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Describing Patterns of Weight Changes Using Principal Components Analysis: Results from the Action for Health in Diabetes (Look AHEAD) Research Group

Mark A. Espeland, PhD¹, George A. Bray, MD², Rebecca Neiberg, MS¹, W. Jack Rejeski, PhD³, William C. Knowler, MD, DrPH⁴, Wei Lang, PhD¹, Lawrence J. Cheskin, MD⁵, Don Williamson, PhD², C. Beth Lewis, MD⁶, and Rena Wing, PhD [on behalf of and the Look AHEAD Study Group]⁷

¹Department of Biostatistical Sciences, Wake Forest University School of Medicine, Winston-Salem, NC

²Division of Clinical Obesity and Metabolism, Pennington Biomedical Research Center, Baton Rouge, LA

³Department of Health and Exercise Sciences, Wake Forest University, Winston-Salem, NC

⁴Diabetes Epidemiology and Clinical Research Section, NIDDK, Phoenix, AZ

⁵Department of Health, Behavior & Society, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD

⁶Division of Preventive Medicine, The University of Alabama at Birmingham, Birmingham, AL

⁷Centers for Behavioral and Preventive Medicine, The Miriam Hospital Medical School, Providence, RI

Abstract

PURPOSE—To demonstrate how principal components analysis can be used to describe patterns of weight changes in response to an intensive lifestyle intervention

METHODS—Principal components analysis was applied to monthly percent weight changes measured on 2,485 individuals enrolled in the lifestyle arm of the Action for Health in Diabetes (Look AHEAD) clinical trial. These individuals were 45–75 years of age, with Type 2 diabetes and body mass indices $>25 \text{ kg/m}^2$. Associations between baseline characteristics and weight loss patterns were described using analyses of variance.

RESULTS—Three components collectively accounted for 97.0% of total intra-subject variance: a gradually decelerating weight loss (88.8%), early versus late weight loss (6.6%), and a mid-year trough (1.6%). In agreement with previous reports, each of the baseline characteristics we examined had statistically significant relationships with weight loss patterns. As examples, males tended to have a steeper trajectory of percent weight loss and to lose weight more quickly than women.

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Address correspondence: Mark A. Espeland, PhD, Department of Biostatistical Sciences, Wake Forest University School of Medicine, Medical Center Blvd, Winston-Salem, NC 27157 (mespelan@wfubmc.edu).

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Trial Registration: clinicaltrials.gov

Individuals with higher HbA1c tended to have a flatter trajectory of percent weight loss and to have mid-year troughs in weight loss compared to those with lower HbA1c.

CONCLUSIONS—Principal components analysis provided a coherent description of characteristic patterns of weight changes and is a useful vehicle for identifying their correlates and potentially for predicting weight control outcomes.

Keywords

Principal components analysis; intervention studies; weight loss

INTRODUCTION

Individuals respond differently to interventions, even if extensive efforts are taken to standardize protocols. For weight loss interventions, this translates into variation in the overall weight losses and, importantly, in the patterns of longitudinal weight changes. Plots of longitudinal mean weights may mask important individual differences in weight loss and may not, in fact, portray the experience of any individual.

Much research has been conducted to identify predictors of which individuals will gain or lose weight or which will meet definitions based on weight change cut points that have been adopted for “maintainers” or “cyclers” (1–4), however, there are surprisingly few unconstrained descriptions of the variability that is encountered in patterns of weight changes over time. Moreover, these studies have focused on assessing differences among means, rather than among individuals (5–7). One reason for this trend may be the difficulty involved in capturing the main types of variation in patterns of weight changes that can occur. Plotting individual trajectories may be helpful, but even for reasonably limited sample sizes, overlapping lines quickly obscure individual patterns. It would be helpful to find a means to express patterns more succinctly. Principal components analysis permits this by identifying predominant patterns and sources of variation.

We used monthly weights taken over one year from individuals enrolled in a standardized intensive lifestyle intervention to describe differences in how an individual’s weight changes over this time period. Principal components analysis was used to identify major differences in patterns of percent weight changes. The results of these analyses were then used to identify characteristics of individuals that were associated with these different patterns of weight loss.

MATERIALS AND METHODS

Look AHEAD is a multi-center randomized clinical trial that has enrolled 5,145 overweight or obese volunteers with type 2 diabetes (8,9). It is assessing the long-term effects on cardiovascular outcomes of an intensive lifestyle intervention program designed to achieve and maintain weight loss primarily through decreased caloric intake and increased physical activity. The comparison group receives diabetes support and education only.

At enrollment, Look AHEAD participants had type 2 diabetes, were aged 45–75 years, and were overweight or obese (collectively, body mass index ≥ 25 kg/m², or ≥ 27 kg/m² if treated with insulin). Other inclusion requirements were a source of medical care, systolic blood pressure < 160 mm Hg (treated or untreated), diastolic blood pressure < 100 mmHg, HbA1c $< 11\%$, plasma triglycerides < 600 mg/dl, and willingness to accept random assignment and participate in the study for the proposed 11.5 years. Potential volunteers who were judged unlikely to carry out the weight loss intervention components were excluded. Recruitment began in June 2001 and was completed in March 2004.

Intensive Lifestyle Intervention

Approximately half (N= 2,570) of the Look AHEAD enrollees were randomly assigned to participate in a weight loss intervention that has been described previously (10). Briefly, the intervention combined diet modification and increased physical activity and was designed to induce a minimum weight loss of 7% of initial body weight during the first year. Individual participants were encouraged to lose 10% (or more) of their initial body weight and to have 175 minutes of moderate-intensity physical activity per week. The intervention was modeled on group behavioral programs developed for the treatment of obese patients with type 2 diabetes. During the first 6 months, participants were seen weekly with 3 group meetings and 1 individual session per month. During months 7–12 participants were seen in the clinic at least twice per month: group sessions every other week and a monthly individual session. The sessions were led by interventionists trained in nutrition and exercise counseling; participants were weighed using a digital scale at all intervention visits.

Restriction of caloric intake was the primary method of achieving weight loss. To aim for a weight loss of 10% of initial weight, the calorie goals were 1200–1500 for individuals weighing 250 lbs (114 kg) or less at baseline and 1500–1800 for individuals weighing more than 250 lbs. The composition of the diet was structured to enhance glycemic control and to improve cardiovascular disease risk factors, and included a maximum of 30% of total calories from fat, a maximum of 10% of total calories from saturated fat, and a minimum of 15% of total calories from protein.

During the first 4 weeks of the intervention, participants followed a portion-controlled diet. This included the daily use of liquid meal replacements for 2 meals, snacks bars, and an evening meal of either a frozen entree or conventional table foods. Those who did not accept or tolerate the liquid or prepared meals had the option to use a very structured meal plan. Individuals who were successful and desired to continue on the portion-controlled diet were allowed to do so, with a monthly review at the individual session to reassess progress.

The physical activity program of the weight loss intervention was home-based with gradual progression toward a goal of 175 minutes of moderate intensity physical activity per week by the end of the first 6 months. Exercise bouts of 10 minutes and longer were counted toward this goal. Participants were directed to exercise at least 5 days/week. In general, occupational activity was not counted towards the physical activity goal. Moderate-intensity walking was encouraged as the primary type of physical activity. To enhance participation, the intervention allowed for individual choices in types of moderate physical activities and the tailoring of exercise programs based on physical fitness tests and safety issues.

The intervention plan called for 6 months of treatment with lifestyle strategies alone. After these initial 6 months, the “toolbox” algorithm included use of a weight loss medication (orlistat) and/or advanced behavioral strategies for individuals having difficulty with weight loss. Advanced behavioral strategies included provision of exercise equipment or enrolling participants in a cooking class. Orlistat or advanced behavioral strategies were only initiated after the first 6 months and only for those having difficulty with weight loss. Specific protocols were used to determine when to initiate these approaches, to monitor participants during their use, and to determine when to stop the use of medication and/or the advanced behavioral strategies.

Data Collection Protocol for Cardiovascular Disease Risk Factors

Standardized interviewer-administered questionnaires were used to obtain self-reported data on demography and medical history. A history of cardiovascular disease was defined as self-report of prior myocardial infarction, stroke, coronary or lower extremity angioplasty, carotid

endarterectomy, or coronary bypass surgery. Seated blood pressure was measured in duplicate with an automated device. Hypertension was defined as systolic blood pressure ≥ 140 mmHg, diastolic blood pressure ≥ 90 mmHg, or use of antihypertensive medicines. Whole-blood samples for HbA1c analysis were shipped by overnight express within 24 hours of sample collection for measurement by a dedicated ion exchange, high performance liquid chromatography instrument (Biorad Variant 11).

Statistical Analysis

Each month was represented by the weight measured nearest to its end, which was converted to percent weight changes from baseline. The intra-subject covariance matrix of the longitudinal data was estimated using maximum likelihood methods for incomplete data (11). Principal components analysis was applied to this covariance matrix (rather than the correlation matrix, because all scores were in the same units) to identify predominant patterns and linear equations for calculating individual principal component scores. Using the intra-subject covariance rather than the inter-subject covariance gives focus to the pattern, rather than amount of weight loss. Scree plots (e.g. 12) were used to select the number of important components. Analyses were conducted on 2,485 (96.7%) participants. For the 69.4% of these with complete data (e.g. all 12 monthly weight changes), principal component scores for each individual were calculated directly from their percent weight changes subtracted from the mean of their 12 monthly percent weight changes. For those missing one or more of these monthly values, principal component scores were estimated using weighted least squares. Standard errors for the principal component scores were computed (which varied according to the completeness of data), for use in weighted analyses of relationships with baseline characteristics. The rates of missing data were as follows: 13.8% (missing one month), 9.3% (missing 2–3 months), 4.3% (missing 4–6 months), and 3.2% (missing >6 months). These relationships were examined for each of the major individual principal components, after covariate-adjustment for clinic site and the other principal components. With the sample sizes available for analysis, this two-stage approach to inference is efficient and would be expected to produce results congruent with estimates from multivariate models (e.g. 13).

RESULTS

Of the 2,485 participants, 59.5% were women and 36.9% were from ethnic minorities (15.2% African-American, 5.1% American Indian/Pacific Islander, 13.4% Hispanic/Latino, and 3.1% other/multiple races). At baseline, the mean (SD) body mass index was 35.9 (6.0) kg/m² and the mean (SD) HbA1c was 7.7 (1.1) %. Figure 1 summarizes the distribution of monthly mean percent weight changes for these individuals over the initial 12 months. Portrayed are the 10th, 25th, 50th, 75th, and 90th percentiles at each month. Mean weight decreased steadily through the first six months of intervention, and then remained fairly constant at slightly more than 7% weight loss. The 75th percentile exceeded 10% weight loss during the last half of this time period.

Table 1 presents the factor loadings for the first three components, which collectively accounted for 97.0% of the total variance. The first principal component corresponded to a gradual weight loss, the rate of which decelerated over time. It accounted for 88.8% of the total variation: the trajectory of weight loss according to this pattern was the major source of differences among individuals. The second principal component (6.6% of the variation) was related to the timing of the weight loss, contrasting weight losses from months 1–7 with those from months 8–12. Individuals who scored highly on this component had relatively greater weight loss during the first 7 months and less weight loss thereafter compared to individuals who scored low on this component. The third principal component (1.6% of the variation) contrasted weight losses during months 4–8 with those both earlier and later. Individuals with high scores for this

component tended to have greater “troughs” in their mid-year weights compared to others. None of the remaining components accounted for as much as 1% of the variation and will not be addressed. Scores from the first three components were calculated for each individual and scatter plots were used to examine their joint distributions. There was no evidence of clustering that might represent discrete subgroups of individuals who had distinct trajectories. Instead, the distributions gave the impression that individuals were arrayed along a continuum of varying patterns of weight changes.

To demonstrate how principal component scores reflect individual’s weight change patterns, we selected representatives at the 25th and 75th percentiles of the principal component distribution. The top panel in Figure 2 portrays the patterns of weight changes for individual participants near these cutpoints for the first and second principal components (and who were near the median of the third principal component, i.e. had a “typical” value). The top two lines correspond to individuals who scored relatively low on the first principal component, and thus had relatively less gradual weight loss. For these, the second principal component distinguishes relatively early weight loss (followed by some regain) from relatively late weight loss. The bottom two lines correspond to individuals who scored relatively high on the first principal component, and thus had steeper trajectories of weight loss. For these individuals, the second principal component distinguished between those with relatively early versus later weight loss.

The bottom panel of Figure 2 portrays the patterns of weight changes for individuals near the 25th and 75th percentiles of the first and third principal components (and who were near the median of the second principal component). For these, the third principal component helped to identify those who tended to have a trough in weight during the year.

To demonstrate how principal components scores can be used to identify differences in characteristic patterns of weight changes among important subgroups, we used weighted analyses of covariance to compare means scores for each component (adjusting for clinical site and scores of the other two principal components). In Table 2, we examined subgroups defined by sex, HbA1c, age, baseline body mass index, insulin use, hypertension, and prior cardiovascular disease. Mean differences in principal component scores relative to a reference subgroup are presented.

There were significant differences with respect to the first principal component with respect to sex ($p<0.001$), HbA1c ($p<0.001$), race/ethnicity ($p<0.001$), body mass index ($p<0.001$), insulin use ($p=0.008$), hypertension ($p=0.03$), and prior cardiovascular disease ($p=0.01$), but not age. Steeper trajectories of gradual weight losses tended to occur among men, those with lower HbA1c, non-Hispanic whites, those with higher initial body mass index, those not using insulin, those with hypertension, and those without cardiovascular disease.

Sex ($p<0.001$), age ($p=0.04$), ethnicity ($p<0.001$), body mass index ($p=0.002$), and insulin use ($p=0.04$) were associated with significant differences in the second principal component. These results indicate that percent weight loss tended to occur earlier among men; younger individuals; those with higher HbA1c; members of the American Indian, other/multiple, or non-Hispanic white racial/ethnic groups; those with lower initial body mass index; and those not using insulin.

The third principal component was significantly related to HbA1c ($p=0.02$) and body mass index ($p=0.05$), such that the weights for individuals with relatively poorer diabetes control or lower body mass index tended to trough during the year.

Taken together, these results suggest that men had stronger and earlier responses to the weight loss intervention compared to women. Figure 3 portrays fitted mean percent weight losses for the sexes (with covariate adjustment for clinic site) from a repeated measures general linear

model, confirming these projections. These results also suggest that participants with poorer diabetes control had less steep trajectories of weight loss and a tendency for an intra-year trough. Fitted means from general linear models support this projection (Figure 4), with a slight increase in mean weights following month 8 for those with a HbA1c $\geq 9.0\%$. These figures portray the magnitudes of differences that were detectable with the large sample size.

DISCUSSION

Principal components analysis of longitudinal weights provided concise and coherent descriptions of major components underlying patterns of weight changes. By developing components from an estimate of the intra-subject covariance matrix for longitudinal percent weight losses, we were able to employ methods developed to accommodate missing data. The features identified by this analysis (degree of gradually decelerating weight loss, timing of weight loss, and rebound) are intriguing. Whether these features have long-term clinical significance with respect to predicting either future weight change patterns or important markers of health remains to be seen.

The patterns of percent weight changes varied among individuals and were distributed across continuums. There was little evidence of discrete pattern clusters. This suggests that the analysis of mean principal component scores to identify general differences was appropriate and enabled us to detect relatively small differences that may not be evident from simple graphical displays.

A number of characteristics have been reported to be associated with better overall response to behavioral weight loss interventions. These include male sex (14–17), white ethnicity (14, 15), greater initial weight (18), and poorer blood pressure control (16). These same relationships were uncovered in our current analyses of the Look AHEAD data. In addition, we found that markers of poorer diabetes control (i.e. requirement for insulin, higher HbA1c) and a history of cardiovascular disease were associated with flatter weight loss responses. A separate Look AHEAD report notes relatively greater 1-year weight losses among males and non-Hispanic whites (19).

In agreement with our findings, there have been at least three other reports that women and African-Americans tend to lose weight more slowly during behavioral interventions than men and other races/ethnicities (14,20,21). We also found that older individuals, those with lower initial body mass index, and individuals using insulin also tended to have lower rates of initial weight loss.

One year is a relatively short time to identify patterns of weight regain, which may explain why the third principal component in our analyses contributed so little towards explaining the overall variance in weight changes. It is probable that future analyses on longer term weight changes may produce different patterns than were observed over one year. Greater weight regain has previously been reported to be associated with higher initial body mass index (22, 23), as we have found. In addition, we found the pattern of initial weight loss followed by regain to be associated with higher baseline HbA1c.

Several limitations to our work can be noted. We have not attempted to parse out the separate effects of individual intervention components (e.g. advanced behavioral strategies, orlistat) on weight loss trajectories. This is difficult, in that they were differentially triggered based on individual participant's performance and preferences; additional discussion of this appears elsewhere (19). We considered only principal components analysis to identify characteristics patterns, while many other methodologies may also be adopted, including factor analysis, latent structure models, and cluster analysis.

All of the above relationships occur along a continuum and, as our analysis supports, are not sufficiently strong to identify accurately individuals who are likely to respond differently to behavioral interventions. They may, however, identify characteristics of subgroups for which special tailoring of behavioral interventions is warranted. Within the Look AHEAD trial, one-year weight loss was related to improved diabetes control and cardiovascular risk factors and reduced medication use (24), so that the potential public health importance of refining weight loss interventions may be great.

SUMMARY

Principal components analysis applied to longitudinal changes in weight can be used to identify characteristic patterns of weight change and to order individuals along continuums of these patterns. The associations we found between baseline predictors and these weight change patterns agree with prior reports. The degree to which weight change patterns during the first year of Look AHEAD are associated with long-term weight and outcomes requires further follow-up and study.

Abbreviations

HbA1c, Glycosylated hemoglobin; BMI, Body mass index; SD, Standard deviation.

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Clinical Sites

The Johns Hopkins Medical Institutions Frederick L. Brancati, MD, MHS¹; Jeff Honas, MS²; Lawrence Cheskin, MD³; Jeanne M. Clark, MD, MPH³; Kerry Stewart, EdD³; Richard Rubin, PhD³; Jeanne Charleston, RN; Kathy Horak, RD

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Harvard Center

Massachusetts General Hospital: David M. Nathan, MD¹; Heather Turgeon, RN, BS, CDE²; Kristina Schumann, BA²; Enrico Cagliero, MD³; Linda Delahanty, MS, RD³; Kathryn Hayward, MD³; Ellen Anderson, MS, RD³; Laurie Bissett, MS, RD; Richard Ginsburg, PhD; Valerie Goldman, MS, RD; Virginia Harlan, MSW; Charles McKittrick, RN, BSN, CDE; Alan McNamara, BS; Theresa Michel, DPT, DSc CCS; Alexi Poulos, BA; Barbara Steiner, EdM; Joclyn Tosch, BA

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Beth Israel Deaconess Medical Center: George Blackburn, MD, PhD¹; Christos Mantzoros, MD, DSc³; Kristinia Day, RD; Ann McNamara, RN

¹Principal Investigator

²Program Coordinator

³Co-Investigator

University of Colorado Health Sciences Center James O. Hill, PhD¹; Marsha Miller, MS, RD²; JoAnn Phillipp, MS²; Robert Schwartz, MD³; Brent Van Dorsten, PhD³; Judith Regensteiner, PhD³; Salma Bencheikroun MS; Ligia Coelho, BS; Paulette Cohrs, RN, BSN; Elizabeth Daeninck, MS, RD; Amy Fields, MPH; Susan Green; April Hamilton, BS, CCRC; Jere Hamilton, BA; Eugene Leshchinskiy; Michael McDermott, MD; Lindsey Munkwitz, BS; Loretta Rome, TRS; Kristin Wallace, MPH; Terra Worley, BA

Baylor College of Medicine John P. Foreyt, PhD¹; Rebecca S. Reeves, DrPH, RD²; Henry Pownall, PhD³; Ashok Balasubramanyam, MBBS³; Peter Jones, MD³; Michele Burrington, RD; Chu-Huang Chen, MD, PhD; Allyson Clark, RD; Molly Gee, MEd, RD; Sharon Griggs; Michelle Hamilton; Veronica Holley; Jayne Joseph, RD; Patricia Pace, RD; Julieta Palencia, RN; Olga Satterwhite, RD; Jennifer Schmidt; Devin Voiding, LMSW; Carolyn White

University of California at Los Angeles School of Medicine Mohammed F. Saad, MD¹; Siran Ghazarian Sengardi, MD²; Ken C. Chiu, MD³; Medhat Botrous; Michelle Chan, BS; Kati Konersman, MA, RD, CDE; Magguri Perpetua, RD

The University of Tennessee Health Science Center

University of Tennessee East: Karen C. Johnson, MD, MPH¹; Carolyn Gresham, RN²; Stephanie Connelly, MD, MPH³; Amy Brewer, RD, MS; Mace Coday, PhD; Lisa Jones, RN; Lynne Lichtermann, RN, BSN; Shirley Vosburg, RD, MPH; and J. Lee Taylor, MEd, MBA

University of Tennessee Downtown: Abbas E. Kitabchi, PhD, MD¹; Helen Lambeth, RN, BSN²; Debra Clark, LPN; Andrea Crisler, MT; Gracie Cunningham; Donna Green, RN; Debra Force, MS, RD, LDN; Robert Kores, PhD; Renate Rosenthal PhD; Elizabeth Smith, MS, RD, LDN; and Maria Sun, MS, RD, LDN; and Judith Soberman, MD³

University of Minnesota Robert W. Jeffery, PhD¹; Carolyn Thorson, CCRP²; John P. Bantle, MD³; J. Bruce Redmon, MD³; Richard S. Crow, MD³; Scott Crow, MD³; Susan K Raatz, PhD, RD³; Kerrin Brelje, MPH, RD; Carolyne Campbell; Jeanne Carls, MEd; Tara Carmean-Mihm, BA; Emily Finch, MA; Anna Fox, MA; Elizabeth Hoelscher, MPH, RD, CHES; La Donna James; Vicki A. Maddy, BS, RD; Therese Ockenden, RN; Birgitta I. Rice, MS, RPh CHES; Tricia Skarphol, BS; Ann D. Tucker, BA; Mary Susan Voeller, BA; Cara Walcheck, BS, RD

St. Luke's Roosevelt Hospital Center Xavier Pi-Sunyer, MD¹; Jennifer Patricio, MS²; Stanley Heshka, PhD³; Carmen Pal, MD³; Lynn Allen, MD; Diane Hirsch, RNC, MS, CDE; Mary Anne Holowaty, MS, CN

University of Pennsylvania Thomas A. Wadden, PhD¹; Barbara J. Maschak-Carey, MSN, CDE²; Stanley Schwartz, MD³; Gary D. Foster, PhD³; Robert I. Berkowitz, MD³; Henry Glick, PhD³; Shiriki K. Kumanyika, PhD, RD, MPH³; Johanna Brock; Helen Chomentowski; Vicki Clark; Canice Crerand, PhD; Renee Davenport; Andrea Diamond, MS, RD; Anthony Fabricatore, PhD; Louise Hesson, MSN; Stephanie Krauthamer-Ewing, MPH; Robert Kuehnle, PhD; Patricia Lipschutz, MSN; Monica Mullen, MS, RD; Leslie Womble, PhD, MS; Nayyar Iqbal, MD

University of Pittsburgh David E. Kelley, MD¹; Jacqueline Wesche-Thobaben, RN, BSN, CDE²; Lewis Kuller, MD, DrPH³; Andrea Kriska, PhD³; Janet Bonk, RN, MPH; Rebecca Danchenko, BS; Daniel Edmundowicz, MD³; Mary L. Klem, PhD, MLIS³; Monica E. Yamamoto, DrPH, RD, FADA³; Barb Elnyczky, MA; George A. Grove, MS; Pat Harper, MS, RD, LDN; Janet Krulia, RN, BSN, CDE; Juliet Mancino, MS, RD, CDE, LDN; Anne Mathews, MS, RD, LDN; Tracey Y. Murray, BS; Joan R Ritchea; Jennifer Rush, MPH; Karen Vujevich, RN-BC, MSN, CRNP; Donna Wolf, MS

The Miriam Hospital/Brown Medical School Rena R Wing, PhD¹; Renee Bright, MS²; Vincent Pera, MD³; John Jakicic, PhD³; Deborah Tate, PhD³; Amy Gorin, PhD³; Kara Gallagher, PhD³; Amy Bach, PhD; Barbara Bancroft, RN, MS; Anna Bertorelli, MBA, RD; Richard Carey, BS; Tatum Charron, BS; Heather Chenot, MS; Kimberley Chula-Maguire, MS; Pamela Coward, MS, RD; Lisa Cronkite, BS; Julie Currin, MD; Maureen Daly, RN; Caitlin Egan, MS; Erica Ferguson, BS, RD; Linda Foss, MPH; Jennifer Gauvin, BS; Don Kieffer, PhD; Lauren Lessard, BS; Deborah Maier, MS; JP Massaro, BS; Tammy Monk, MS; Rob Nicholson, PhD; Erin Patterson, BS; Suzanne Phelan, PhD; Hollie Raynor, PhD, RD; Douglas Raynor, PhD; Natalie Robinson, MS, RD; Deborah Robles; Jane Tavares, BS

The University of Texas Health Science Center at San Antonio Steven M. Haffner, MD¹; Maria G. Montez, RN, MSHP, CDE²; Carlos Lorenzo, MD³

University of Washington / VA Puget Sound Health Care System Steven Kahn MB, ChB¹; Brenda Montgomery, RN, MS, CDE²; Robert Knopp, MD³; Edward Lipkin, MD³; Matthew L. Maciejewski, PhD³; Dace Trence, MD³; Terry Barrett, BS; Joli Bartell, BA; Diane Greenberg, PhD; Anne Murillo, BS; Betty Ann Richmond, MEd; April Thomas, MPH, RD

Southwestern American Indian Center. Phoenix, Arizona and Shiprock, New Mexico William C. Knowler, MD, DrPH¹; Paula Bolin, RN, MC²; Tina Killean, BS²; Cathy Manus, LPN³; Jonathan Krakoff, MD³; Jeffrey M. Curtis, MD, MPH³; Justin Glass, MD³; Sara Michaels, MD³; Peter H. Bennett, MB, FRCP³; Tina Morgan³; Shandiin Begay, MPH; Bernadita Fallis RN, RHIT, CCS; Jeanette Hermes, MS, RD; Diane F. Hollowbreast; Ruby Johnson; Maria Meacham, BSN, RN, CDE; Julie Nelson, RD; Carol Percy, RN; Patricia Poorthunder; Sandra Sangster; Nancy Scurlock, MSN, ANP-C, CDE; Leigh A. Shovestull, RD, CDE; Janelia Smiley; Katie Toledo, MS, LPC; Christina Tomchee, BA; Darryl Tonemah PhD

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Coordinating Center

Wake Forest University Mark A. Espeland, PhD¹; Judy L. Bahnson, BA²; Lynne Wagenknecht, DrPH³; David Reboussin, PhD³; W. Jack Rejeski, PhD³; Alain Bertoni, MD, MPH³; Wei Lang, PhD³; Gary Miller, PhD³; David Lefkowitz, MD³; Patrick S. Reynolds, MD³; Paul Ribisl, PhD³; Mara Vitols, DrPH³; Michael Booth, MBA²; Kathy M. Dotson, BA²; Amelia Hodges, BS²; Carrie C. Williams, BS²; Jerry M. Barnes, MA; Patricia A. Feeney, MS; Jason Griffin, BS; Lea Harvin, BS; William Herman, MD, MPH; Patricia Hogan, MS; Sarah Jaramillo, MS; Mark King, BS; Kathy Lane, BS; Rebecca Neiberg, MS; Andrea Ruggiero, MS; Christian Speas, BS; Michael P. Walkup, MS; Karen Wall, AAS; Michelle Ward; Delia S. West, PhD; Terri Windham

Central Resources Centers

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Central Laboratory. Northwest Lipid Research Laboratories Santica M. Marcovina, PhD, ScD¹; Greg Strlewick, MS

ECG Reading Center. EPICARE. Wake Forest University School of Medicine

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Figure 1.
Percentiles of percentage weight change over one-year.

Figure 2.

Plots of weight changes for representative individual participants at the 25th, 50th, and 75th percentiles of the first, second, and third principal component scores.

Figure 3.
Fitted mean weight change for 1478 women and 1007 men.

Figure 4.

Fitted mean percent weight changes by baseline HbA1c level at baseline for N=1162 with HbA1c < 7.0%, N=1116 with HbA1c 7.0–8.9%, and N=207 with HbA1c ≥ 9.0%.

Table 1

Factor loadings for first three principal components (PC) of percent weight changes from baseline (and proportion of variance explained by each).

Month	First PC Loadings (88.8%)	Second PC Loadings (6.6%)	Third PC Loadings (1.6%)
1	-0.078	-0.278	0.456
2	-0.140	-0.384	0.409
3	-0.189	-0.421	0.217
4	-0.234	-0.403	-0.020
5	-0.275	-0.316	-0.275
6	-0.303	-0.188	-0.442
7	-0.323	-0.050	-0.346
8	-0.334	0.104	-0.155
9	-0.348	0.203	0.006
10	-0.350	0.273	0.154
11	-0.352	0.316	0.247
12	-0.364	0.268	0.280

Table 2

Associations between baseline characteristics and principal component scores controlled for differences among clinical sites: relatively greater positive scores on the first, second, and third principal components reflect steeper weight loss trajectory, earlier weight loss, and weight loss followed by weight regain, respectively. Differences are presented from reference groups for clarity.

Baseline Characteristic	N	First Principal Component		Second Principal Component		Third Principal Component	
		Mean (SE)	p-value	Mean (SE)	p-value	Mean (SE)	p-value
Sex							
Female	1478	-3.63 (0.70)	<0.001	-1.09 (0.17)	<0.001	0.14(0.09)	0.45
Male (reference)	1007	0.00		0.00			
Age, years							
45–54	616	-2.22 (1.03)		0.71 (0.25)		0.04(0.12)	
55–59	813	-1.70 (0.97)	0.13	0.38 (0.23)	0.04	0.21(0.12)	0.08
60–64	572	-0.72 (1.04)		0.31 (0.25)		-0.06(0.13)	
65–75 (ref.)	484	0.00		0.00		0.00	
HbA1c, %							
< 7.0%	1162	8.29 (1.27)		-0.41 (0.31)		-0.43 (0.16)	
7.0–8.9%	1116	3.65 (1.26)	<0.001	-0.25 (0.31)	0.37	-0.35 (0.16)	0.02
9.0–10.9% (ref.)	207	0.00		0.00		0.00	
Race/Ethnicity							
African-American	378	-7.75 (1.02)		-1.04(0.25)		0.14(0.13)	
A-I/A-N	128	-8.62 (4.26)		1.14(1.05)		0.08 (0.54)	
Hispanic / Latino	334	-5.40 (1.45)	<0.001	-0.26 (0.36)	<0.001	0.23 (0.18)	0.47
Other / multiple	77	-5.20 (1.95)		0.37 (0.47)		0.28 (0.24)	
N-H White (ref.)	1568	0.00		0.00		0.00	
BMI, kg/m ²							
25–29	386	-5.43 (1.12)		0.82 (0.27)		0.29 (0.14)	
30–34	889	-1.92 (0.92)	<0.001	0.94(0.22)	0.002	0.11(0.11)	0.05
35–39	653	-1.71 (0.97)		0.45 (0.23)		-0.06(0.12)	

Baseline Characteristic	N	First Principal Component		Second Principal Component		Third Principal Component	
		Mean (SE)	p-value	Mean (SE)	p-value	Mean (SE)	p-value
≥ 40 (ref.)	553	0.00		0.00		0.00	
Insulin use							
No	2115	2.51 (0.95)	0.008	0.48 (0.23)	0.04	-0.12 (0.12)	0.28
Yes (ref.)	370	0.00		0.00		0.00	
Hypertension							
No	2090	-1.97(0.93)	0.03	0.15 (0.22)	0.51	0.03(0.11)	0.77
Yes (ref.)	395	0.00		0.00		0.00	
Prior CVD							
No	2126	2.48 (0.96)	0.01	-0.20 (0.23)	0.38	-0.02 (0.12)	0.84
Yes (ref.)	359	0.00		0.00			