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FULL LENGTH MANUSCRIPT

Reallocating Time to Physical Activity and Sleep: Associations with Body Mass Index in Cancer Survivors

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Abstract

Background Body mass index (BMI) above ≥ 25 kg/m^2 is associated with increased risk for cancer-related morbidity and mortality. Achieving recommended amounts of physical activity (PA), sedentary time (ST), and sleep can help cancer survivors (CS) attain a healthy BMI. This cross-sectional study examined the potential role of reallocating time between moderate and light PA, ST, and sleep on BMI in CS.

Method A sample of CS ($N = 73$, $M_{age} = 53.7 \pm 12.9$) wore an activPAL and Actiwatch accelerometer for 7 days, 24 h per day to measure PA intensity and sleep, respectively. Self-reported height and weight or scale/stadiometer were used to calculate BMI. Isotemporal substitution models were used to reallocate time, averaged over the 7-day period, from one activity of interest to another and examine the associations with BMI. Statistical significance was set at $p < .05$.

Results The following reallocations of 30 min were significantly associated with BMI: sleep to ST (+ 0.80 kg/m^2, $p = 0.02$) and ST to light PA (− 0.53 kg/m^2, $p = 0.008$). No significant associations with BMI were observed for reallocating time to or away from moderate-vigorous PA.

Conclusion The results of this study suggest that sleep and light PA may have important implications for achieving a healthy BMI in CS. Therefore, future research should include interventions which target light PA and sleep to determine if they can improve BMI in CS.

Keywords Isotemporal substitution · Sedentary behavior · Survivorship · Lifestyle behavior

Introduction

In the USA, 36% of individuals (40.9% of males, 32.2% of female) living with cancer (i.e., cancer survivors) are overweight or obese, defined as a body mass index (BMI) ≥ 25 kg/m [1, 2]. Overweight and obesity are associated with worse cancer-related outcomes including cancer recurrence, progression, and survival [1, 3]. Therefore, strategies to achieve and maintain a healthy BMI is of utmost importance for cancer survivors.

Modifying lifestyle behaviors such as increasing physical activity (PA), limiting sedentary time, and sleeping 7–9 h per night can help cancer survivors achieve a healthy BMI [4–6]. However, the majority of previous studies that have examined the effect of these lifestyle behaviors on BMI in cancer survivors have not accounted for the interdependent nature of these activities (i.e., increasing time in one activity requires decreasing time in another). For this reason, many scholars have now suggested that PA, sedentary time, and sleep should be studied within the context of the 24-h day [7]. To date, only one study has examined how reallocating

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time between PA, sedentary time, and sleep may impact BMI in cancer survivors. This study, by Boyle et al. [17], found that replacing 30 min of sleep, sedentary time, or light PA to moderate-vigorous PA (MVPA) was associated with lower BMI (decrease of 0.52–0.93 kg/m^2). However, this study was limited to breast cancer survivors and relied on subjective measures of sleep, which are known to only moderately correlate with objective sleep measurement and systematically result in over-reporting [8]. Therefore, the aims of this study were to evaluate the potential positive or negative associations of reallocating PA, sedentary time, and sleep on BMI in a mixed sample of cancer survivors, using objective measures of sleep and active behaviors.

Methods

Seventy-three participants took part in an initial lab visit (either in-person ($n = 38$) or virtually ($n = 35$)). Participants provided consent and completed a battery of questionnaires. At the conclusion of the visit, participants were fitted with the activPAL and Actiwatch-2 accelerometers at the laboratory. Virtual study visits consisted of a phone call to complete electronic consent followed by questionnaire completion, both done through REDCap. The accelerometers were delivered and picked up by study staff to the participant's home or the devices were shipped with a return envelope and label for the participant to return after completing the 7-day wear protocol. Participants were provided written instructions for placing the devices and, if necessary, a virtual visit was conducted to properly place the devices.

Participants

Participants were recruited through local and regional cancer centers, flyers and presentations at community locations and events (e.g., senior center, American Cancer Society Relay for Life), email and website posting via the University faculty and staff listserv, and the Colorado State University from 01/20 to 06/21. Participants were eligible if they were > 18 years at time of diagnosis, and within 60 months of treatment completion (i.e., surgery, chemotherapy, immunotherapy, and/or radiation therapy). Informed consent was obtained from all participants and all procedures performed in this study were in accordance with the ethical standards of Colorado State University institutional review board (IRB#19-8914H).

Sleep

Sleep period was measured using an Actiwatch-2, a validated device that utilizes light exposure and accelerations to determine sleep–wake intervals worn on the non-dominant wrist [9, 10]. Sleep period was defined as minutes spent asleep (minutes between time of sleep onset and time of sleep offset). Sleep onset was determined by 10 consecutive minutes with no activity counts, utilizing the event marker pressed by participants as a guide. Sleep offset was determined after 10 consecutive minutes of zero activity counts were disrupted, utilizing the event marker pressed by participants as a guide. Participants wore the device for 7 days, 24 h per day. To be included in the analyses, participants must have had a minimum of 4 valid nights of sleep, including 1 weekend day.

Physical Activity and Sedentary Time

PA and sedentary time were measured using the activPAL accelerometer (PAL Technologies, Glasgow, Scotland). The activPAL has been validated to quantify free-living sedentary and ambulatory activities using accelerations and has been previously used in cancer survivors [11–13]. Participants wore the activPAL for 7 consecutive days, 24 h per day at the midpoint of the right thigh. To be included in analyses, participants had to have had a minimum of 4 valid days, including 1 weekend day. The activPAL software allows for 4 h of non-wear time in a 24-h period to be considered 24-h wear compliant. Non-wear time in this study ranged from 1.5 to 33.4 min. This time was manually categorized as sedentary time as no participants reported removing the device for activity on their log forms. Light PA was measured by subtracting "non-wear time" and "primary lying time" (i.e., TIB measured by activPAL) from 24 h to create a "daytime" variable. This variable was then used to calculate light PA by subtracting MVPA and sedentary time from daytime wear time. MVPA was measured using "stepping time, in minutes, with a cadence ≥ 75 and duration > 1 min" and "cycling time". Sedentary time was measured by the time in minutes that participants were sitting or lying down (i.e., secondary lying time). All time measurements were collected as minutes per day. Of note, sleep onset and sleep offset, measured by the Actiwatch, were manually input into the activPAL software to ensure proper categorization of activities. Measurements from both accelerometers were averaged over the 7-day wear period.

Body Mass Index

Body mass index (BMI, kg/m^2), measured using height and weight, was the primary outcome. Participants either had height and weight measured in the laboratory (primary choice of measurement) or self-reported height and weight via an online questionnaire, pending comfort of reporting to the laboratory due to the COVID-19 pandemic. For those measured in the laboratory, participants were asked to remove their footwear and any outerwear for the height and weight

measurement, measured using a stadiometer. For those that self-reported BMI, participants were asked to report height and weight on a questionnaire.

Statistical Analysis

Demographics and descriptive statistics of PA, sedentary time, and sleep were summarized using mean ± standard deviation or frequencies. To examine the effects of time reallocation between PA, sedentary time, and sleep on BMI, an isotemporal substitution model of cross-sectional data was conducted. Isotemporal substitution models were done in two parts: single effects and the isotemporal model. Due to full 24-h measurement for all participants, the partition model which is in congruence with Mekary et al. (2008) and previous reallocation literature is no longer needed [14–17]. The single effects model estimated the association between BMI and each activity individually. The isotemporal substitution model represented the outcome when the same unit of time in one activity was substituted with another by including total time and all measured activities minus the activity of interest. Due to measurement of the full 24-h day in this study, the total time variable is no longer needed as all participants have exactly 48, 30-min bouts of activity. Therefore, it was removed for isotemporal substitution analyses and reduces risk of multicollinearity. From the isotemporal model, the regression coefficient was interpreted as the mean effect on the outcome when substitution time from the omitted activity to each of the included activities, holding total activity constant [15]. Four activities (i.e., MVPA, light PA, sedentary time, and sleep) were evaluated for substitution effects, requiring four isotemporal substitution models. Effects represented between person estimates, given the cross-sectional design of the study. A priori power analysis indicated an optimal sample size of 70 participants. All variables were converted to units of 30 min (e.g., 30 min = 1). Of note, the 30 min did not need to be continuously accumulated. Total time in the activity was divided by 30 to create the 30-min "bouts" to be used in the reallocation analyses. Current recommendations for PA in cancer survivors is 150 min/week of PA, often broken into 30/min/day across 5 days. This provided the rationale for using 30-min time reallocations in the current study [18]. Covariates were included in all models chosen based on significance found in previous literature: age, cancer type, and time since diagnosis [14, 17].

Results

Demographic information and participant characteristics are presented in Table 1. Briefly, participants were 53 ± 12 years old, mostly female (75.7%); the majority were diagnosed with breast ($n = 29.7\%$) or colorectal cancer ($n = 33.8\%$); and the average BMI was 26.7 ± 5.7 kg/m^2. Thirty-five (48.0%) self-reported their height and weight. On average, participants accumulated 24.0 ± 18.9 min/day of MVPA, 291.9 ± 100.6 min/day of light PA, 593.1 ± 108.3 min/day of sedentary time, and 486.6 ± 57.6 min/night of sleep, resulting in 48 total 30-min bouts to be included in analyses (range 46.42–48.0 bouts) (Table 2).

The single effects models revealed significant associations between BMI and sedentary time ($p = 0.002$) and light PA ($p = 0.02$).

Reallocating 30 Min from Sleep (Fig. 1)

Reallocating 30 min of sleep to sedentary time resulted in a statistically significant association with BMI (+0.61 kg/m^2, 95% CI [0.005, 1.22], $p = 0.048$). Reallocating 30 min of sleep to light PA resulted in no significant association with BMI (+0.10 kg/m^2, 95% CI [−0.52, 0.72], $p = 0.75$). Reallocating 30 min of sleep to MVPA resulted in no significant association with BMI (−0.22 kg/m^2, 95% CI [−2.17, 1.73], $p = 0.82$).

Reallocating 30 Min from Sedentary Time (Fig. 1)

Reallocating 30 min of sedentary time to sleep resulted in a statistically significant association with BMI (−0.61 kg/m^2, 95% CI [−1.22, −0.005], $p = 0.048$). Reallocating 30 min of sedentary time to light PA resulted in a statistically significant association with BMI (−0.51 kg/m^2, 95% CI [−0.88, −0.14], $p = 0.007$). Reallocating 30 min of sedentary time to MVPA resulted in no significant association with BMI (−0.83 kg/m^2, 95% CI [−2.67, 1.03], $p = 0.38$).

Reallocating 30 Min from Light PA (Fig. 1)

Reallocating 30 min of light PA to sleep resulted in no significant association with BMI (−0.10 kg/m^2, 95% CI [−0.72, 0.52], $p = 0.75$). Reallocating 30 min of light PA to sedentary time resulted in a statistically significant association with BMI (+0.51 kg/m^2, 95% CI [0.14, 0.88], $p = 0.007$). Reallocating 30 min from light PA to MVPA resulted in no significant association with BMI (−0.32 kg/m^2, 95% CI [−2.27, 1.63], $p = 0.75$).

Reallocating 30 Min from MVPA (Fig. 1)

Reallocating 30 min of MVPA to sleep resulted in no significant association with BMI (0.22 kg/m^2, 95% CI [−1.73, 2.17], $p = 0.82$). Reallocating 30 min of MVPA to sedentary time resulted in no significant association with BMI (+0.83 kg/m^2, 95% CI [−1.03, 2.69], $p = 0.38$). Reallocating 30 min of MVPA to light PA resulted in no significant association with BMI (0.32 kg/m^2, 95% CI [−1.63, 2.26], $p = 0.75$).

Table 1 Demographics

$N = 73$	Mean ± standard deviation or frequency (%)
Age	53 ± 13
Sex (% female)	75.7
Race (% white)	93.2
Education (% ≥ undergraduate degree)	74.3
Income (% ≥ $50,000/year)	74.3
Body mass index (kg/m^2)	27.0 ± 5.7
Normal (18–24.9 kg/m^2)	38.4
Overweight (25–29.9 kg/m^2)	37.0
Obese (≥ 30 kg/m^2)	24.7
Diagnosis	
Breast	29.7
Colorectal	33.8
Leukemia/lymphoma	9.5
Other	27.0
Stage	
0–2	62.2
3–4	29.7
Do not know	8.1
Time since diagnosis (months)	33.9 ± 26.4
Time since surgery (months) ($n = 66$)	31.2 ± 28.3
Time since chemotherapy (months) ($n = 54$)	24.8 ± 22.8
Time since radiation therapy (months) ($n = 38$)	30.5 ± 17.4
Time since other therapies (months) ($n = 12$)	16.3 ± 13.9

Discussion

The study sought to examine the effect of reallocating time between daily activities (i.e., MVPA, light PA, sedentary time, and sleep) on BMI in cancer survivors. Reallocating 30 min of sedentary time to sleep or light PA was associated with lower BMI, supporting that sleep, sedentary time, and light PA may significantly contribute to BMI.

To our knowledge, only one previous study has examined the effects of reallocating activity and sleep on BMI in cancer survivors (Boyle et al. [17]), and found that reallocating 30 min from sleep, sedentary time, and light PA to MVPA was associated with lower BMI [17]. These results differ from the current study which revealed no significant effect of reallocating time away from, or to MVPA on BMI. However, the study by Boyle et al. [17] utilized a waist-worn accelerometer to measure waking behaviors, potentially introducing measurement error when distinguishing between sedentary time and standing behaviors or misclassifying MVPA with light PA for ambulatory activities [19, 20]. It is also important to note that although the benefits of MVPA are well-established, there is a limit to how much MVPA an individual can realistically do in a 24-h period due to time restraints, physical abilities, etc. and the diminishing return of MVPA once PA guidelines are achieved [21, 22]. Additionally, higher sedentary time is positively associated with BMI, even when controlling for MVPA [23], which may explain why reallocating sedentary time resulted in significant associations with BMI while reallocating MVPA time did not in this active sample of cancer survivors. Further, the current study also provides some evidence for a potential positive effect of reallocating sedentary time to light PA on BMI. Previous literature supports the role of light PA in cancer survivor for physical function and decreasing cancer mortality, regardless of MVPA [24, 25]. Therefore, findings from this study suggest that for survivors who are achieving recommended amounts of MVPA (i.e., ≥ 30 min per day) similar to this sample of cancer survivors, decreasing

Table 2 Physical activity, sedentary time, and sleep profiles

	Mean ± standard deviation [range] or %
MVPA (min/day)	24.0 ± 18.9 [0–83.1]
Light PA (min/day)	291.9 ± 100.6
Sedentary time (min/day)	593.1 ± 108.3
Sleep period (min/day)	482.2 ± 57.6
> 30 min/day of MVPA	80.8%
> 7 h/night of sleep	90.4%

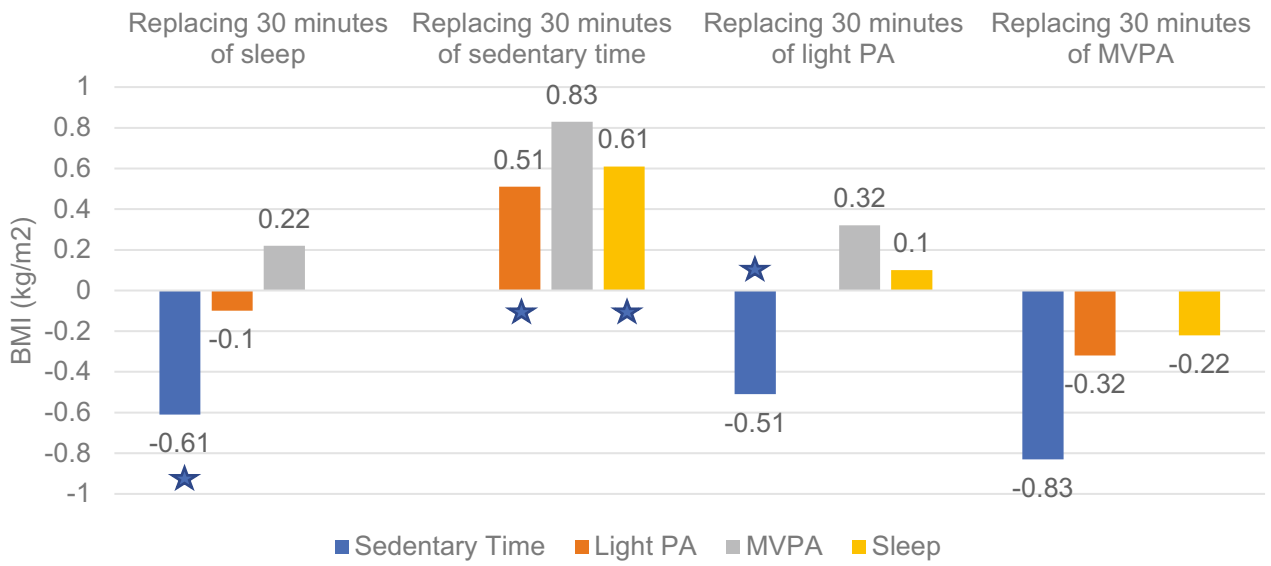

Fig. 1 Reallocating 30 min between sleep, sedentary time, light and moderate-vigorous physical activity, and the association with BMI. The star indicates statistical significance. BMI, body mass index; PA, physical activity; MVPA, moderate-vigorous physical activity

sedentary time by spending more time in light PA or sleeping may have a positive effect on BMI.

The current study adds to the literature by utilizing objective measures of sleep (in addition to PA and sedentary time), and the novel finding that reallocating time from sleep to sedentary time was associated with higher BMI. Inversely, reallocating time from sedentary time to sleep was associated with lower BMI (i.e., more time spent sedentary and less time sleeping was associated with higher BMI). These findings suggest that cancer survivors may benefit from spending less time sedentary by dedicating more time to sleep.

Strengths of this study include objectively measured PA, sedentary time, and sleep. To date, no reallocation studies in cancer survivors have utilized objective measures for all 24-h activities. Previous time reallocation studies have relied on subjective measures of PA and sleep, a measurement technique known to have poor reliability and validity, potential for recall bias, and floor effects due to questionnaires failing to capture spontaneous or light activities of daily living (i.e., chores, caregiving) [26, 27]. This study allowed for evaluating activities simultaneously rather than independently, providing more context for the effects on BMI of increasing or decreasing time in specific activities throughout the 24-h day (i.e., in order to increase time in one activity, time in another was decreased).

Limitations of this study include small sample size, limiting ability to examine additional activity characteristics (i.e., continuous bouts of MVPA and sedentary time, standing time) as well as other potentially significant socioeconomic covariates (i.e., education, working status). Of particular note, to allow for a full 24-h day analysis with the limited sample size, standing time was included within light PA, which could alter the reallocation results. Sample size also limited the ability for subgroup analyses (i.e., different BMI thresholds) and inclusion of additional covariates (i.e., socioeconomic position, work status, and sex). Additionally, the cancer survivors in this study were mostly female, white, and high income, limiting generalizability. The mix of self-report height and weight ($n = 35$, 48% of participants) and measured height and weight due to COVID-19 restrictions also poses a limitation, despite evidence that self-report and measured height and weight for BMI are often similar [28]. This is a limitation for this study as overweight or obese individual, which included 61.7% ($n = 45$) of the participants in this study, tend to underreport weight to a greater extent than those in a healthy BMI category, potentially leading to discrepancies in BMI reporting [28]. The statistical approach of isotemporal substitution may also be considered a limitation. However, Biddle and colleagues (2019) found that results from the isotemporal substitution model compared

to compositional data analysis were not significantly different, resulting in the same conclusions being drawn from both statistical models but easier interpretation from the isotemporal substitution model [29].

Future studies should aim to include a larger sample size to increase generalizability and allow for post-hoc analyses to examine those meeting MVPA and sleep guidelines versus those not currently meeting guidelines, compare those with a BMI > 25 kg/m^2 versus BMI < 25 kg/m^2, and allow for additional confounders including socioeconomic status, comorbidities, and age. Further, this study support the importance of differentiating between sedentary time and sleep, and the effect that these behaviors may have on important cancer-related outcomes [30]. Older adults are often less active as the day progresses, resulting in longer time spent sedentary immediately prior to bed [31]. Therefore, future studies should explore the role of sedentary time, specifically time spent prior to bedtime (i.e., watching TV, reading in bed), on BMI, as a reduction in sedentary time to increase sleep period may positively impact cancer survivors. Future studies that examine within-person change in time allocations on change in BMI are needed. A within-person analysis would allow for determining a causal effect of pre-determined time reallocation, furthering the importance of considering the interdependence of 24-h activity. In addition, more detailed measures of weight status including waist circumference, lean mass, body fat percentage, and bone mass should be utilized as these all have important implications in cancer survivors [17, 32].

In conclusion, this study found that replacing 30 min of sedentary time with light PA or sleep was associated with lower BMI, reinforcing the importance of reducing sedentary time and encouraging sufficient sleep for cancer survivors [4, 33]. To date, findings related to the importance of reducing sedentary time and increasing light PA for reducing BMI have come from prospective cohort studies [24, 34]. This study builds on these findings, and suggest that future interventions aimed at reducing sedentary time by replacing it with sleep or light PA may be advantageous for cancer survivors to help them achieve a healthy BMI [35].

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Declarations

Ethics Approval The study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Institutional Review Board at Colorado State University (IRB#19-8914H, Initial Approval: 9/18/2019).

Consent to Participate Informed consent was obtained from all individual participants included in the study.

Consent for Animal Welfare Not applicable.

Competing Interests The authors declare no competing interests.

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