1) weight loss if they had >3% reduction in weight, (2) stable weight if they had a change in weight $\leq 3\%$, and (3) weight gain if they experienced >3% increase in weight at the end of the 60-month follow-up period. We compared between-group changes in SBP and DBP.

Statistical Analysis

We used means and standard deviations (SDs) to describe the baseline distribution of continuous variables between the weight loss groups, as well as the mean weight changes in the 3 weight change groups over time. We used Pearson correlation coefficients to summarize the unadjusted relationship between weight change and BP change as continuous variables. SAS PROC GLIMMIX (SAS Institute Inc, Cary, NC) was used to compare changes in SBP (and in separate models DBP) across weight groups while adjusting for clinical site, phase 1 weight change, age, and initial SBP (DBP). Additional models including race, sex, and their interaction did not significantly improve the fit to the data and are not reported here. The SAS LSMEANS statement was used to generate adjusted point estimates and corresponding standard errors based on these models. Analyses included all participants randomized to phase 2 at 3 clinical sites minus 4 deaths. As described in more detail elsewhere,[7,8] we used multiple imputation to replace missing data and, except for weight change from study entry to the end of phase 3 or when otherwise noted in the text, report results that are averaged across the 5 imputed datasets. Follow-up weights were imputed for 0 individuals at month 0, 44 individuals (3 weight loss, 6 weight stable, 35 weight gain) at 30 months, and 191 individuals (14 weight loss, 37 weight stable, 140 weight gain) at 60 months who missed data collection visit. SBP and DBP were imputed for 0 individuals at month 0, 65 individuals (6 weight loss, 11 weight stable, 48 weight gain) at 30 months, and 194 individuals (14 weight loss, 39 weight stable, 141 weight gain) at 60 months who missed data collection visit. All analyses were conducted using SAS, version 9.2 (SAS Institute Inc, Cary, NC). All P values are two-sided with <.05 considered statistically significant.

RESULTS

Participant Characteristics

A total of 1685 participants entered phase 1 of the WLM trial at 4 sites with 1311 individuals enrolled at the 3 clinical sites of interest. Seven hundred forty-five of these participants were subsequently randomized into phase 2. With the exclusion of 4 people who died, 741 participants constitute the population included in this

analysis. A total of 34% were men, 48% were African American, and the mean age at study entry was 55 years (Table I). The majority were obese (body mass index ≥ 30 kg/m^2), as opposed to overweight, and were taking medications for both hypertension and dyslipidemia. The mean overall weight change from study entry to the end of phase 3 (ie, 66 months) was −2.2 kg (SD=7.4) and 62% of participants weighed less at the end of the study than they did at study entry.

Correlation Between Weight Change and BP Change

There was a significant positive correlation between weight change from randomization and SBP change from randomization at all time points, with the strongest correlation occurring 30 months after initial weight loss (Table II). For each 1-kg increase in weight, there was an associated 0.3-, 0.5-, and 0.2-mm Hg increase in SBP at 12, 30, and 60 months, respectively. There was a statistically significant correlation between weight change and DBP change at 30 months only (R=0.15, P<.0001).

Weight Group Categories

After categorizing participants into weight groups as specified above, 67 (9%) experienced an additional weight loss of >3% (weight loss group), 153 (21%) had a weight change of ±3% or less (weight stable group), and 521 (70%) experienced a weight gain of >3% (weight gain group). The group with weight gain was younger than the group with stable weight (54.6±8.7 years vs 56.8±9.4 years); however, no other baseline characteristics differed clinically between the weight change groups (Table I). The observed differences in mean number of reported antihypertensive medications between the 3 weight groups were not clinically relevant (Table III).

Weight Changes

The cumulative change in weight from the start of phase 1 to the end of phase 3 by weight group is represented in Figure 1. Follow-up weight measurements at 0, 30, and 60 months were collected in 67, 64, and 53 individuals with weight loss; 153, 147, and 116 individuals with

TABLE I. Baseline Characteristics and Clinical Measures of 741 Participants Randomized to Phase 2 of the WLM Trial at 3 Clinical Sites

	All (N=741)	Weight Loss (n=67)	Weight Stable (n=153)	Weight Gain (n=521)
Age, y	55.2±8.9	56.4±8.2	56.8±9.4	54.6±8.7
Men	255 (34)	17 (25)	59 (39)	179 (34)
African Americans	352 (48)	28 (42)	79 (52)	245 (47)
Income				
<$60,000, %	42	41	40	43
Education				
Some college or less, %	39	39	32	41
Weight, kg				
Phase 1 entry	96.0±16.5	96.8±16.3	96.5±17.9	95.7±16.2
Phase 2 entry	88.0±15.9	89.7±15.6	89.2±17.6	87.4±15.3
SBP, mm Hg				
Phase 2 entry	121.9±13.5	123.3±15.0	122.3±13.3	121.5±13.3
DBP, mm Hg				
Phase 2 entry	73.1±9.3	71.7±10.6	72.3±8.8	73.6±9.2

Abbreviations: DBP, diastolic blood pressure; SBP, systolic blood pressure, WLM, Weight Loss Maintenance. Values are expressed as mean±standard deviation.

TABLE II. Mean Weight and BP Changes With Correlations for Participants Randomized to Phase 2 of the WLM Trial at 3 Clinical Sites

	Δ Weight, kg	Δ SBP, mm Hg	SBP-Weight Correlation Coefficient	*P* Value	Δ DBP, mm Hg	DBP-Weight Correlation Coefficient	*P* Value
Randomization to 12 months	3.1±4.7	3.3±11.3	0.11	<.01	1.9±7.5	0.06	.14
Randomization to 30 months	5.0±5.9	3.0±12.7	0.22	<.0001	0.7±8.1	0.15	<.0001
Randomization to 60 months	5.8±7.6	3.9±15.8	0.10	<.01	0.2±10.0	0.04	.38

Abbreviations: Δ, change; DBP, diastolic blood pressure; SBP, systolic blood pressure; WLM, Weight Loss Maintenance. Values are expressed as mean±standard deviation. [a]No imputed data. The number for weight at 12, 30, and 60 months is 709, 697, and 550, respectively. The number for blood pressure (BP) at 12, 30, and 60 months is 707, 676, and 544, respectively.

TABLE III. Mean Number of Reported Antihypertensive Medications for Phase 2 Participants by Weight Change Group

	Weight Loss	Weight Stable	Weight Gain
Phase 1 entry	1.8±0.9	1.9±0.9	1.8±0.8
No.	54	131	462
Phase 2 entry	1.7±0.8	1.9±0.9	1.8±0.8
No.	54	127	447
Phase 3 entry	1.9±0.8	2.0±0.9	1.9±0.8
No.	50	122	403
Phase 3 end	2.2±0.9	1.9±0.9	2.0±0.9
No.	41	92	326

Values are expressed as mean±standard deviation. Values do not include imputed data.

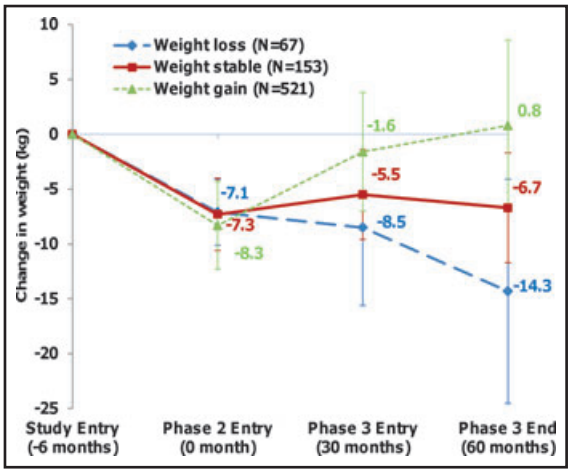

FIGURE 1. Cumulative mean change in weight of phase 2 participants (n=741) from study entry to study end by weight change group. Values are expressed as means and standard errors.

stable weight; and 521, 486, and 381 individuals with weight gain, respectively. From the time of initial randomization to the end of the study (60 months), weight change for the weight loss group, weight stable group, and weight gain group were −7.1 kg (SD 8.0), 0.6 kg (SD 3.0), and 9.1 kg (SD 8.4), respectively. The weight gain group finished the study within 0.8 kg of their entry weight. Both the weight loss and weight stable groups ended the study with a clinically significant[5,13] weight loss of −14.3 kg (SD 9.0) and −6.7 kg (SD 4.4), respectively, below their mean entry weight.

BP Changes

Cumulative changes in mean SBP from the beginning of phase 2 to the end of phase 3 by weight group (n=741) after adjusting for clinical site, age at study entry, weight change during phase 1, and SBP at the start of phase 2 are represented in Figure 2. Follow-up BP measurements were completed for 91% (n=676) of participants at the end of phase 2 and 74% (n=547) of

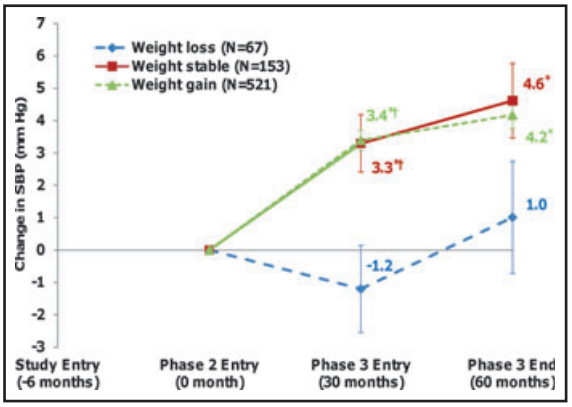

FIGURE 2. Adjusted cumulative mean change in systolic blood pressure (SBP) from phase 2 entry to study end by weight change group (n=741). Analysis includes all participants randomized to phase 2 at 3 clinical sites minus 4 deaths. Results are based on linear regression adjusting for clinical site, phase 1 weight change, age, and SBP at randomization. Values are expressed as means and standard errors. *P<.01 for within-group change from month 0. †P<.01 for between-group difference compared with the continued weight loss group.

participants at the end of phase 3. Mean SBP in the weight gain group increased by 3.4 mm Hg (standard error [SE] 0.5, P<.001) at 30 months and 4.2 mm Hg (SE 0.6, P<.001) at 60 months. Mean SBP also increased in the weight stable group by 3.3 mm Hg (SE 0.9, P<.001) and 4.6 mm Hg (SE 1.1, P<.001), at 30 months and 60 months, respectively. SBP for the weight loss group did not differ significantly at either 30 months (−1.2±SE=1.3 mm Hg, P=.38) or 60 months (1.0± SE=1.7 mm Hg, P=.53). The pattern of DBP change for the 3 weight groups was similar to that of SBP; however, a statistically significant increase in DBP from randomization was observed only for the weight gain group at 30 months (Figure 3). Mean SBP and DBP change for both the weight gain and weight stable groups were significantly higher than the weight loss group ($P \leq .02$) at 30 months. At 60 months, only mean DBP change for the weight stable group was higher than the weight loss group (P=.01).

Recognizing that the definition of weight maintenance based on a 3% change was somewhat arbitrarily set, we also assessed change in SBP and DBP after redefining groups by 2 separate, additional criteria: a 2% change (n=78 weight loss, 104 weight stable, 559 weight gain) and a 5% change (n=40 weight loss, 267 weight stable, 434 weight gain) in weight from the start of phase 2 to the end of phase 3. A similar pattern was seen for these re-defined groups. Again, the weight gain and weight stable groups had a significant increase in SBP at 30 and 60 months and the weight loss group was unchanged at these time points. When the weight loss group was defined by >2% weight reduction from randomization, mean SBP change (−0.9 mm Hg, SE 1.2) was significantly lower than the weight stable (+3.0 mm Hg, SE 1.1) and weight gain (+3.5 mm Hg, SE 0.5) groups at

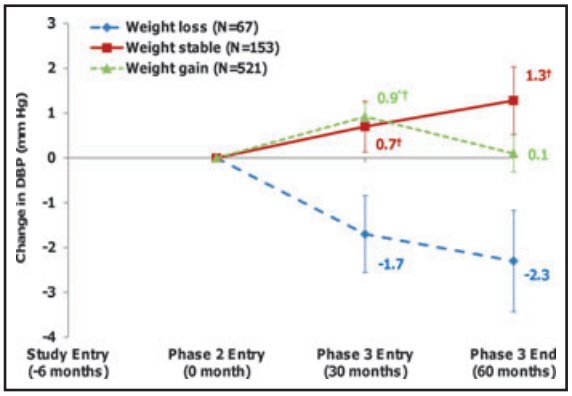

FIGURE 3. Adjusted cumulative mean change in diastolic blood pressure (DBP) from phase 2 entry to 66 months by weight change group (n=741). Analysis includes all participants randomized to phase 2 at 3 clinical sites minus 4 deaths. Results are based on linear regression adjusting for clinical site, phase 1 weight change, age, and initial DBP. Values are expressed as means and standard errors. *P<.01 for within-group change from month 0. †P<.02 for between-group difference compared with the continued weight loss group.

30 months only. DBP decreased significantly both at 30 months (−3.4 mm Hg, SE 1.1, P<.01) and 60 months (−4.1 mm Hg, SE 1.4, P=.01) when the weight loss group was defined by >5% weight reduction from randomization.

DISCUSSION

In this study of overweight and obese adults at high risk for cardiovascular disease, we were able to evaluate long-term BP changes in relation to weight change during a 5-year follow-up period. We found that there is a modest positive relationship between weight change and SBP change 12, 30, and 60 months after initial weight loss. In addition, we found that SBP increased significantly at 60 months not only in participants whose weight increased >3% following initial weight loss, but also in participants whose weight remained within 3%. It was only in participants who lost an additional $\geq$3% of weight that SBP remained stable as opposed to increasing.

Numerous studies, predominantly short-term, have shown an association between weight loss and BP reduction.[3,14] A meta-analysis of 25 randomized controlled trials (N=4874) evaluating the impact on BP of weight reduction, by means of energy restriction and/or increased physical activity, estimated that a −1.05-mm Hg decrease in SBP and −0.92-mm Hg decrease in DBP resulted from every 1 kg of weight loss,[15] data consistent with our analysis for SBP. However, studies included in the meta-analysis did not have a minimum participant weight loss requirement and weight loss ranged from −0.6 to −11.9 kg (mean −5.1% or −5.8% of initial body weight). The majority of studies included were also of shorter duration, with a follow-up period of $\geq$3 years in just 5 of the trials. In the longest trial, a 7-year follow-up study,[16] the mean overall end weight for the weight loss intervention group was higher than the mean entry weight (+4.9 kg). Our analysis, although limited only to the subset of participants who were randomized in phase 2 at 3 of 4 clinical sites, involves a large number of participants (N=741) who lost a considerable amount of weight in a relatively short period (average of 8.0 kg over 6 months in phase 1) and remained at or below entry weight at 5-year follow-up, allows us to comment on the BP changes during a period of successful weight loss maintenance.

As we anticipated, SBP increased significantly in participants who had >3% weight gain during the 5-year follow-up period. Based on previous studies,[17] we anticipated that BP would either (1) remain unchanged for participants whose weight remained stable and decrease for participants who continued to lose weight, or (2) be lower in the group with stable weight and lower still in those with additional weight loss. However, this was not observed. Instead, mean SBP increased despite weight remaining stable (within 3%) for the weight stable group and was not significantly different from that of the weight gain group. In addition, SBP was unchanged for the weight loss group who lost an additional $\geq$3% of their weight. This pattern was also observed after redefining the weight stable group by a stricter criterion of <2% change in weight and the weight loss group by a stricter criterion of >5% weight loss.

It is unclear why the weight loss group failed to experience a reduction in mean SBP and DBP at 5-year follow-up. It is presumed that the greatest effect of weight loss on BP occurred during the behavioral intervention period (phase 1) when participants were encouraged to increase physical activity, reduce caloric intake, and adopt the Dietary Approaches to Stop Hypertension eating pattern.[8] It is quite possible that a plateau effect took place for BP during the early stages of the study. Consequently, any additional weight loss beyond a certain threshold would have no further effect on BP. This could potentially explain why the mean BP for the weight loss group did not change significantly for the duration of the study.

Although we do not have mean entry BP measurements, prior studies[15] demonstrating a direct relationship between weight loss and BP lead us to presume that a BP reduction resulted from the behavioral intervention. Exactly how this initial weight loss influences long-term BP is what our study sought to address. Long-term studies tend to show an attenuated BP-lowering effect of weight loss over time. Even though a subsequent rise in BP is noted, final BP still appears lower than baseline measurements,[3] thus showing a weight loss benefit. BP rises with age. One can propose that weight loss somehow lowers and resets the starting point from which BP rises, thereby preventing, delaying, or attenuating hypertension.

The degree of weight loss needed to improve cardiovascular risk factors was evaluated by Sjostrom and

colleagues who analyzed 10-year data of the Swedish Obesity Study (SOS).[18] After dividing 1801 surgically and conventionally treated severely obese participants into weight change classes, they found that a mean weight loss of $\geq$10 kg was related to significant improvements in SBP (−6.0 mm Hg) when compared with weight stable participants 10 years after surgery. However, a mean weight change of −5 kg to +10 kg was not associated with a significant difference in SBP when compared with weight stable participants during the same time period. Such findings are congruent with our 5-year study results in that no difference in mean SBP was observed between our weight groups. A weight reduction by at least 2%, however, was adequate in our study to observe a significantly lower mean SBP change in the weight loss group at 2.5 years when compared with those who lost less weight or gained weight. Taking SOS observations into account with our results, it can be suggested that larger degrees of weight loss may be necessary as time progresses to maintain a BP benefit.

Whether the known increase in BP with advancing age was responsible for our observed increase in BP despite maintenance of weight loss is not clear. Observational studies have found that both age and level of BP influence the rate of BP rise.[19,20] Our participants were middle-aged when they entered WLM (mean age 55 years) and remained in the study for a total of 5.5 years (phases 1–3). Without taking baseline age and BP into account, epidemiologic studies have estimated SBP to rise at a rate of 0.287 to 0.638 mm Hg per year in US populations,[21] corresponding to an increase in SBP of 1.4 to 3.2 mm Hg over 5 years. The mean overall change in SBP for the weight stable and weight gain groups were +4.6±1.1 mm Hg and +4.2±0.6 mm Hg, respectively, which is 1.4 to 3.2 mm Hg and 1.0 to 2.8 mm Hg higher than predicted. This suggests that factors other than aging alone may have contributed to SBP rise. Using the same estimates, the mean change in SBP for the weight loss group was +1.0±1.7 mm Hg, which was 0.4 to 2.2 mm Hg lower than predicted. This suggests that the effects of aging may have been mitigated by weight loss itself or by other factors associated with ongoing weight loss (ie, increased physical activity, caloric restriction, negative energy balance). One would still anticipate a divergence in BP between the weight gain and the weight stable groups at 30 and 60 months in our study. This did not occur even with the inclusion of baseline age, a significant covariate, in our model to adjust for age effect on BP. Our observations suggest that after BP lowering associated with initial weight loss, a long-term BP advantage may not be gained by persons who maintain a stable weight compared with persons who regain weight during the same period. This finding supports observations from the SOS.[18]

Although sustained weight loss is challenging, these data suggest that even small amounts of continued weight loss over 5 years has a clinically significant impact: the expected rise in BP over that period did not occur with annual weight loss of as little as 3 to 4 lb.

LIMITATIONS

We acknowledge that our study has limitations. As an observational study of a randomized trial, establishing a causal relationship between weight change and BP change, is not possible. Also, by design, WLM only included those participants who lost $\geq$4 kg during the phase 1 weight loss intervention limiting our analysis to participants who were enrolled at 3 of 4 participating sites. Another limitation is that BP was not measured at the beginning of phase 1. Based on the study design in which participants were only randomized if they lost at least 4 kg in phase 1, it was anticipated that a large proportion of phase 1 participants would never be randomized. Thus, we decided not to use valuable study resources to obtain BP measurements until entry into phase 2. We felt this decision was a reasonable compromise for a study in which the primary outcomes were based on weight measurements, but understood the limitation it would pose for BP secondary outcome. In particular, we are unable to determine whether BP after 5 years of weight maintenance is lower than baseline BP prior to weight loss. While we controlled for several factors that may contribute to BP change independent of weight change, we do recognize that there were some factors that may influence BP which we did not account for, including sex, level of physical activity, dietary pattern, alcohol consumption, body composition, hours of sleep, sleep apnea, duration of hypertension, remote cardiovascular disease events, undiagnosed diabetes mellitus, comorbidities, heredity, and unintentional weight loss. Similarly, we did not directly test whether the association between weight change and BP change differs by sex, although this is unlikely given the absence of an association between sex and BP change. In addition, although the number of antihypertensive medications did not change from study entry to study end, we do not have data to assess changes in medication dose.

CONCLUSIONS

WLM provides an opportunity to gain insight into long-term BP changes associated with behavioral weight loss. Our results suggest that (1) the BP-lowering effect of weight loss does not persist long-term when weight is regained or even when weight remains stable, and (2) larger degrees of weight must be lost to achieve a long-term BP benefit. Modest, persistent weight loss, or factors associated with weight loss, is necessary to overcome age-related rise in BP over time. Our finding of a rise in BP despite weight stability has important implications for the use of weight loss strategies for hypertension prevention and control.

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References

1. Chobanian AV, Bakris GL, Black HR, et al. Seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. *Hypertension*. 2003;42:1206–1252.
2. Expert Panel on the Identification, Evaluation, and Treatment of Overweight in Adults. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: executive summary. *Am J Clin Nutr*. 1998;68:899–917.
3. Trials of Hypertension Prevention Collaborative Research Group. The effects of nonpharmacologic interventions on blood pressure of persons with high normal levels. Results of the Trials of Hypertension Prevention, Phase I. *JAMA*. 1992;267:1213–1220.
4. Schotte DE, Stunkard AJ. The effects of weight reduction on blood pressure in 301 obese patients. *Arch Intern Med*. 1990;150:1701–1704.
5. Trials of Hypertension Prevention Collaborative Research Group. Effects of weight loss and sodium reduction intervention on blood pressure and hypertension incidence in overweight people with high-normal blood pressure. The Trials of Hypertension Prevention, phase II. The Trials of Hypertension Prevention Collaborative Research Group. *Arch Intern Med*. 1997;157:657–667.
6. Sjostrom CD, Peltonen M, Sjostrom L. Blood pressure and pulse pressure during long-term weight loss in the obese: the Swedish Obese Subjects (SOS) Intervention Study. *Obes Res*. 2001;9:188–195.
7. Brantley P, Appel L, Svetkey L, et al. Five Year Results from the Weight Loss Maintenance Trial [Abstract]. Nutrition, Physical Activity and Metabolism Scientific Sessions 2010 (NPAM); March 2–4, 2010; Atlanta, GA.
8. Svetkey LP, Stevens VJ, Brantley PJ, et al. Comparison of strategies for sustaining weight loss: the weight loss maintenance randomized controlled trial. *JAMA*. 2008;299:1139–1148.
9. Hollis JF, Gullion CM, Stevens VJ, et al. Weight loss during the intensive intervention phase of the weight-loss maintenance trial. *Am J Prev Med*. 2008;35:118–126.
10. Brantley P, Appel L, Hollis J, et al. Design considerations and rationale of a multi-center trial to sustain weight loss: the Weight Loss Maintenance Trial. *Clin Trials*. 2008;5:546–556.
11. Weight Loss Maintenance Research Group. Weight Loss Maintenance Public Site. http://www.kpchr.org/WLMPublic. Copyright 2007. Accessed November 16, 2012.
12. Stevens J, Truesdale KP, McClain JE, Cai J. The definition of weight maintenance. *Int J Obes*. 2006;30:391–399.
13. Knowler WC, Barrett-Connor E, Fowler SE, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *N Engl J Med*. 2002;346:393–403.
14. Wing RR, Lang W, Wadden TA, et al. Benefits of modest weight loss in improving cardiovascular risk factors in overweight and obese individuals with type 2 diabetes. *Diabetes Care*. 2011;34:1481–1486.
15. Neter JE, Stam BE, Kok FJ, et al. Influence of weight reduction on blood pressure: a meta-analysis of randomized controlled trials. *Hypertension*. 2003;42:878–884.
16. He J, Whelton PK, Appel LJ, et al. Long-term effects of weight loss and dietary sodium reduction on incidence of hypertension. *Hypertension*. 2000;35:544–549.
17. Stevens VJ, Obarzanek E, Cook NR, et al. Long-term weight loss and changes in blood pressure: results of the Trials of Hypertension Prevention, phase II. *Ann Intern Med*. 2001;134:1–11.
18. Sjostrom CD, Lystig T, Lindroos AK. Impact of weight change, secular trends and ageing on cardiovascular risk factors: 10-year experiences from the SOS study. *Int J Obes*. 2011;35:1413–1420.
19. Wills AK, Lawlor DA, Matthews FE, et al. Life course trajectories of systolic blood pressure using longitudinal data from eight UK cohorts. *PLoS Med*. 2011;8:e1000440.
20. Franklin SS, Gustin W, Wong ND, et al. Hemodynamic patterns of age-related changes in blood pressure: the Framingham Heart Study. *Circulation*. 1997;96:308–315.
21. Rodriguez BL, Labarthe DR, Huang B, Lopez-Gomez J. Rise of blood pressure with age. New evidence of population differences. *Hypertension*. 1994;24:779–785.