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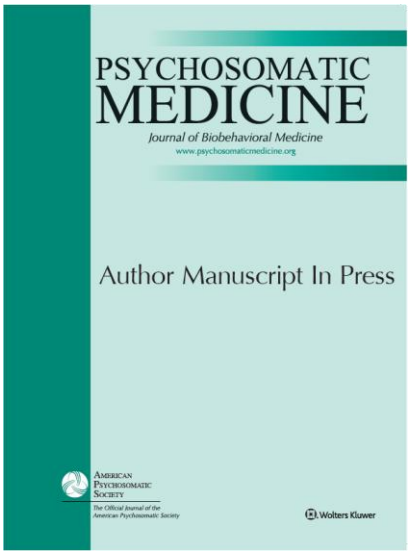

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Weight loss, weight-loss maintenance, and cellular aging in the Supporting Health through Nutrition and Exercise (SHINE) Study

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Abstract

Objective: To determine, within a weight-loss clinical trial for obesity, the impact of intervention arm, weight change, and weight-loss maintenance on telomere length (TL).

Methods: Adults (*N*=194) with a BMI between 30 and 45 were randomized to a 5.5-month weight-loss program with (*n*=100) or without (*n*=94) mindfulness training and identical diet-exercise guidelines. We assessed TL at baseline and 3, 6, and 12 months post-baseline in immune cell populations (primarily in peripheral blood mononuclear cells [PBMCs], but also in granulocytes and T and B lymphocytes). We defined weight-loss maintenance as having lost at least 5% or 10% of body weight (tested in separate models) from pre- to post-intervention, and having maintained this loss at 12 months. We predicted that greater weight loss and weight-loss maintenance would be associated with TL lengthening.

Results: Neither weight-loss intervention significantly predicted TL change, nor did amount of weight change, at any timepoint. Across all participants, weight-loss maintenance of at least 10% was associated with longer PBMC TL [*b*=239.08, 95% CI (0.92, 477.25), *p*=.049], CD8+ TL [*b*=417.26, 95% CI (58.95, 775.57), *p*=.023], and longer granulocyte TL [*b*=191.56, 95% CI (-4.23, 387.35), *p*=.055] at 12 months after accounting for baseline TL. Weight-loss maintenance of 5% or greater was associated with longer PBMC TL (*b*=163.32, 95% CI 4.00, 320.62], *p*=.045) at 12 months after accounting for baseline TL. These tests should be interpreted in light of corrections for multiple tests.

Conclusions: Among individuals with obesity, losing and maintaining a weight loss of 10% or greater may lead to TL lengthening, which may portend improved immune and metabolic function. TL lengthening in this study is of unknown duration beyond 12 months, and requires further study.

Trial Registration: Clinicaltrials.gov identifier NCT00960414; Open Science Framework (OSF) preregistration: https://osf.io/t3r2g/

Keywords: Telomere length; weight-loss maintenance; mindfulness; behavioral intervention

Acronyms:

BMI = body mass index

CD4+ = cluster of differentiation 4 (indicating a CD4+ T lymphocyte)

CD8+ = cluster of differentiation 8 (indicating a CD8+ T lymphocyte

CD19+ = cluster of differentiation 19 (indicating a B lymphocyte)

CI = confidence interval

FACS = fluorescence-activated cell sorting

H = hours

HBME = human brain microvascular endotheliocyte

MET = metabolic equivalent of task

MIN = minutes

PBMC = peripheral blood mononuclear cell

RBC = red blood cell

S = seconds

TL = telomere length

T/S Ratio = telomere to single copy gene ratio

WBC = white blood cell

WK = weeks

Introduction

Telomeres are hexameric (TTAGGG) nucleotide sequences at the ends of eukaryotic chromosomes that play important roles in diseases of aging (1). DNA polymerases are unable to completely replicate the ends of chromosomes with each cellular division, which leads to shorter TL over time. When TL is critically shortened, its associated proteins can no longer fully form the protective cap that promotes chromosomal stability, ultimately leading to cellular senescence. Telomerase, a cellular ribonucleoprotein enzyme, can add hexameric repeats to the telomeric ends of chromosomes, thereby increasing TL (2,3). Thus, TL can serve as a bidirectional index physiological and psychological factors on aging over time (4), and studies linking shorter TL with cardiovascular diseases and diabetes (5–7), and mortality (8,9) provide evidence that TL is also related to a range of important health outcomes.

Obesity may be an important determinant of associations between TL and disease states. Oxidative stress and systemic inflammation, which are both elevated in the context of obesity (10,11), shorten TL, and these findings form the basis for the hypothesis that obesity might promote accelerated TL shortening (12,13). Indeed, more than 30 cross-sectional studies report associations between TL and adiposity (as indexed by BMI), and meta-analyses have reported that greater adiposity is associated with shorter TL (14,15).

Few studies, however, have examined associations between TL and weight loss in terms of nationally recommended weight-loss guidelines, such as 5% (16–18) and 10% (19,20) of total body weight. One study found that in individuals with obesity treated with a bioenteric intragastric balloon (BIB), weight loss was associated with TL lengthening (21). In other research, individuals with obesity who underwent bariatric surgery evidenced TL lengthening 10 years later relative to age- and sex-matched normal-weight controls (22). In a prospective cohort

study, an analysis of 2,912 Chinese women of obese or overweight status who reduced their weight to a normal BMI (<25) showed TL lengthening in comparison to their counterparts who gained weight (23). Self-reported weight cycling, defined as losing and regaining 20 lbs., has also been associated with TL shortening (24). Thus, a small but methodologically diverse body of literature suggests that weight loss may either reduce TL shortening and/or increase TL lengthening.

A second mediator of associations between TL and disease states may be psychological stress (25,26). Greater psychological stress is associated with shorter TL (27,28), through mechanisms related to exposure to cortisol, inflammation, and oxidative stress (29). Thus, interventions targeting both psychological stress and metabolic health may best promote TL lengthening. For example, one small pilot study found that men with prostate cancer who received an intensive lifestyle intervention targeting decreased stress, increased exercise, and improved nutrition showed TL lengthening 5 years later relative to a control group (30). Thus, the combined effects of decreased stress, increased exercise, and improved nutrition may have promoted the observed TL lengthening, though participants were not randomized to condition.

Interventions targeting weight loss and stress reduction may hold promise for slowing TL shortening. For example, a pilot intervention that preceded the present trial randomized women who were overweight or obese to a waitlist control or a mindfulness intervention that focused on reducing stress and increasing mindful eating. “As treated” participants who received a minimum dose of the mindfulness intervention (>40%) showed an 18% greater increase in telomerase activity than those randomized to the waitlist control group, although this was not a significant difference (31). Additionally, greater reductions in stress and fasting glucose levels were associated with greater increases in telomerase activity. Mindful eating may lead to reductions in

binge eating (32,33), which may promote weight loss. Mindfulness-based stress reduction (MBSR; (34), can lead to reductions in psychological stress. Hence, a behavioral intervention that combines mindfulness training for stress reduction and mindful eating with dietary recommendations may address two targets – stress reduction and metabolic health – which slow TL shortening and/or promote TL lengthening.

Present study

We analyzed data from a randomized, controlled trial testing the effects of a 5.5-month mindfulness-based weight loss intervention versus an active control intervention in which both intervention arms included the same standard diet and exercise guidelines. We examined the effects of (1) intervention arm, (2) weight change, and (3) weight-loss maintenance (defined using national guidelines of 5% and 10% or greater) on changes in TL (PBMCs, granulocytes, CD4+ and CD8+ T-cells, and CD19+ B-cells) within a 12-month period. We hypothesized in preregistered analyses on the Open Science Framework https://osf.io/t3r2g/ that: (1) participants randomized to the mindfulness arm (relative to those randomized to the active control arm) would experience larger increases (or smaller decreases) in TL from baseline to 12 months post-baseline, and (2) that greater weight loss from baseline to mid-intervention (3 months), post-intervention (6 months), and follow-up (12 months) would be associated with larger increases (or smaller decreases) in TL during those respective time periods. Finally, we explored whether individuals who maintained weight loss over time, as defined by guidelines of 5% and 10% of body weight loss (relative to those who do not), would show larger increases (or smaller decreases) in TL at 12 months. We defined weight-loss maintenance using the abovementioned guidelines: Specifically, we examined groups of participants who lost 10% or greater (Status A)

or 5% or greater (Status B) of their body weight from baseline to 6 months post-baseline and who maintained this loss at 12 months. Our pre-specified primary outcome variables were PBMC and granulocyte TL, and our pre-specified secondary outcome variables included TL in CD4+ and CD8+ T-cells, and CD19+ B-cells.

Method

Design

The current analyses used data from the Supporting Health by Integrating Nutrition and Exercise (SHINE) clinical trial (Clinicaltrials.gov registration: NCT00960414). Adults with obesity (BMI range 30-45) were randomized in a 1:1 ratio to a 5.5-month diet and exercise weight-loss program with or without mindfulness training that included mindfulness training targeting eating behavior, stress management, emotion regulation, and exercise. The study design and methods are reported in detail elsewhere (35). The University of California, San Francisco (UCSF) Institutional Review Board (IRB) approved all study procedures. All participants provided informed consent.

Participants

Participants learned of the study through newspaper advertisements, flyers, online postings, and referrals made within university medical clinics. The study was advertised as a comparison of two weight-loss interventions that each involved changes in diet, exercise, and stress management, yet differed in the emphasis placed on each. To avoid selective attrition post-randomization due to any disappointment upon not being randomized to a preferred trial arm and to mask participants to study hypotheses regarding mindfulness practices, recruitment materials

did not specifically advertise that mindfulness training would be taught in one of the arms. Inclusion criteria included abdominal obesity (waist circumference > 102 cm for men and >88 cm for women) and age 18 years or older. Exclusion criteria included types 1 and 2 diabetes mellitus (fasting glucose ≥ 126 or hemoglobin A1C (HbA1c) > 6.5 or between 6.0 and 6.5% with an abnormal oral glucose tolerance test); pregnancy, breastfeeding, or fewer than 6 months post-partum; use of corticosteroid and/or immune-suppressing or immune-modulating medications; use of prescription weight-loss medications; untreated hypothyroidism; history of or active bulimia; current meditation or yoga practice; engagement in any other structured weight-management or weight-loss program; or having participated in a mindfulness-based stress reduction (MBSR) course.

Procedures

Each intervention arm included 12 weekly group evening sessions (2-2.5 h), followed by 3 biweekly sessions, followed by 1 follow-up session four weeks later (5.5 months total). Participants completed an all-day weekend session near the eighth week (5.0 h for the active control arm, 6.5 h for the mindfulness intervention arm). Registered dietitians taught the control arm sessions. Different registered dietitians and experienced mindfulness instructors taught the mindfulness arm sessions. See (35) for intervention details.

Interventions

Mindfulness arm. Intervention content included mindfulness training for eating behavior, stress management, emotion regulation, and exercise. Mindful eating practices targeted awareness of physical hunger, stomach fullness, taste satisfaction, food cravings, and other

eating triggers (33). Instructors did not teach participants to avoid particular foods, but rather encouraged them to eat favorite foods in smaller portions that fit with their calorie goals. Instructors encouraged participants to become aware of, and to savor, food tastes and textures, with the intention of deriving satisfaction from smaller amounts of favorite foods that tended to be of higher caloric density (e.g., sweets and desserts). Mindfulness training targeting stress management and emotion regulation incorporated components of mindfulness-based programs (34,36) including seated meditation, mindful yoga and walking, and loving-kindness meditations. Instructors also led extended exhalation breathing practices to promote initial physiological relaxation. Home-based activities included sitting meditation for up to 30 min a day/6 days a week, eating meals mindfully, mini-meditations before meals, and mindful (chi) walking (37).

Active control arm. Intervention content accounted for the additional time, attention, social support, and expectations of benefit that the mindfulness participants may have experienced by providing additional group curricula about nutrition and physical activity. This included presentations about nutritional choices, discussion of socio-political issues that affect food choice, how to make well-informed decisions about diet products, and tutorials on strength training with exercise bands. To address participant expectations of receiving stress management tools, intervention content included instruction in progressive muscle relaxation and cognitive-behavioral skills, although at a lower dose than in the mindfulness intervention. To reduce participant burden while ensuring perceptions of benefit, sessions were reduced from 2.5 to 2.0 h after session 9. Home-based activities reinforced diet and exercise lessons.

Diet-exercise guidelines. Diet and exercise components were the same for each intervention arm. Intervention instructors encouraged participants to focus on decreasing consumption of calorically dense, nutrient-poor foods such as refined carbohydrates, and increasing consumption

of fresh fruits and vegetables, healthy oils, and proteins. To this end, participants set a goal of reducing daily food intake of their choice by 500 calories. The exercise component focused on increasing physical activity throughout the day as well as initiating structured aerobic and anaerobic exercise, such as bicycling, swimming, strength training, and walking.

Measures

Weight. We assessed weight in-person at all timepoints (baseline, 3, 6, and 12 months) and height at baseline. For all study visits, we used the same calibrated digital scale (Wheelchair Scale 6002, Scale-Tronix, Carol Stream IL), which rounded to the nearest 0.1 kg. Participants wore a hospital gown for all weight assessments. We rounded height to the nearest 0.1 cm.

Cell processing. We assayed TL in PBMCs (baseline, and 3-, 6-, and 12-month timepoints), sorted PBMCs (baseline and 12-months post-baseline), and granulocytes (baseline, and 3-, 6-, and 12-months post-baseline). Due to financial and timeline constraints (this study component was funded by a supplement with a shorter timeline than the parent study), we: (1) assayed TL in PBMCs among all participants who provided at least one follow-up timepoint (3-, 6-, or 12-months post-baseline), (2) assayed TL in sorted PBMC cells (CD4+, CD8+ T-cells, and B-cells) only among participants in the first four (of six) waves who provided data at both baseline and 12-months post-baseline, and (3) assayed TL in granulocytes in all but the first wave (of six) waves, as we did not begin collecting red blood cells (RBCs) until the second wave. See (38) for further details.

Fluorescence-activated cell sorting (FACS). Cryopreserved PBMCs were thawed, washed, counted, and stained for sorting as previously described (39). Before staining, an aliquot of 1 million PBMCs was removed, pelleted, and frozen at -80 °C to assess PBMC TL. Thawed

cells were first stained with LIVE/DEAD™ Fixable Aqua Dead Cell Stain Kit (Invitrogen) for exclusion of non-viable cells, and were then stained with the following fluorescently conjugated monoclonal antibodies: anti-CD4-PE-Texas Red® (Invitrogen); anti-CD3-V450, anti-CD19 PE-CyTM5, anti-CD28-PE, anti-CD45 FITC and anti-CD8-APC (all from BD Biosciences). Stained cells were sorted on a customized BD FACSAriaTM II into the following fractions, using standard gating strategies: CD4+ T-cells (CD45+CD3+CD4+), CD8+ T-cells (CD45+CD3+CD8+), and CD19+ B-cells (CD45+CD3-CD19+). Cells were collected into AIM V serum-free media (Invitrogen), pelleted by centrifugation, and stored at -80 °C.

Granulocyte preparation. Immediately following Ficoll preparation of PBMCs, the RBC/granulocyte pellet was removed from the Ficoll tube, mixed with 3 volumes of ACK lysis buffer (QIAGEN, cat #158902) to lyse the RBCs, and incubated at room temperature for 10 min, with inversion every 2 min. Cells were then washed twice in phosphate-buffered saline, pelleted, and stored at -80 °C.

Assay of telomere length. Total genomic DNA was purified using QIAamp® DNA Mini kit (QIAGEN, Cat#51104) and stored at -80°C for batch TL measurement. The TL assay was adapted from the originally published method by Cawthon (39,40). The telomere thermal cycling profile comprised: cycling for T(telomic) PCR at 96 °C for 1 m, denaturing at 96 °C for 1 s, and annealing/extending at 54 °C for 60 s with fluorescence data collection for 30 cycles, and cycling for S (single copy gene) PCR at 96 °C for 1 m, denaturing at 95 °C for 15 s, annealing at 58 °C for 1 s, and extending at 72 °C for 20 s for 8 cycles. This was followed by denaturing at 96 °C for 1 s, annealing at 58°C for 1 s, extending at 72°C for 20 s, and holding at 83°C for 5 s for 35 cycles. The primers for the telomere PCR are tel1b [5'-CGGTTT(GTTTGG)$_5$GTT-3'], used at a final concentration of 100 nM, and tel2b [5'-GGCTTG(CCTTAC)$_5$CCT-3'], used at a final

concentration of 900 nM. The primers for the single-copy gene (human beta-globin) PCR are hbg1 [5'-GCTTCTGACACAACTGT GTTCACTAGC-3'], used at a final concentration of 300 nM, and hbg2 [5'-CACCAACTTCATCCACGTTCACC-3'], used at a final concentration of 700 nM. The final reaction mix contains 20 mM Tris–HCl, pH 8.4; 50 mM KCl; 200 lM each dNTP; 1% DMSO; 0.4 Syber Green I; 22 ng E. coli DNA per reaction; 0.4 Units of Platinum Taq DNA polymerase (Invitrogen Inc.) per 11 microliter reaction; 0.5–10 ng of genomic DNA. Tubes containing 26, 8.75, 2.9, 0.97, 0.324 and 0.108 ng of a reference DNA (from Hela cancer cells) were included in each PCR run so that the quantity of targeted templates in each research sample could be determined relative to the reference DNA sample by the standard curve method. We used the same reference DNA for all PCR runs.

To control for inter-assay variability, we included 8 control DNA samples in each run. We measured the telomere to single copy gene ratio (T/S ratio) for each sample twice. When the duplicate T/S value and the initial value varied by more than 7%, we ran the sample a third time and used the two closest values. In each batch, we divided the T/S ratio of each control DNA by the average T/S for the same DNA from 10 runs to get a normalizing factor. We repeated this for all 8 samples, and used the average normalizing factor for all 8 samples to obtain the final T/S ratio. We used the same assay plate for each participant when measuring sorted cell TL (CD4+, CD8+ T-cells and B-cells). In this sample, the average coefficient of variation was 3.4% for sorted cell TL data, 3.1% for granulocyte TL data, and 2.2% for PBMC TL data. Technicians were masked to intervention condition.

To determine the conversion factor for the calculation of approximate base pair TL from the T/S ratio, we measured T/S ratios for a set of genomic DNA samples from the human fibroblast primary cell line IMR90 at different population doublings, as well as in the telomerase

protein subunit gene (hTERT) transfected into a lentiviral construct. We determined the mean terminal restriction fragment length from these DNA samples using Southern blot analysis. Comparison between T/S ratios and base pairs derived from Southern blot analysis generated the following formula to convert T/S ratios to base pairs: base pairs= 3274+2413*(T/S) (41).

Covariates. We assessed participants' age (years), cigarette use (average number of cigarettes in last week), alcohol use (0=none; 1=once/month, 2=2-3X/month, 3=1X/wk, 4=2X/wk, 5=3-4X/wk, 6=5-6X/wk), educational attainment (0=less than a Bachelor's degree; 1=Bachelor's and above), and race (White, Black, Latino/a, Asian or Pacific Islander, Native American, Other) in-person at baseline. We assessed participants' physical activity using the International Physical Activity Questionnaire (IPAQ) long form (42), which is a self-report measure that captures physical activity completed in the past week. From this, we computed the total prorated metabolic equivalent of task (METs (43)) as (3.3*m walking/wk + 4*m moderate activity/wk + 8*m vigorous activity/wk), where m for each activity are prorated down to 180 if the reported m exceeded the cut-off of 180.

Statistical analysis

We tested each hypothesis using models that included either (1) age and any covariates that were statistically significantly associated with outcomes, or (2) intervention arm as well as any covariates that were statistically significantly associated with outcomes. We also report unadjusted models, which included only the predictors and outcomes. To ascertain whether to include a given covariate in adjusted models, we examined bivariate associations between each covariate and each outcome metric at 12 months. If a covariate was statistically significantly associated with an outcome (assessed at the final timepoint examined in each model), we

retained this covariate in the final adjusted model. If a covariate was associated with some cell types, but not all, we retained it in all models to maximize consistency in interpretation. We used SAS PROC MIXED (fixed effects only) to test each hypothesis, and modeled change in an outcome from baseline to 3, 6, or 12 months by including the latter timepoint as the outcome variable and accounting for baseline as a covariate, rather than modeling a change score directly (44). Models testing intervention effects accounted for baseline BMI. Models testing effects of weight loss and weight-loss maintenance did not include baseline BMI as a covariate, as baseline BMI is a component of the primary predictor variable (weight change from baseline to subsequent timepoint). We defined two types of weight-loss maintenance: having lost 10% of body weight from baseline to 6 months, and having maintained this loss at 12 months (Status A), and having lost 5% of body weight from baseline to 6 months, and having maintained this loss at 12 months (Status B). We report scale-dependent betas, standard errors, 95% confidence intervals, and p values in narrative and tables. As we conducted statistical tests using four primary predictors (intervention arm, weight change, weight-loss maintenance of 10%, and weight-loss maintenance of 5%) and five outcomes (PBMC, granulocytes, CD4+, CD8+, CD19+ cells), we interpreted statistical significance using a Bonferroni correction for 20 tests (*p* value criterion computed as: .05/20=.0025).

Results

Participant Characteristics

Participants randomized to each arm were similar on baseline characteristics (Table 1), session attendance was similar for the mindfulness and control arms (74.7% versus 71.2%, respectively), and researchers observed no serious adverse events in either intervention arm. See

(35,45) for further details on intervention engagement, attrition, compliance, and changes in other factors, such as stress. Figure 1, Panels A1 and B1, depict weight loss for participants who lost and maintained a loss of 10% (n=17) and participants who lost and maintained a loss of 5% (n=51).

Candidate covariates (cigarette use, alcohol use, educational attainment, and race) did not significantly correlate with telomere length (PBMC, granulocytes, and sorted cells) at 12 months, and therefore we did not retain them in adjusted models. Intervention arms (mindfulness vs. active control) did not differ in METs at any timepoint (baseline, and 3, 6, or 12 months; ps>.38), in change between baseline and any timepoint, or in change between 6 and 12 months (ps>.25). This pattern and statistical significance of results was identical for weight-loss maintenance of ≥10% (Status A; maintainers versus non-maintainers; all ps>.18), and also for seven of eight tests for weight-loss maintenance of ≥5% (Status B; maintainers versus non-maintainers; all ps>.18). Given the well-known association between age and TL (46–48), we included age as a covariate in all models (see Supplemental Digital Content Tables S1 and S2 for models excluding age, http://links.lww.com/PSYMED/A489). We also note that correlations between baseline TL and 12-month TL were high (ps<.000) for each cell type and appear in Table S3, Supplemental Digital Content, http://links.lww.com/PSYMED/A489).

Intervention Effects

Age was statistically significantly associated with 12-month PBMC, CD4+, and CD8+ TL, and was therefore retained in all adjusted models. No other assessed covariates (cigarette use, alcohol use, educational attainment, and race) demonstrated this significant association, hence, we did not include others in adjusted models. As shown in Table 2, intervention arm did

not statistically significantly predict 12-month TL change in any cell type. Greater baseline BMI, however, was associated with decreased PBMC [*b*(SE)=-26.89(9.75), 95% CI (-46.17, -7.71), *p*=.007] and B-cell TL [*b*(SE)=-46.53(21.32), 95% CI (-89.03, -4.04), *p*=.032], however, these p values exceed the Bonferroni-corrected threshold of *p*=.0025.

Weight Change Effects

Weight loss. In both unadjusted models and models adjusted for age and intervention arm, weight change from baseline to each subsequent timepoint was not associated with change in TL in those respective periods: baseline to 3 months [Adjusted models: PBMC: *b*(SE)=-3.88(7.54), 95% CI (-18.79, 11.04), *p*=.608; Granulocytes: *b*(SE)=3.59(8.35), 95% CI (-12.99, 20.17), *p*=.668]; baseline to 6 months [Adjusted models: PBMC: *b*(SE)=-0.57(6.57), 95% CI (-13.56, 12.42), *p*=.931; Granulocyte: *b*(SE)=4.99(6.27), 95% CI (-7.47, 17.44), *p*=.428), and baseline to 12 months [Adjusted models: PBMC: *b*(SE)=-10.58(6.43), 95% CI (-10.58, 6.43), *p*=.102; Granulocyte: *b*(SE)=0.30(5.64), 95% CI (-10.91, 11.51), *p*=.957; CD4+ T-cell: *b*(SE)=9.19(7.56), 95% CI (-5.86, 24.25), *p*=.228; CD8+ T-cell: *b*(SE)=-11.64(10.49), 95% CI (-32.55, 9.26), *p*=.271; CD19+ B-cell: *b*(SE)=-18.99(14.74), 95% CI (-48.40, 10.42), *p*=.202).

Weight-loss maintenance of 10% of body weight. As shown in Table 3, associations between weight-loss maintenance status and changes in TL varied by cell type. Weight-loss maintenance of 10% or greater (Status A) was associated with longer 12-month PBMC TL [*b*(SE)=239.08(120.35), 95% CI (0.92, 477.25), *p*=.049] after accounting for age, intervention arm, and baseline PBMC TL, and trended toward association with longer 12-month granulocyte TL [*b*(SE)=191.56(98.56), 95% CI (-4.23, 387.35), *p*=.055]. Of note, these p values exceed the Bonferroni-corrected threshold of *p*=.0025. Granulocyte TL evidenced a slight decrease from

baseline to 3 months, before increasing from 3 months to 6 and 12 months (Figure 1, A3). Among sorted cells, weight-loss maintenance of 10% or greater (Status A) was associated with longer 12-month CD8+ T-cell TL before [*b*(SE)=440.34(189.74), 95% CI (62.35, 818.32), *p*=.023] and after [*b*(SE)=417.26(179.78), 95% CI (58.95, 775.57), *p*=.023] accounting for age, intervention arm, and baseline CD8+ T-cell TL (though this exceeded the Bonferroni-corrected threshold of *p*=.0025). Thus, weight-loss maintenance of 10% or greater of body weight may confer benefit in terms of longer PBMC TL (especially within CD8+ cells) and granulocyte TL (Figure 1, Panels A2 and A3).

Weight-loss maintenance of 5% of body weight. As shown in Table 4, weight-loss maintenance of 5% or greater (Status B) was associated with longer 12-month PBMC TL [*b*(SE)=162.32(80.00), 95% CI (4.00, 320.62), *p*=.045] after accounting for age, intervention arm, and baseline PBMC TL (though this exceeded the Bonferroni-corrected threshold of *p*=.0025). Weight-loss maintenance of 5% or greater did not evidence a similar association with 12-month granulocyte TL [*b*(SE)=59.82(66.58), 95% CI (-72.45, 192.09), *p*=.371]. Of note, granulocyte TL evidenced a slight decrease from baseline to 3 months, before increasing from 3 to 6 months and staying similar (non-maintainers) or increasing (maintainers) from 6 to 12 months (Figure 1, B3). Among sorted cells, weight-loss maintenance of 5% or greater (Status B) was positively associated with longer 12-month CD8+ T-cell TL [*b*(SE)=199.34(113.14), 95% CI (-26.15, 424.83), *p*=.082] after accounting for age, intervention arm, and baseline CD8+ TL (though this exceeded the Bonferroni-corrected threshold of *p*=.0025). Thus, weight-loss maintenance of 5% or greater of body weight may confer benefit in terms of longer PBMC TL (especially CD8+ T-cells; Figure 1, Panels B2 and B3).

Discussion

Although healthy lifestyle factors are associated with longer telomere length (TL; e.g., (49,50), few studies have documented telomere lengthening. Here we examined a sample of healthy men and women with obesity who were randomized to receive a diet and exercise program with or without added mindfulness training. To our knowledge, this is the first randomized controlled trial testing a weight-loss intervention that examined TL as an outcome.

As reported in prior research (14), we found a positive cross-sectional association between greater BMI and shorter PBMC TL. We did not observe differential effects of the two weight-loss intervention arms on 12-month TL, nor did we observe significant associations between simultaneous changes in weight and TL. We did, however, observe that successful weight-loss maintenance of 10% was associated with greater TL lengthening within PBMCs, granulocytes (Figure 1, Panels A2 and A3), and CD8+ T-cells at 12 months. Successful weight-loss maintenance of 5% or greater showed a similar pattern, although these effects were smaller and did not reliably differ from zero. Of note, all observed associations exceeded the Bonferroni-corrected threshold of p=.0025, and should be interpreted in light of correction for multiple testing.

TL has primarily been examined in whole blood or in PBMCs; however, in this study, we examined TL in both granulocytes and PBMCs, as well as different sub-types of lymphocytes that make up much of the PBMC population. Although characterizing TL in white blood cell (WBC) subsets is more expensive and complex, this approach adds potentially important detail to understanding changes in TL (39,51,52). Because TL can systematically vary among different WBC types, changes in whole blood or PBMC TL may reflect actual changes in TL, or may simply reflect changes in the distribution of specific WBC populations in the blood, such as

shifts between the blood and tissue compartments. Granulocytes are typically the most common WBC, and granulocyte TL is thus most highly correlated with whole blood TL (mature RBCs do not have nuclei and thus do not have telomeres, hence measures of TL in whole blood only reflect TL in WBCs; (53)). In contrast, PBMCs reflect longer-lived WBC populations (54,55).

Within PBMCs, T-cell TL tends to shorten more rapidly than B-cell TL (56,57). Here, we observed increased CD8+ T-cell TL among individuals with the most successful weight-loss maintenance (10% of initial body weight). CD8+ T-cells are the main effector cells in adaptive, or "learned," cellular immune responses, and shortened TL and replicative immunosenescence (inability to replicate) in CD8+ T-cells are associated with poorer immune responses to immunologic challenges, including poorer vaccine responses (58–60). Hence, this begins to suggest a pathway through which weight-loss maintenance among individuals with obesity may reduce immune system aging.

The clinical significance of TL is becoming more well-established. Large studies have linked shorter TL with greater likelihood of psychiatric disorders (61), greater psychosocial stress (62), and greater depressive symptoms (63). Large observational studies have also linked shorter TL to increased risk of ischemic heart disease (64), and recent research suggests a causal role of TL in Alzheimer's disease (65) and cardiovascular disease (66). Although population studies reporting associations linking TL to components of metabolic health do not show causality (67), pilot data have implied that intensive lifestyle interventions may affect TL (30), hence, healthy lifestyle factors may improve TL. Longitudinal data have demonstrated that shorter TL may confer additional risk in the development of insulin resistance (68). Other work has shown that fasting insulin may mediate an association between TL and coronary heart disease (69). The clinical significance of telomere lengthening, however, has not been

determined, and may also depend on stability of this improvement. Future studies should test causal associations between TL and components of metabolic health that influence aging-related disease.

In the current study, TL appeared stable from baseline to six months, and we observed TL lengthening at 12 months among individuals who maintained a weight loss of 10% (7.5 kg). Notably, this was merely 17 participants (8.76% of the total sample). Thus, results may be interpreted as a proof of concept that successful weight loss up to a year later may confer beneficial effects on TL, though this magnitude of weight-loss maintenance (10%) may be difficult for most people to achieve. However, 51 participants (26.29%) maintained a weight loss of 5%, which has clear beneficial effects on metabolic health (70) and may connote some beneficial effect on TL. We conclude that the overall pattern of results indicates that greater than 10% weight-loss maintenance may be associated with longer telomere length in PBMCs and CD8+ T cells. We do apply caution to this conclusion; future work should seek to replicate this pattern of results. Of note, in these analyses, we pre-specified our intention to include covariates that were associated with outcomes, and though we ultimately included only age, which is a robust correlate of TL (26,46,47), we may have increased the risk of overfitting our models (71). Future work should a priori select covariates for inclusion regardless of correlation with the outcome variables being examined.

Of note, although health behavior such as exercise is associated with longer TL (72,73), there was no evidence of systematic differences in exercise across intervention arms (mindfulness versus active control) or weight-loss maintenance groups (Status A, ≥10%; Status B, ≥5%). Thus, the observed benefits may be more attributable to metabolic benefit derived from weight loss rather than those achieved through cardiovascular conditioning, etc. Preventing TL

shortening may theoretically positively affect immune function and reduce risk for age-related diseases. It is unclear why we observed a short-term decrease in TL at the 3 month timepoint. Although this may have been a chance finding and requires future investigation, one hypothesis is that initial weight loss may have induced a catabolic state that represented a physiological stressor that contributed to initial TL shortening.

Mindfulness-based interventions have traditionally focused on stress reduction as a pathway to psychological and physiological health benefits. Notably, this sample had, on average, lower Perceived Stress Scale scores (*M*=14.41, *SD*=5.76) than national averages (74). Although psychological stresses, particularly work-related and family-related stresses, have been associated with obesity (75–77), in this study's sample, stress may not have been high enough such that stress reduction would have conferred benefit, or the intervention may not have engaged stress as an intervention target. Indeed, as reported elsewhere (45), participants in the mindfulness and active control groups did not experience significant differences in stress reduction. In contrast, participants in this sample had an average baseline BMI of 35.5, and weight loss *was* large enough that maintenance of such losses, which ostensibly occurred via changes in dietary intake, may have led to TL lengthening. Participants in this trial were encouraged to reduce caloric intake and to increase intake of foods traditionally recommended in Mediterranean diets (e.g., fresh fruits and vegetables, nuts, olive oil, fish). Indeed, prior work has shown that adherence to a Mediterranean diet, which has been shown to reduce cardiovascular risk factors (78), is associated with longer TL (79).

Conclusions

Contrary to our initial hypothesis, we did not find evidence that the mindfulness-based weight-loss intervention differed from the control group in terms of change in TL. Additionally,

we did not find evidence to suggest weight loss to be contemporaneously associated with TL change. We did, however, find support for the hypothesis that weight-loss maintenance of 10% or more (of initial body weight) was associated with TL lengthening 12 months later. Overall, results suggest a model in which initial weight loss may represent a physiologic stress for TL (resulting in shortening or no change), but that maintaining weight loss may produce longer-term benefits in TL (resulting in lengthening). Future research should further test this model.

References

1. Blasco MA. Telomeres and human disease: Ageing, cancer and beyond. Nat Rev Genet. 2005 Aug;6(8):611–22.
2. Blackburn EH. Telomeres and telomerase: Their mechanisms of action and the effects of altering their functions. FEBS Lett. 2005;579(4):859–862.
3. Chan SRWL, Blackburn EH. Telomeres and telomerase. Philos Trans R Soc Lond B Biol Sci. 2004 Jan 29;359(1441):109–22.
4. Lin J, Epel E, Blackburn E. Telomeres and lifestyle factors: Roles in cellular aging. Mutat Res Mol Mech Mutagen. 2012 Feb 1;730(1–2):85–9.
5. D'Mello MJJ, Ross SA, Briel M, Anand SS, Gerstein H, Paré G. The association between shortened leukocyte telomere length and cardio-metabolic outcomes: A systematic review and meta-analysis. Circ Cardiovasc Genet. 2014 Nov 18;CIRCGENETICS-113.
6. Haycock PC, Heydon EE, Kaptoge S, Butterworth AS, Thompson A, Willeit P. Leucocyte telomere length and risk of cardiovascular disease: Systematic review and meta-analysis. BMJ. 2014 Jul 8;349:g4227.
7. Zhao J, Miao K, Wang H, Ding H, Wang DW. Association between Telomere Length and Type 2 Diabetes Mellitus: A Meta-Analysis. PLOS ONE. 2013 Nov 21;8(11):e79993.
8. Mons U, Müezzinler A, Schöttker B, Dieffenbach AK, Butterbach K, Schick M, et al. Leukocyte telomere length and all-cause, cardiovascular disease, and cancer mortality: Results from individual-participant-data meta-analysis of 2 large prospective cohort studies. Am J Epidemiol. 2017 Jun 15;185(12):1317–26.

9. Rode L, Nordestgaard BG, Bojesen SE. Peripheral blood leukocyte telomere length and mortality among 64 637 individuals from the general population. JNCI J Natl Cancer Inst. 2015 Jun;107(6).
10. Furukawa S, Fujita T, Shimabukuro M, Iwaki M, Yamada Y, Nakajima Y, et al. Increased oxidative stress in obesity and its impact on metabolic syndrome. J Clin Invest. 2004;114(12):1752.
11. Maury E, Brichard SM. Adipokine dysregulation, adipose tissue inflammation and metabolic syndrome. Mol Cell Endocrinol. 2010 Jan 15;314(1):1–16.
12. Bonomini F, Rodella LF, Rezzani R. Metabolic syndrome, aging and involvement of oxidative stress. Aging Dis. 2015 Mar 10;6(2):109–20.
13. Rode L, Nordestgaard BG, Weischer M, Bojesen SE. Increased body mass index, elevated C-reactive protein, and short telomere length. J Clin Endocrinol Metab. 2014;99(9):E1671–E1675.
14. Müezzinler A, Zaineddin AK, Brenner H. Body mass index and leukocyte telomere length in adults: A systematic review and meta-analysis. Obes Rev. 2014 Mar 1;15(3):192–201.
15. Mundstock E, Sarria EE, Zatti H, Mattos Louzada F, Kich Grun L, Herbert Jones M, et al. Effect of obesity on telomere length: Systematic review and meta-analysis. Obesity. 2015;23(11):2165–2174.
16. US Preventive Services Task Force. Final Recommendation Statement: Obesity in Adults: Screening and Management [Internet]. 2016. Available from: https://www.uspreventiveservicestaskforce.org/Page/Document/RecommendationStatementFinal/obesity-in-adults-screening-and-management

17. Food and Drug Administration. Guidance for industry developing products for weight management. Wash DC Food Drug Adm. 2007;
18. Williamson DA, Bray GA, Ryan DH. Is 5% weight loss a satisfactory criterion to define clinically significant weight loss? Diabetes. 2015;211:s216.
19. Jensen MD, Ryan DH, Apovian CM, Ard JD, Comuzzie AG, Donato KA, et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and The Obesity Society. J Am Coll Cardiol. 2014;63(25(Part B)):2985–3023.
20. NHLBI Obesity Education Initiative Expert Panel on the Identification E. Summary of Evidence-Based Recommendations. National Heart, Lung, and Blood Institute; 1998.
21. Carulli L, Anzivino C, Baldelli E, Zenobii MF, Rocchi MBL, Bertolotti M. Telomere length elongation after weight loss intervention in obese adults. Mol Genet Metab. 2016;118(2):138–142.
22. Laimer M, Melmer A, Lamina C, Raschenberger J, Adamovski P, Engl J, et al. Telomere length increase after weight loss induced by bariatric surgery: Results from a 10 year prospective study. Int J Obes. 2016 May;40(5):773–8.
23. Cui Y, Gao Y-T, Cai Q, Qu S, Cai H, Li H-L, et al. Associations of leukocyte telomere length with body anthropometric indices and weight change in Chinese women. Obesity. 2013;21(12):2582–2588.
24. Kim S, Parks CG, DeRoo LA, Chen H, Taylor JA, Cawthon RM, et al. Obesity and weight gain in adulthood and telomere length. Cancer Epidemiol Prev Biomark. 2009 Mar 1;18(3):816–20.

25. Schutte NS, Palanisamy SK, McFarlane JR. The relationship between positive psychological characteristics and longer telomeres. Psychol Health. 2016;31(12):1466–1480.
26. Starkweather AR, Alhaeeri AA, Montpetit A, Brumelle J, Filler K, Montpetit M, et al. An integrative review of factors associated with telomere length and implications for biobehavioral research. Nurs Res. 2014;63(1):36.
27. Puterman E, Lin J, Krauss J, Blackburn EH, Epel ES. Determinants of telomere attrition over one year in healthy older women: Stress and health behaviors matter. Mol Psychiatry. 2015 Apr;20(4):529–35.
28. Van Ockenburg SL, Bos EH, De Jonge P, Van Der Harst P, Gans ROB, Rosmalen JGM. Stressful life events and leukocyte telomere attrition in adulthood: a prospective population-based cohort study. Psychol Med. 2015;45(14):2975–2984.
29. Epel ES. Psychological and metabolic stress: A recipe for accelerated cellular aging. Horm Athens. 2009;8(1):7–22.
30. Ornish D, Lin J, Chan JM, Epel E, Kemp C, Weidner G, et al. Effect of comprehensive lifestyle changes on telomerase activity and telomere length in men with biopsy-proven low-risk prostate cancer: 5-year follow-up of a descriptive pilot study. Lancet Oncol. 2013 Oct 1;14(11):1112–20.
31. Daubenmier J, Lin J, Blackburn E, Hecht FM, Kristeller JL, Maninger N, et al. Changes in stress, eating, and metabolic factors are related to changes in telomerase activity in a randomized mindfulness intervention pilot study. Psychoneuroendocrinology. 2012 Jul;37(7):917–28.
32. Kristeller JL, Wolever RQ. Mindfulness-based eating awareness training for treating binge eating disorder: The conceptual foundation. Eat Disord. 2010;19(1):49–61.

33. Kristeller JL, Wolever RQ, Sheets V. Mindfulness-Based Eating Awareness Training (MB-EAT) for binge eating: A randomized clinical trial. Mindfulness. 2014 Jun 1;5(3):282–97.
34. Kabat-Zinn J, Hanh TN. Full catastrophe living: Using the wisdom of your body and mind to face stress, pain, and illness. New York: Random House LLC; 2009.
35. Daubenmier J, Moran PJ, Kristeller J, Acree M, Bacchetti P, Kemeny ME, et al. Effects of a mindfulness-based weight loss intervention in adults with obesity: A randomized clinical trial. Obesity. 2016;24(4):794–804.
36. Segal ZV, Williams JMG, Teasdale JD. Mindfulness-based cognitive therapy for depression. Guilford Press; 2012.
37. Dreyer D, Dreyer K. ChiWalking: Fitness Walking for Lifelong Health and Energy. New York, NY: Simon & Schuster; 2006.
38. Prather AA, Gurfein B, Moran P, Daubenmier J, Acree M, Bacchetti P, et al. Tired telomeres: Poor global sleep quality, perceived stress, and telomere length in immune cell subsets in obese men and women. Brain Behav Immun. 2015 Jul;47:155–62.
39. Lin J, Epel E, Cheon J, Kroenke C, Sinclair E, Bigos M, et al. Analyses and comparisons of telomerase activity and telomere length in human T and B cells: Insights for epidemiology of telomere maintenance. J Immunol Methods. 2010 Jan 31;352(1–2):71–80.
40. Cawthon RM. Telomere measurement by quantitative PCR. Nucleic Acids Res. 2002;30(10):e47–e47.
41. Farzaneh-Far R, Lin J, Epel E, Lapham K, Blackburn E, Whooley MA. Telomere length trajectory and its determinants in persons with coronary artery disease: Longitudinal findings from the heart and soul study. PLOS ONE. 2010 Jan 8;5(1):e8612.

42. Hagströmer M, Oja P, Sjöström M. The International Physical Activity Questionnaire (IPAQ): A study of concurrent and construct validity. Public Health Nutr. 2006;9(6):755–762.
43. Ainsworth BE, Haskell WL, Leon AS, Jacobs DRJ, Montoye HJ, Sallis JF, et al. Compendium of physical activities: Classification of energy costs of human physical activities. Med Sci Sports Exerc. 1993 Jan;25(1):71–80.
44. Cohen J, Cohen P, West SG, Aiken LS. Applied multiple regression/correlation analysis for the behavioral sciences. Routledge; 2003.
45. Mason A, Epel ES, Aschbacher K, Lustig RH, Acree M, Kristeller J, et al. Reduced reward-driven eating accounts for the impact of a mindfulness-based diet and exercise intervention on weight loss: Data from the SHINE randomized controlled trial. Appetite. 2016 May 1;100:86–93.
46. Benetos A, Okuda K, Lajemi M, Kimura M, Thomas F, Skurnick J, et al. Telomere length as an indicator of biological aging: the gender effect and relation with pulse pressure and pulse wave velocity. Hypertension. 2001 Feb 1;37(2):381–5.
47. Frenck RW, Blackburn EH, Shannon KM. The rate of telomere sequence loss in human leukocytes varies with age. Proc Natl Acad Sci U S A. 1998 May 12;95(10):5607–10.
48. Starkweather AR, Alhaeeri AA, Montpetit A, Brumelle J, Filler K, Montpetit M, et al. An Integrative Review of Factors Associated with Telomere Length and Implications for Biobehavioral Research. Nurs Res. 2014;63(1):36–50.
49. Njajou OT, Hsueh W-C, Blackburn EH, Newman AB, Wu S-H, Li R, et al. Association between telomere length, specific causes of death, and years of healthy life in health, aging, and body composition, a population-based cohort study. J Gerontol Ser A. 2009 Aug 1;64A(8):860–4.

50. Sun Q, Shi L, Prescott J, Chiuve SE, Hu FB, Vivo ID, et al. Healthy lifestyle and leukocyte telomere length in U.S. women. PLOS ONE. 2012 May 31;7(5):e38374.

51. Lin J, Cheon J, Brown R, Coccia M, Puterman E, Aschbacher K, et al. Systematic and cell type-specific telomere length changes in subsets of lymphocytes. J Immunol Res. 2016;2016:1–9.

52. Weng N, Granger L, Hodes RJ. Telomere lengthening and telomerase activation during human B cell differentiation. Proc Natl Acad Sci. 1997 Sep 30;94(20):10827–32.

53. Kimura M, Gazitt Y, Cao X, Zhao X, Lansdorp PM, Aviv A. Synchrony of telomere length among hematopoietic cells. Exp Hematol. 2010 Oct;38(10):854–9.

54. Beverley PC, Michie CA, Young JL. Memory and the lifespan of human T lymphocytes. Leukemia. 1993 Aug;7 Suppl 2:S50-54.

55. Tak T, Tesselaar K, Pillay J, Borghans JAM, Koenderman L. What's your age again? Determination of human neutrophil half-lives revisited. J Leukoc Biol. 2013 Oct;94(4):595–601.

56. Martens UM, Brass V, Sedlacek L, Pantic M, Exner C, Guo Y, et al. Telomere maintenance in human B lymphocytes. Br J Haematol. 2002;119(3):810–818.

57. Son NH, Murray S, Yanovski J, Hodes RJ, Weng N. Lineage-specific telomere shortening and unaltered capacity for telomerase expression in human T and B lymphocytes with age. J Immunol. 2000;165(3):1191–1196.

58. Chou J, Effros R. T cell replicative senescence in human aging. Curr Pharm Des. 2013;19(9):1680–1698.

59. Najarro K, Nguyen H, Chen G, Xu M, Alcorta S, Yao X, et al. Telomere length as an indicator of the robustness of B- and T-Cell response to influenza in older adults. J Infect Dis. 2015 Oct 15;212(8):1261–9.

60. Saurwein-Teissl M, Lung TL, Marx F, Gschösser C, Asch E, Blasko I, et al. Lack of antibody production following immunization in old age: association with CD8+ CD28- T cell clonal expansions and an imbalance in the production of Th1 and Th2 cytokines. J Immunol. 2002;168(11):5893–5899.

61. Darrow SM, Verhoeven JE, Révész D, Lindqvist D, Penninx BW, Delucchi KL, et al. The association between psychiatric disorders and telomere length: A meta-analysis involving 14,827 persons. Psychosom Med. 2016;78(7):776.

62. Verhoeven JE, van Oppen P, Puterman E, Elzinga B, Penninx BW. The association of early and recent psychosocial life stress with leukocyte telomere length. Psychosom Med. 2015;77(8):882–891.

63. Whisman MA, Richardson ED. Depressive symptoms and salivary telomere length in a probability sample of middle-aged and older adults. Psychosom Med. 2017;79(2):234–242.

64. Scheller Madrid A, Rode L, Nordestgaard BG, Bojesen SE. Short telomere length and ischemic heart disease: Observational and genetic studies in 290 022 individuals. Clin Chem. 2016 Aug;62(8):1140–9.

65. Zhan Y, Song C, Karlsson R, Tillander A, Reynolds CA, Pedersen NL, et al. Telomere length shortening and Alzheimer Disease--A mendelian randomization study. JAMA Neurol. 2015 Oct;72(10):1202–3.

66. Codd V, Nelson CP, Albrecht E, Mangino M, Deelen J, Buxton JL, et al. Identification of seven loci affecting mean telomere length and their association with disease. Nat Genet. 2013 Apr;45(4):422–7, 427e1-2.
67. Révész D, Milaneschi Y, Verhoeven JE, Lin J, Penninx BWJH. Longitudinal associations between metabolic syndrome components and telomere shortening. J Clin Endocrinol Metab. 2015 Aug;100(8):3050–9.
68. Verhulst S, Dalgård C, Labat C, Kark JD, Kimura M, Christensen K, et al. A short leucocyte telomere length is associated with development of insulin resistance. Diabetologia. 2016 Jun;59(6):1258–65.
69. Zhan Y, Karlsson IK, Karlsson R, Tillander A, Reynolds CA, Pedersen NL, et al. Exploring the causal pathway from telomere length to coronary heart disease: A network mendelian randomization study. Circ Res. 2017;CIRCRESAHA–116.
70. Magkos F, Fraterrigo G, Yoshino J, Luecking C, Kirbach K, Kelly SC, et al. Effects of moderate and subsequent progressive weight loss on metabolic function and adipose tissue biology in humans with obesity. Cell Metab. 2016 Apr 12;23(4):591–601.
71. Babyak MA. What you see may not be what you get: a brief, nontechnical introduction to overfitting in regression-type models. Psychosom Med. 2004;66(3):411–421.
72. Cherkas LF, Hunkin JL, Kato BS, Richards JB, Gardner JP, Surdulescu GL, et al. The association between physical activity in leisure time and leukocyte telomere length. Arch Intern Med. 2008 Jan 28;168(2):154–8.
73. Tucker LA. Physical activity and telomere length in U.S. men and women: An NHANES investigation. Prev Med. 2017 Jul;100:145–51.

74. Cohen S, Janicki-Deverts D. Who's stressed? Distributions of psychological stress in the United States in probability samples from 1983, 2006, and 2009. J Appl Soc Psychol. 2012;42(6):1320–1334.
75. Block JP, He Y, Zaslavsky AM, Ding L, Ayanian JZ. Psychosocial stress and change in weight among US adults. Am J Epidemiol. 2009;170(2):181–92.
76. Kivimäki M, Head J, Ferrie JE, Shipley MJ, Brunner E, Vahtera J, et al. Work stress, weight gain and weight loss: Evidence for bidirectional effects of job strain on body mass index in the Whitehall II study. Int J Obes. 2006;30(6):982–987.
77. Nyberg ST, Heikkilä K, Fransson EI, Alfredsson L, De Bacquer D, Bjorner JB, et al. Job strain in relation to body mass index: Pooled analysis of 160 000 adults from 13 cohort studies. J Intern Med. 2012;272(1):65–73.
78. Kastorini C-M, Milionis HJ, Esposito K, Giugliano D, Goudevenos JA, Panagiotakos DB. The effect of Mediterranean diet on metabolic syndrome and its components: A meta-analysis of 50 studies and 534,906 individuals. J Am Coll Cardiol. 2011;57(11):1299–1313.
79. Boccardi V, Paolisso G. Malleability of short felomeres by felomerase activators: A mini-review. Aging Sci. 2013;1(108):2.

Figure Caption

Figure 1. Percentage weight change from baseline to 3, 6, and 12 months post-baseline) and telomere length in PBMCs (base pairs) and granulocytes (base pairs) at each timepoint by maintainer status type (Left: Status A, 10% weight-loss maintenance; Right: Status B, 5% weight-loss maintenance). Error bars reflect standard errors derived from within-timepoint t-tests.

Figure 1

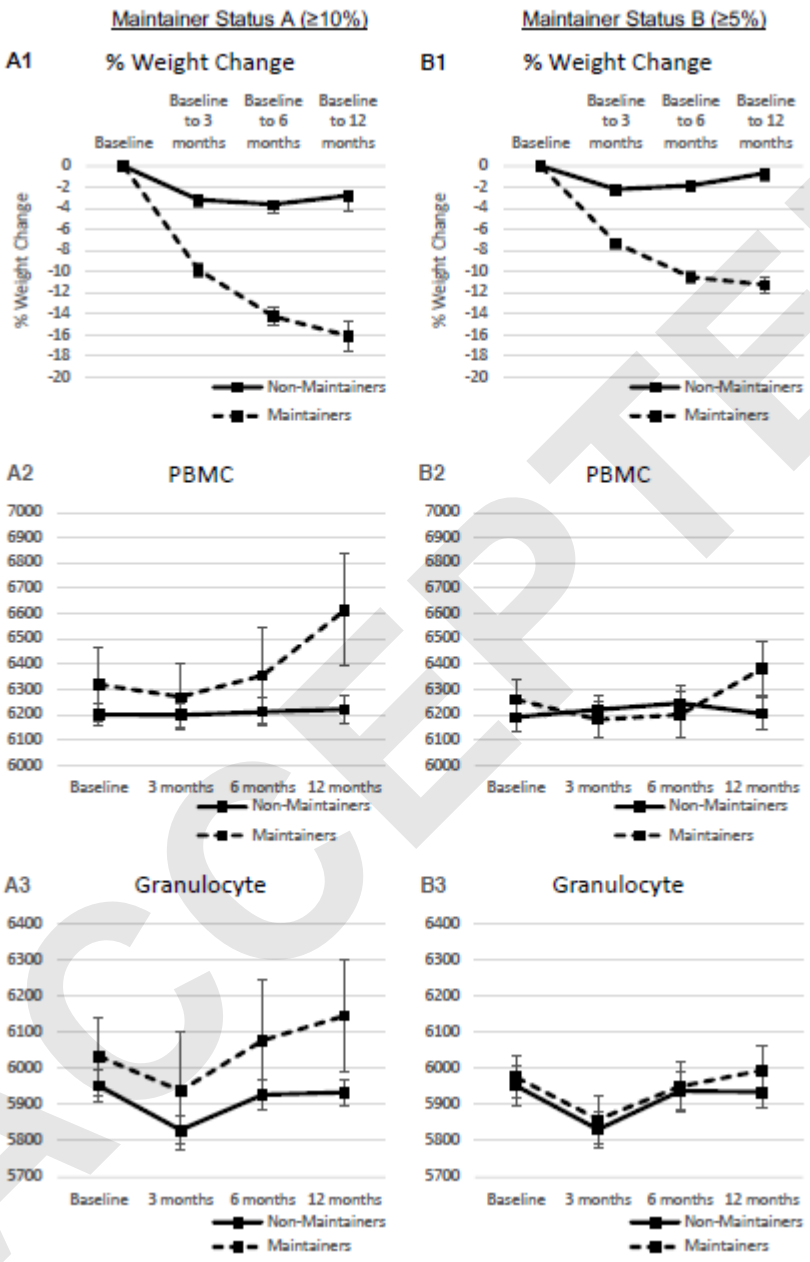

Table 1. Participant characteristics on all study variables by intervention arm and entire sample.

				Maintainer Status A (≥10%)		Maintainer Status B (≥5%)	
	Total Sample	**Active Control**	**Mindfulness**	**Maintainers**	**Non-Maintainers**	**Maintainers**	**Non-Maintainers**
N (%)	162 (100.0%)	74 (45.7%)	87 (54.3%)	17 (11.7%)	126 (88.3%)	50 (35.0%)	93 (65.0%)
Biol. sex (n, % female)	162 (79.0%)	61 (82.4%)	67 (76.1%)	12 (70.6%)	102 (81.0%)	37 (74.0%)	77 (82.8%)
Age, years (*M*, SD)	48.2 (12.5)	48.7 (12.0)	47.8 (13.0)	50.2 (13.5)	49.0 (12.3)	51.2 (11.8)	48.1 (12.6)
Race / Ethnicity (*n*, %)							
White	99 (61.5%)	43 (58.1%)	56 (64.4%)	14 (82.4%)	78 (62.4%)	36 (72.0%)	56 (60.9%)
Black	20 (12.4%)	10 (13.5%)	10 (11.5%)	1 (5.9%)	18 (14.4%)	6 (12.0%)	13 (14.1%)
Latino/a	20 (12.4%)	13 (17.6%)	7 (8.0%)	1 (5.9%)	13 (10.4%)	1 (2.0%)	13 (14.1%)
Asian or Pacific Islander	14 (8.7%)	7 (9.5%)	7 (8.0%)	0 (0.0%)	12 (9.6%)	5 (10.0%)	7 (7.6%)
Other	8 (5.0%)	1 (1.4%)	7 (8.0%)	1 (5.9%)	4 (3.2%)	2 (4.0%)	3 (3.3%)
Educational attainment (*n,* %; Bachelor's degree+)	112 (69.6%)	48 (64.9%)	64 (73.6%)	10 (58.8%)	92 (73.6%)	37 (74.0%)	65 (70.6%)
Physical activity METs (*M*, SD)	2564.2 (2618.7)	2506.8 (2917.2)	2612.4 (2354.7)	2197.1 (2161.3)	2588.3 (2709.8)	2625.4 (2208.1)	2496.8 (2865.5)
Cigarette use (*M,* SD)	0.2 (1.2)	0.1 (0.5)	0.2 (1.5)	0 (0.0%)	0.1 (1.0)	0.2 (1.4)	0.1 (0.4)
Alcohol use (*M,* SD)	2.1 (1.9)	2.2 (1.8)	2.1 (1.9)	2.3 (2.1)	2.2 (1.8)	2.4 (1.9)	2.2 (1.8)
Randomized to mindfulness intervention arm (n, %)	-	-	-	9 (11.5%)	69 (88.5%)	33 (42.3%)	45 (57.7%)
BMI, kg/m^2 (*M*, SD)	35.4 (3.7)	35.1 (3.8)	35.3 (3.5)	35.7 (4.6)	35.3 (3.5)	35.0 (3.5)	35.5 (3.7)
Weight change, baseline to 12 months (*M*, SD)	-4.1 (6.9)	-3.0 (6.5)	-5.1 (7.1)	-16.4 (6.2)	-2.6 (5.1)	-11.1 (5.8)	-0.6 (4.0)

Note. BMI = body mass index; Biol. sex = biological sex; Physical activity METs = physical activity metabolic equivalent of task; Maintainer Status A = ≥10% body weight lost from baseline to 6 months and maintenance of this loss at 12 months; Maintainer Status B = ≥5% body weight lost from baseline to 6 months and maintenance of this loss at 12 months.

Table 2. Models predicting 12-month telomere length (TL)

Outcome (12 months)	Effect	*b*	95% CI (Lower, Upper)	*p*
PBMC	Intervention arm	0.70	(-138.44, 139.84)	.992
	Baseline PBMC	0.68	(0.54, 0.82)	<.000
	Age	-11.02	(-17.39, -4.65)	.001
	Baseline BMI	-26.89	(-46.17, -7.61)	.007
Granulocyte	Intervention arm	44.75	(-76.07, 165.57)	.464
	Baseline Granulocyte	0.49	(0.32, 0.65)	<.000
	Age	-2.70	(-8.09, 2.68)	.321
	Baseline BMI	-5.58	(-22.98, 11.81)	.525
CD4+ T-cell	Intervention arm	78.45	(-70.88, 227.79)	.299
	Baseline CD4+	0.66	(0.49, 0.83)	<.000
	Age	-11.96	(-19.35, -4.57)	.002
	Baseline BMI	-15.86	(-37.34, 5.62)	.146
CD8+ T-cell	Intervention arm	18.09	(-193.33, 229.51)	.865
	Baseline CD8+	0.49	(0.31, 0.67)	<.000
	Age	-17.52	(-27.36, -7.68)	.001
	Baseline BMI	-27.41	(-56.95, 2.14)	.069
B-cell	Intervention arm	-134.57	(-440.72, 171.58)	.384
(CD19+)	Baseline CD19+	0.49	(0.23, 0.75)	<.000
	Age	-8.52	(-22.41, 5.37)	.226
	Baseline BMI	-46.53	(-89.03, -4.04)	.032

Note. See Table 1 note. Intervention arm = 0 = active control, 1 = mindfulness; CI = confidence interval; PBMC = peripheral blood mononuclear cell; CD4+ = cluster of differentiation 4 (indicating a CD4+ T lymphocyte); CD8+ = cluster of differentiation (indicating a CD8+ T lymphocyte); B-cell = cluster of differentiation (indicating B lymphocyte).

Table 3. Models predicting 12-month telomere length from weight-loss maintenance status A (≥10% of initial body weight).

Outcome (12 months)	Model Type	Effect	b	95% CI	*p*
PBMC	Adjusted for Age	Maintainer Status A	238.81	(1.54, 476.07)	.049
		Baseline PBMC	0.66	(0.51, 0.82)	<.000
		Age	-11.86	(-18.50, -5.23)	.001
	Adjusted for Age and Intervention Arm	Intervention arm	-19.51	(-166.93, 127.91)	.794
		Maintainer Status A	239.08	(0.92, 477.25)	.049
		Baseline PBMC	0.66	(0.51, 0.82)	<.000
		Age	-11.92	(-18.59, -5.24)	.001
Granulocyte	Adjusted for Age	Maintainer Status A	192.49	(-1.54, 386.53)	.052
		Baseline Granulocyte	0.41	(0.25, 0.58)	<.000
		Age	-4.69	(-9.93, 0.55)	.079
	Adjusted for Age and Intervention Arm	Intervention arm	6.90	(-113.46, 127.26)	.910
		Maintainer Status A	191.56	(-4.24, 387.36)	.055
		Baseline Granulocyte	0.42	(0.25, 0.59)	<.000
		Age	-4.66	(-9.95, 0.64)	.084
CD4+ T-cell	Adjusted for Age	Maintainer Status A	-36.77	(-330.38, 256.84)	.803
		Baseline CD4+	0.70	(0.51, 0.89)	<.000
		Age	-11.34	(-19.42, -3.27)	.009
	Adjusted for Age and Intervention Arm	Intervention arm	52.36	(-107.81, 212.54)	.517
		Maintainer Status A	-40.34	(-335.35, 254.67)	.786
		Baseline CD4+	0.70	(0.51, 0.90)	<.000
		Age	-10.98	(-19.16, -2.79)	.009
CD8+ T-cell	Adjusted for	Maintainer Status A	414.83	(58.57, 771.08)	.023

	Age	Baseline CD8+	0.51	(0.33, 0.68)	<.000
		Age	-15.58	(-25.10, -6.06)	.002
	Adjusted for Age and Intervention Arm	Intervention arm	-51.24	(-259.31, 156.82)	.625
		Maintainer Status A	417.26	(58.95, 775.57)	.023
		Baseline CD8+	0.51	(0.34, 0.69)	<.000
		Age	-15.66	(-25.24, -6.08)	.002
B-cell (CD19+)	Adjusted for Age	Maintainer Status A	47.04	(-491.80, 585.87)	.862
		Baseline CD19+	0.54	(0.27, 0.80)	<.001
		Age	-7.85	(-21.86, 6.16)	.267
	Adjusted for Age and Intervention Arm	Intervention arm	-93.07	(-413.69, 227.55)	.564
		Maintainer Status A	46.76	(-494.82, 588.35)	.864
		Baseline CD19+	0.53	(0.26, 0.80)	<.000
		Age	-8.58	(-22.88, 5.72)	.236

Note. See Table 2 note. Maintainer Status A = losing ≥10% of body weight and maintaining this loss at 12 months (0 = non-maintainer; 1 = maintainer).

Table 4. Models predicting 12-month telomere length from weight-loss maintenance status B (≥5% of initial body weight).

Outcome (12 months)	Model Type	Effect	*b*	95% CI	*p*
PBMC	Adjusted for Age	Maintainer Status B	153.75	(-1.63, 309.13)	.052
		Baseline PBMC	0.67	(0.51, 0.82)	<.000
		Age	-12.35	(-19.03, -5.67)	<.000
	Adjusted for Age and Intervention Arm	Intervention Arm	-45.52	(-195.23, 104.19)	.548
		Maintainer Status B	162.32	(4.00, 320.63)	.045
		Baseline PBMC	0.66	(0.51, 0.82)	<.000
		Age	-12.52	(-19.24, -5.80)	<.000
Granulocyte	Adjusted for Age	Maintainer Status B	60.05	(-66.34, 186.45)	.348
		Baseline Granulocyte	0.42	(0.25, 0.60)	<.000
		Age	-4.45	(-9.79, 0.89)	.102
	Adjusted for Age and Intervention Arm	Intervention Arm	0.81	(-126.03, 127.64)	.990
		Maintainer Status B	59.82	(-72.45, 192.09)	.371
		Baseline Granulocyte	0.43	(0.25, 0.59)	<.000
		Age	-4.44	(-9.85, 0.97)	.107
CD4+ T-cell	Adjusted for Age	Maintainer Status B	-36.96	(-213.61, 139.68)	.678
		Baseline CD4+	0.71	(0.52, 0.89)	<.000
		Age	-11.09	(-19.29, -2.88)	.009
	Adjusted for Age and Intervention Arm	Intervention Arm	57.89	(-103.82, 219.60)	.478
		Maintainer Status B	-46.64	(-225.96, 132.67)	.606
		Baseline CD4+	0.71	(0.52, 0.90)	<.000
		Age	-10.59	(-18.94, -2.23)	.014
	Adjusted for Age	Maintainer Status B	190.86	(-32.06, 413.78)	.092
		Baseline CD8+	0.50	(0.33, 0.68)	<.000

		Age	-16.84	(-26.55, -7.14)	.001
CD8+ T-cell	Adjusted for Age and Intervention Arm	Intervention Arm	-66.98	(-279.58, 145.62)	.532
		Maintainer Status B	199.34	(-26.16, 424.84)	.082
		Baseline CD8+	0.51	(0.33, 0.69)	<.000
		Age	-16.99	(-26.75, -7.23)	.001
B-cell (CD19+)	Adjusted for Age	Maintainer Status B	248.02	(-78.47, 574.51)	.134
		Baseline CD19+	0.54	(0.29, 0.80)	<.000
		Age	-8.79	(-22.53, 4.95)	.206
	Adjusted for Age and Intervention Arm	Intervention Arm	-116.31	(-432.70, 200.08)	.466
		Maintainer Status B	259.28	(-69.82, 588.37)	.121
		Baseline CD19+	0.54	(0.28, 0.80)	<.000
		Age	-9.73	(-23.76, 4.29)	.171

Note. See Table 2 note. Maintainer Status B = losing ≥5% of body weight and maintaining this loss at 12 months (0 = non-maintainer; 1 = maintainer).