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Objective monitoring of physical activity after a cancer diagnosis: challenges and opportunities for enhancing cancer control

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Abstract

Background—Because physical activity (PA) provides multiple medical and psychosocial benefits after a cancer diagnosis, greater integration of objective activity monitoring into research and clinical practice is warranted.

Objectives—To review randomized PA trials in cancer survivors after diagnosis using an accelerometer or pedometer and make recommendations for integrating objective monitoring into research and practice.

Major Findings—Ten published PA and post-cancer diagnosis randomized trials have used pedometers (n=3), accelerometers (n=3), or both (n=4). Pedometers were primarily used to motivate PA adherence with several studies also using unblinded pedometers to assess the intervention effect on PA adherence. Accelerometers were primarily used to assess PA adherence after a PA intervention with one study using accelerometers to assess PA increase as a benefit of a non-PA intervention. One study used accelerometers to document sufficient ground forces for improving bone density in cancer survivors. Across studies, the reported objective monitoring outcome varied and was not always consistent with the stated intervention goal.

Conclusions—PA and post-cancer diagnosis randomized trials have used objective monitoring primarily for motivation and/or adherence assessment. Investigators and practitioners are encouraged to expand the use of objective monitoring to also include understanding mechanisms of PA benefits and assess non-PA treatment modality effects. Future clinical and research protocols should consider the 1) outcome to be measured and reported, 2) need (or not) for blinding of the instrument outputs to participants, 3) appropriateness of activity intensity cutpoints for interpreting accelerometer data, and 4) logistical issues relevant to cancer survivors after diagnosis.

Keywords

behavior; exercise; measurement; oncology; survivorship

Introduction

Physical activity (PA) improves the health and well-being of patients after a cancer diagnosis and may reduce the risk of colorectal and breast cancer recurrence and mortality.^{1–4} Given that over 11 million individuals are living with cancer in the United States (US) alone,⁵ enhancing clinical practice and research in this large population with

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optimal PA measurement is a worthy objective. Physical activity can be measured by self-report, direct observation, or objective monitoring (e.g., accelerometer or pedometer).⁶ Indirect measures of PA such as doubly-labeled water (i.e., energy expenditure) and maximal exercise testing (i.e., cardiorespiratory fitness)^{6, 7} may be costly, uncomfortable, and less applicable to clinical practice and research in the field.⁸ Self-report methods such as questionnaires about habitual or recent activity behaviors are limited by over- or under-reporting by participants while direct observation may not be feasible for larger, population-based studies and home-based interventions.⁶ Objective monitoring, however, can be less expensive (depending on the equipment used and clinical charges for testing) and is a valid tool for assessing PA in the field and motivating PA adherence.^{9–12} Their dual purpose and potential for objectivity support accelerometers and pedometers as particularly useful tools for optimizing the health benefits of PA after a cancer diagnosis.

Only a limited number of post-cancer diagnosis randomized trials report using objective PA monitoring^{13–22} but these trials represent an increase in objective monitoring use and provide an important foundation for research and practice. Although randomized trials of supervised exercise have documented adherence by observation (i.e., attendance),^{23, 24} these studies have not assessed PA outside of the supervised sessions with objective monitoring. Because supervised exercise programs may not be feasible for larger populations due to cost, equipment, and staff requirements, home-based interventions are also being tested. To date, only a limited number of studies reporting benefits of home-based programs in cancer survivors have documented adherence with objective monitoring. Therefore, objective monitoring of PA is an important but underutilized tool for advancing our understanding of 1) the optimal PA amount, intensity, duration, and frequency for realizing valued health outcomes, 2) biopsychosocial mechanisms linking PA with these outcomes, and 3) the structure and delivery of effective interventions designed to enhance PA adherence in cancer survivors after diagnosis.

Multiple PA benefits after a cancer diagnosis include, but are not limited to, improved muscle strength, fitness, quality of life, and self-esteem, as well as, reductions in fatigue, anxiety, and cancer mortality risk.^{1–4} Because of the recognized importance of PA in cancer survivors and the need to integrate objective monitoring into future studies and practice, the primary purpose of this report is to review published randomized PA trials in cancer survivors after diagnosis using an accelerometer or pedometer for adherence motivation (i.e., increasing the amount of PA performed), adherence assessment (i.e., determining the amount of PA performed), documentation of PA as a benefit of non-PA intervention, and/or examining mechanisms underlying PA benefits. The results of the review will be discussed in the context of ongoing research trials, challenges experienced when using objective monitoring, and recommendations for integrating objective monitoring into future research and clinical practice.

Methods

Using PubMed, the following four searches were performed in July 2010: 1) [accelerometer OR pedometer OR actigraph] AND cancer; 2) steps AND cancer AND [exercise OR physical activity]; 3) objectively measured AND cancer AND [exercise OR physical activity]; 4) related articles for Rogers, et al²² AND [accelerometer OR pedometer OR actigraph]. The abstracts for each search were reviewed to determine if the study was randomized, used an accelerometer or pedometer for PA measurement (as opposed to sleep or sleep/wake cycle assessment), and specifically enrolled cancer survivors (i.e., history of cancer regardless of time since diagnosis). The references cited in each of the identified randomized trials were reviewed for potential trials missed during the original search. Lastly, ongoing randomized trials were identified by using the following three search

strategies on the ClinicalTrials.gov and the Controlled-trials.com websites (United States and United Kingdom, respectively): 1) cancer AND accelerometer, 2) cancer AND pedometer, and 3) cancer AND actigraph.

Results

Ten randomized trials in cancer survivors after diagnosis reported use of an accelerometer and/or pedometer (Tables 1 and 2).^{13–22} For five^{13–15, 22, 25} of the trials (Table 1), the primary study purpose was to determine the effect of a PA behavior change intervention on PA behavior, with the remaining five^{16–18, 20, 21} (Table 2) examining a non-PA intervention (i.e., neuromuscular electrical stimulation²⁰) effects on PA levels or a PA intervention effects on health outcomes (e.g., body composition,^{17, 18} quality of life,^{18, 21} fatigue,²¹ and physical performance¹⁶). Seven trials enrolled breast cancer survivors,^{13–18, 22} one enrolled lung cancer survivors,²⁰ and two enrolled both breast and prostate cancer survivors.^{19, 21} Only two studies enrolled patients on chemotherapy or radiation therapy^{18, 21} with earlier stage and less ill individuals enrolled in all trials. All interventions were PA-related with the exception of a single study testing the benefits of neuromuscular electrical stimulation in lung cancer survivors.²⁰ All nine of the PA-related trials^{13–18, 21, 22, 26} included home-based exercise exclusively or were delivered in combination with supervised sessions carried out in designated study facilities (e.g., clinical setting, exercise laboratory, local health club). The particular brand of pedometer used was not specified by three trials^{14, 17, 21} with the Digiwalker (Yamax, Tokyo, Japan) used by three^{13, 15, 16} and the Accusplit Eagle (Accusplit Inc, San Jose, CA, US) by one²⁶. The specific brand of accelerometer was not specified by one trial¹⁸ with the remaining brands used in one trial each: Caltrac (Muscle Dynamics, Torrance, CA, US),¹³ RT3 Triaxial Research Tracker (Stayhealthy, Inc., Monrovia, CA, US),¹⁹ MTI Actigraph (ActiGraph, Pensacola, FL, US),¹⁴ GT1M Actigraph (ActiGraph, Pensacola, FL, US),²² triaxial accelerometer (Newtest Oy, Oulu, Finland),¹⁶ and ActivPal™ (PAL Technologies Ltd, Glasgow, UK).²⁰

Adherence motivation: Increasing the amount of PA performed

Objective monitoring can be used to motivate individuals to adhere to recommended amounts of PA. For example, pedometers can provide immediate feedback on steps taken per day to motivate individuals to work toward the goal of 10,000 steps per day. Six^{13–15, 17, 21, 26} of the ten identified trials provided pedometers as part of their behavior support materials. One trial used the pedometer to determine daily steps at baseline and mid-intervention while also allowing both the intervention and control group to keep the pedometers for the duration of the intervention.¹⁶ Because it has been demonstrated that providing unblinded (i.e., unsealed) pedometers along with daily recording of steps may increase PA without providing other behavioral change support,²⁷ investigators acknowledged the possibility of unintentional motivation of PA in the control group.¹⁶ Interestingly, pedometers are a more effective motivational tool when the intervention goal is a specified number of daily steps²⁸ but step counts were a specified intervention target for only two of the six trials using pedometers for motivation.^{16, 21} Although exact details were not reported, pedometers may still have been used in the remaining studies as motivational tools to encourage walking in spite of the inconsistency with stated intervention goals focused on intensity, time, and frequency. Given that current accelerometers typically do not directly output data on a display screen that is readily accessible to participants, no PA and cancer trial has reported using accelerometers for motivation purposes.

Adherence assessment: Determining the amount of PA performed

Pedometers and accelerometers can be used to determine if the PA goal recommended clinically or in a research trial has been achieved. Because supervised exercise interventions

can use attendance records to document adherence, objective monitoring is especially important for home-based interventions. Although four trials assessed adherence with pedometers (reported in steps per day),^{15–17, 21} no trial did so exclusive of their use to motivate change in PA. Importantly, no trial has blinded participants to pedometer results during assessment, that is, all participants have been asked to read and record daily pedometer results for return to study personnel, methodology that may increase PA without providing other behavioral support.²⁷ Statistically significant between group differences for daily step counts for the intervention when compared with the control group were reported in two of the four trials (i.e., +1681 and +5857 steps per day).^{17, 21} These two trials with statistically significant results either specified a target of 10,000 steps per day²¹ or generally encouraged walking as the exercise type.¹⁷ The trial focused on bone density that prescribed a specific number of jumps during step aerobics also demonstrated a daily increase of 822 steps mid-intervention in the intervention group but this was not statistically significant.¹⁶ The lack of increase in steps per day noted by Vallance, et al¹⁵ (i.e., mean change from baseline to post-intervention for the written materials only, the pedometer with step calendar only, and written materials plus pedometer groups were –191, –55, and –210 steps per day, respectively) may have been due to a replacement of light/casual walking with more intense walking rather than an increase in total steps (i.e., the intervention focused on minutes of activity at $\geq$ moderate intensity rather than a specific total steps per day count).

Accelerometers have been used most frequently for assessing PA adherence after a cancer diagnosis.^{13, 14, 18, 19, 29} In four of these five trials, the accelerometer assessed the effect of a behavior change intervention on adherence (i.e., change in PA behavior).^{13, 14, 19, 29} The primary outcome for the fifth trial¹⁸ was related to PA benefits (e.g., quality of life, body composition) rather than adherence, allowing the accelerometer to be used to demonstrate that the lack of intervention effect on health outcomes (e.g., quality of life) may have been due to the fact that the intervention did not increase PA behavior.¹⁸ The accelerometer outcomes have varied and included the following: caloric expenditure,^{13, 18} PA minutes,^{18, 22, 29} PA counts,^{14, 22} and steps/day.^{14, 20, 22} Also noteworthy, is the fact that several trials have reported greater increases in self-reported PA without comparable increases in objectively monitored PA^{13, 15, 19}; only one study has reported significant increases in both self-reported and accelerometer-monitored PA outcomes.¹⁴

Physical activity as a benefit of a non-PA intervention

One randomized trial has used accelerometer outputs related to PA adherence to assess the benefits of a non-PA intervention after cancer diagnosis. Specifically, Maddocks, et al²⁰ found a nonsignificant between group difference for lung cancer survivors randomized to receive neuromuscular electrical stimulation of the quadriceps muscle when compared with a control group (i.e., mean change in daily steps for the intervention and control groups were +136 and –633, respectively for a between group difference of +768, $P=.48$).

Mechanisms of PA benefits

Great interest exists within the broader scientific field of PA and cancer in determining PA effects on biomarkers of health and cancer risk (e.g., sex steroid hormone effects, etc).³⁰ However, only one trial identified in the process of this review used accelerometers to examine mechanisms underlying health benefits attributed to PA.¹⁶ Specifically, investigators of this feasibility study used accelerometers to determine whether or not a structured exercise program resulted in adequate ground forces for improving bone density; if such forces were documented, the investigators planned to test the program effect on bone density in a larger trial.¹⁶

No published randomized trial was identified by this review as reporting the use of an accelerometer or pedometer to assess whether PA frequency, duration, type, and intensity mediates the known health and psychosocial benefits of PA (e.g., fatigue, quality of life, etc).⁴ Although Courneya, et al³¹ have reported that improved fitness is associated with the effect of an exercise intervention on quality of life outcomes, PA characteristics such as intensity³² and duration of PA bouts³³ may influence the scope and magnitude of benefits that can be achieved. Further research focused on the optimal PA frequency, duration, and intensity that should be recommended to cancer survivors to realize valued health and psychosocial outcomes is needed.

Registered trials: ClinicalTrials.gov and controlled-trials.com websites

The ClinicalTrials.gov website (<http://clinicaltrials.gov/>) is a registry of federally and privately funded clinical trials. This website is administrated by the US National Institutes of Health and clinical trials must be registered before initiating participant recruitment. The Current Controlled Trials website (www.controlled-trials.com) is a voluntary international registry created by Current Controlled Trials Ltd in response to the growing interest in prospectively registering randomized trials. Its *metaRegister* option allows searching of multiple United Kingdom registries, ClinicalTrials.gov, and International Standard Randomised Controlled Trial Number (ISRCTN) Register (international). The ClinicalTrials.gov website was searched separately to identify the occasional trial that was found on the ClinicalTrials.gov that was not found with the *metaRegister* search. Also, two trials identified by the published design paper (ISRCTN43801571) or personal knowledge of the study (NCT00929617) rather than the search were included. Non-randomized trials and trials objectively measuring sleep rather than PA were excluded. A summary of the ongoing trials (i.e., not yet completed) identified by these searches is limited by the fact that full protocol details are not available, the specific accelerometer or pedometer device being used is not provided, and study status may not be routinely updated. Nevertheless, a summary of registered, ongoing trials as of July 14, 2010 provided in Tables 3 and 4 provides registration identification numbers for the increasing number of trials using objective monitoring. The pedometer will be used in 15 trials for the purpose of motivating an increase in PA (n=11), assessing adherence (n=1), or both (n=3). Eight of these 15 trials will occur in breast cancer survivors. The remaining studies plan to enroll head and neck (n=1), prostate (n=1), endometrial (n=1), colon (n=1), or mixed cancer types (n=3). Accelerometers will be used in 13 registered trials to assess adherence and document home exercise (n=8) or assess benefits of a non-PA intervention (n=5). These trials include breast (n=6), lung (n=2), colon (n=1), cervical (n=1), and mixed cancer types (n=3). The non-PA interventions ranged from pharmacologic (e.g., amino acid supplementation and/or testosterone for cachexia) to alternative medicine (e.g., acupuncture).

Southern Illinois University School of Medicine (SIUSOM) exercise and cancer laboratory

The SIUSOM exercise and cancer laboratory is using accelerometers (i.e., GT1M and GT3X Actigraph, Pensacola, FL, US) in two ongoing randomized controlled PA and cancer trials (NCT00929617 and NCT01147367) to assess PA adherence and potential mechanisms of intervention effects, including mechanisms of PA behavior change in cancer survivors using social cognitive theory.³⁴ Prior randomized trials evaluating similar mechanisms of PA adherence have been based on self-report PA^{35–38} with only two using pedometer³⁹ or accelerometer.⁴⁰ As an example of the findings that can be informed by objective monitoring, improvement in accelerometer-determined minutes of $\geq$ moderate intensity activity 3 months after completing a PA behavior change intervention for breast cancer survivors was significantly mediated by self-efficacy and perceived barriers interference.⁴⁰

Also related, objective measurement of PA does not differentiate between leisure (i.e., volitional) and other types of PA (e.g., occupational), therefore, using both self-report and objective monitoring may improve our understanding of activity behavior mechanisms. Pinto, et al³⁹ reported that predictors of pedometer-determined steps/day differed from that of self-report in a prospective study of breast cancer survivors (i.e., self-efficacy predicted both but baseline self-reported PA predicted steps/day only). Consistent with this, we have found that PA correlates differ based on PA type using the International PA Questionnaire among 191 breast cancer survivors in a population-based survey study (sampling methods previously published⁴¹). Specifically, total occupational activity was significantly associated with self-efficacy only where as leisure activity was associated with multiple social cognitive theory constructs such as self-efficacy, PA enjoyment, and perceived barriers interference (Rogers, unpublished data). This suggests that future trials examining the theoretical mediators of intervention effects on PA adherence should consider using both total activity measured objectively and leisure activity by self-report.

To examine the potential interrelationships among the effects of our PA behavior change intervention on self-report and accelerometer adherence data, a post hoc analysis of change in total minutes of $\geq$ moderate intensity activity by accelerometer, self-report leisure activity by the Godin Leisure Time PA Questionnaire,^{42–44} and non-leisure activity (i.e., calculated by subtracting the total self-report minutes from the total accelerometer minutes) is provided in Table 5. The mean of the difference scores for post-intervention minus baseline indicated significantly greater improvements in total activity by accelerometer for the intervention versus usual care group. The greater improvement in self-report leisure activity in the intervention group was not significant, possibly due to large standard deviations reducing study power.²² However, another possible explanation is the replacement of previously inaccurately reported minutes with a more accurate reporting by participants who learned to better judge their activity as part of the intervention. This warrants examination in future trials. Interestingly, the magnitude of reduction in the number of minutes of non-leisure activity was not significant but the pattern suggests that the intervention participants may have been better able to maintain their non-leisure activity behaviors as their leisure activity increased. Future studies should examine whether this pattern truly exists and, if so, whether the maintenance of non-leisure PA explains, at least in part, the improved quality of life and physical functioning (e.g., improved ability to perform activities of daily living) that occurs as a result of regular PA participation.

Challenges when using pedometers and accelerometers: practical lessons learned

Breast cancer survivors may experience weight gain during treatment⁴⁵ with endometrial cancer survivors suffering from a higher prevalence of obesity⁴⁶ interfering with the horizontal pedometer position required to accurately record steps. Also, if not clearly instructed, participants may place pedometers in places that are not recommended (e.g., on their shoes, on the neckline of their shirt). If pedometers are not sealed (i.e., the participant is not blinded to the results) but is not asked to record their results, the pedometer does not appear to increase activity.⁴⁷ However, if the participants are asked to record the daily step count in a diary, then reactivity may occur (e.g., mean daily steps for sealed pedometers versus unsealed with daily recording of steps were 8832 and 9635, respectively; $P=.002$).²⁷ Given that the change in daily steps based on pedometer in the intervention group of the randomized trials reviewed in this paper have been -210 ,¹⁵ $+822$,¹⁶ $+1153$,¹⁴ and $+1621$,¹⁷ reactivity may be as great as that noted in response to some interventions. Lastly, waist worn pedometers can typically only assess steps/day and activities producing vertical movements at the hip and most pedometers have limited ability to assess intensity, sedentary activity time, or duration of PA bouts. However, newer pedometers may provide time in moderate intensity PA (e.g., New-Lifestyles NL-1000, Lees Summit, MO).

We have learned that participants may fail to wear their accelerometer due to forgetfulness, special events (e.g., weddings, church services), and feeling less attractive when wearing the device. Pedometers worn with a belt clip may be more acceptable than the accelerometer usually worn with a Velcro belt. The potential for lack of compliance and rare malfunction of the device requires immediate downloading and review of accelerometer data to confirm that the required number of valid days of monitoring has been achieved. This allows time to repeat monitoring if necessary. Because an individual's PA varies from day to day, accelerometers and pedometers require an adequate number of monitored days to accurately predict average, daily activity level. For example, 3 to 7 days may be required when using pedometers or accelerometers.^{48, 49} Criteria for defining valid days is not applicable with pedometers because output does not include time of monitoring. However, accelerometers must be worn for a specified minimal amount of time for a valid day of measurement (e.g., 10 hours or 60% of waking hours).⁴⁹ The definition of "valid day" and number of required days is set before initiating the study.

Logistical issues regarding use of the accelerometer have been learned in our prior studies. Setting a stop date on the accelerometer prevents the downloading of excess data when there is a delay in returning the accelerometer or sufficient movement occurs during transport to cause the analysis software to erroneously identify a "valid day" of wear by the individual. Study staff using accelerometers should insure that adequate technical support is available to assist with changes in models and software that occur over time when using accelerometers for a multiple year project. Also related, staff administering and analyzing accelerometer data for research or clinical purposes should be experienced in using the current software for preparing, downloading, and analyzing the data for valid days and amount of PA. Accelerometers are primarily used in research rather than clinical settings because of this required level of expertise. However, investing the time to gain this expertise allows acquisition of more detailed information about time spent in a variety of PA intensities, including time in sedentary behavior. This information may be more useful in populations who do little to no moderate intensity activity.

Another logistical concern relates to the size of the pouch and Velcro belt often used to wear accelerometers. If the belt or pouch is too large, the accelerometer may "flop around" causing inadvertent activity counts. Although we have considered using belt clips for accelerometers when a belt and pouch is less acceptable, we have chosen to pin the pouch to the waist band with a safety pin rather than use the clip because the pouch is less apt to fall off and the pouch provides greater protection for the accelerometer. Safety pins can also be used to pin excess belt length.

With regard to data quality when assessing PA adherence in response to an intervention (research or clinical), it is important to clearly instruct participants not to change their usual activity pattern during the monitoring week. Although accelerometer data is not typically viewable by the participants, they are aware that the intervention goal is to increase PA and the accelerometer is measuring this goal. Therefore, individuals may believe that they are supposed to increase their PA if not instructed otherwise. Fortunately, reactivity to blinded (or sealed) objective monitoring is not a significant concern.²⁷ Also, the monitoring time frame is key. If an unusual weather event occurs that interferes with the participant's "usual activities" (e.g., severe winter weather), monitoring may have to be postponed. Although not unique to our experience, accelerometers cannot assess physical activities such as stationary bicycling, etc. Therefore, we provide an activity record sheet along with the accelerometer to insure that such activities can be accounted for in the analysis.

Although not a randomized trial, the SIUSOM laboratory has used accelerometers to collect data for an observational study enrolling head and neck cancer survivors receiving cancer

treatment (data analysis in progress). Due to the rigors of therapy and the frequent psychosocial challenges facing these individuals, we have learned the importance of considering accelerometer cutpoints. The accelerometer calculates activity “counts” based on the amount and intensity of movement. These activity “counts” can then be divided into categories (or “cutpoints”) representing levels of activity intensity based on prediction equations (e.g., inactive [0-499 counts/min], light [500-1951 counts/min], moderate [1952-5724 counts/min], and vigorous [5725+ counts/min]).^{50, 51} Cutpoints may be pre-set by the manufacturer or analysis software may allow customizing these cutpoints based on the needs of the researcher or practitioner. The less intense categories (e.g., sedentary, inactive, and light) are often combined since $\geq$ moderate intensity activity is usually the intensity of interest. Although healthier, more active populations are more apt to engage in $\geq$ moderate intensity activity, cutpoints for clinical populations limited by medical conditions that cannot engage in $\geq$ moderate intensity exercise should differentiate time spent in the less intense and sedentary categories. For example, very ill cancer patients receiving toxic treatments may not engage in $\geq$ moderate intensity activity but decreasing sedentary time and increasing light activity may be a worthy clinical goal. If “inactive” and “light” activities are combined, then accelerometer results may suggest that $\geq$ moderate intensity activity did not change while failing to detect useful increases in light activity.

Cancer type can also influence budget planning. We have found that the proportion of accelerometers lost during a study varies among the different cancer survivors tested in our laboratory. Specifically, approximately half of the accelerometers assigned to a sample of head and neck cancer survivors were not returned compared with a $<10\%$ loss in our samples of breast and endometrial cancer survivors. We theorize that the psychosocial challenges faced by head and neck cancer survivors explain this difference (e.g., higher rates of depression and substance abuse⁵²). Because the replacement cost for a lost accelerometer is approximately $\geq \$400$ (US) (depending on the brand/model), planning ahead for this possibility is recommended. For example, providing participants with pre-paid mailing materials for returning the equipment if they choose to drop out of the study may facilitate accelerometer return while minimizing inconvenience and embarrassment. Depending on institutional review board approval, research participants could be given incentives for equipment return. Clinical practices could require monetary deposits which are refunded once the equipment is returned. Lastly, if a high loss rate is expected, less expensive equipment (e.g., pedometer) may be appropriate. Although lower cost accelerometers marketed to consumers (rather than research scientists) exist [approximate cost of \$80 to \$200 (US)], these devices often require purchasing a subscription to access on-line analysis and limit customization of cutpoints and outcomes provided in the output.

Opportunities for pedometers and accelerometers

The advantages and challenges when using pedometers compared with accelerometers have been provided in Table 6. The primary advantages offered by pedometers are their motivational potential (i.e., they provide real time accessible feedback), low cost [they typically range from \$3 to \$60 (US)], and ease of use (data readily recorded, managed and interpreted). In comparison, accelerometer data will allow the researcher or practitioner to infer time spent in various activity intensities including time spent in sedentary behaviors. Accelerometer data can also be used to examine PA bout durations at varying intensities using improved mathematical models for describing activity patterns.^{8, 53} The ability to do this is enhanced when multisensory accelerometers are used or accelerometer data integrates other measures such as heart rate, skin temperature, or Global Positioning System input.^{8, 54} However, such enhancements may result in additional cost and/or participant burden^{8, 54}, have not been used in randomized PA and cancer trials to date, and may limit their usefulness in clinical practice.

The future of motivating with accelerometers has been demonstrated by Koizumi, et al.¹² Although not focused on cancer survivors specifically, their intervention allowed participants to download their accelerometer results to review for motivational purposes. This same concept supports future studies of biometric calorie management systems (e.g., bodybuggR) that combine accelerometer data with other body measurements (e.g., skin temperature, etc)(http://www.bodybugg.com/science_behind_bodybugg.php) to provide caloric expenditure information that can be downloaded by the individual. Also, the increasing availability of devices such as the Nike + iPod sport kit with pedometer provides an excellent motivational opportunity for cancer survivors that should not be missed by researchers and practitioners. Moreover, the built-in accelerometer in newer communication devices (e.g., iPhone) has lead to Apps which allow individuals to monitor their amount of PA as well as partner with and compete against other App users. Although this is an attractive approach, concerns about missing or erroneous data resulting from not wearing the device attached to the body (e.g., in the purse), acceptability (e.g., novel technology may not be as acceptable to older patients), and long-term use once the novelty effect “wears off” exist.

Practitioners wishing to motivate PA with pedometers should provide the patient with recommendations expressed in steps/day. A diary should be given along with the pedometer to allow patients to monitor if they are reaching their step goal on a daily basis. Practitioners should provide clear instructions as to how to wear the pedometer and check for accuracy (e.g., walk 20 steps then check the pedometer to make sure 20 steps were recorded). On return visits, practitioners should review the pedometer diary and query the patient about whether they wore the pedometer at the waist as instructed. If practitioners wish to determine if a current treatment plan is improving free-living activity, a pedometer or accelerometer could be used at baseline and follow-up. To minimize reactivity, pedometers should be sealed shut and returned one week later for reading by clinic staff (i.e., no diary is kept). Accelerometers can provide more detailed information about sedentary and light activity. Also, the increased risk of breast cancer recurrence and mortality with obesity⁵⁵ and the high prevalence of obesity among endometrial cancer survivors⁴⁶ suggest a role for the energy expenditure output from accelerometers in facilitating weight management counseling. Unfortunately, accelerometers are not as easy to use as pedometers and clinic staff should be aware of the challenges of administration and analysis described earlier. Patients should be given clear instructions (i.e., written and verbal) explaining how to wear the device along with a record sheet for recording physical activities not detectable with the accelerometer (e.g., stationary bicycle) and when the accelerometer was not worn. Staff should be experienced with using the accelerometer software and related analysis. Whether using pedometers or accelerometers, practitioners can minimize the cost of lost equipment by using the less expensive pedometers or possibly asking for a monetary deposit that is reimbursed once the more expensive accelerometer is returned. Lastly, practitioners should use their clinical judgment because objective monitoring protocols may be influenced by factors such as obesity, inability to ambulate, poor medical condition, and primarily sedentary lifestyles.

Discussion

Although over 80 published randomized PA and post-cancer diagnosis trials exist,⁴ only ten trials (PA or non-PA related interventions) were identified for this review that have reported using accelerometers or pedometers in cancer survivors.^{13–22} At this time, pedometers have been most often used for motivation and assessment of adherence and accelerometers have been used primarily for assessment. Accelerometers and pedometers have been primarily used in studies focused on behavior change and intervention benefits with little attention to using them to study mechanisms underlying PA benefits. Also, the use of accelerometers to

assess the impact of treatment modalities other than PA interventions remains an underutilized opportunity. Fortunately, the use of accelerometers and pedometers in PA and post-cancer diagnosis randomized trials is on the rise as demonstrated by the 25 registered, ongoing randomized trials that are using objective monitoring.

With regard to motivation, pedometers are better able to increase exercise if individuals are given exercise goals in terms of specific number of steps per day (e.g., 10,000 steps per day) rather than daily minutes of $\geq$ moderate intensity activity. Therefore, it is concerning that pedometers are sometimes used for motivation when the intervention target is not expressed in steps per day. With regard to adherence assessment after an intervention, accuracy may be limited by the lack of consistency noted in the current published literature between the outcome reported and the primary goal of the intervention (e.g., outcome is activity counts when minutes per week is the intervention goal). Lastly, the use of an unsealed pedometer along with diary of daily steps as both a motivator and PA assessment may increase reactivity (i.e., unintentional increase in activity during the monitoring period; magnitude may be similar to that caused by interventions increasing PA by < 1000 steps per day).²⁷ Therefore, researchers and practitioners should choose the monitoring method most consistent with the intervention goal and/or study aims.

With regard to the future use of objective monitoring in PA and post-cancer diagnosis research and clinical practice, to date such monitoring has primarily occurred in trials enrolling breast cancer survivors with other cancer types remaining understudied. Because each cancer type results in unique PA barriers and challenges,⁵⁶ procedures for objective monitoring use may not be generalizable to all cancer types (e.g., individuals requiring limb amputation for bone cancer may not be able to perform weight bearing activity limiting objective monitoring usefulness). Also, cutpoints should be carefully chosen when using accelerometers in more sedentary survivors (e.g., head and neck cancer, currently receiving toxic cancer therapy, end stage survivors, etc). Furthermore, accelerometer calibration (i.e., determining activity count cutpoints for estimating energy expenditure based on PA intensity⁵⁷) has not been reported in cancer survivors. Given that accelerometer cutpoints for intensity classification may vary in chronic disease populations⁵⁸ and prior calibration studies have reported a variety of possible predication equations and cutpoints,⁵⁷ calibration studies in cancer survivors with differing cancer types, medical status, and ages are needed to more accurately classify PA intensities.

Importantly, possibilities exist for expanding the use of accelerometers in cancer survivors after diagnosis. For example, accelerometers have not been used for motivation but the motivational effect of biometric calorie management systems warrants further study. Also, using accelerometers to assess mechanisms of PA benefits based on intensity, duration, frequency, and/or ground forces remains underutilized perhaps because the field is early and several studies are ongoing. Lastly, objective monitoring should be combined with self-report data to increase our understanding of the impact of programs increasing leisure activity on total activity patterns and mechanisms of PA behavior change.

The use of accelerometers and pedometers in PA and post-cancer diagnosis research trials and clinical practice is expected to increase. This trend should be encouraged with the caveat that investigators and practitioners carefully choose the most appropriate and feasible objective monitoring strategy and outcome by considering the following questions: 1) What is the outcome of interest based on the intervention goal (e.g., steps versus minutes)? 2) What is the primary objective of the research trial or clinical treatment plan (e.g., PA adherence, mechanisms of health benefits, psychosocial outcomes, other)? 3) What is the purpose of the objective monitoring (e.g., motivation, adherence assessment)? 4) What cutpoints are appropriate based on the medical condition, age, and prevalence of sedentary

behavior? 5) Is blinding the participant to the monitoring results feasible and indicated? 6) What adjustments need to be made based on cost, participant burden, issues specific to the cancer type, etc.? Although it is not feasible to include all possible factors influencing the objective monitoring strategy in a single flow chart, Figure 1 can also be used to assist researchers and clinical practitioners in choosing an appropriate objective monitoring strategy. Careful attention to the “when, how, and which outcome” for pedometers and accelerometers will advance our understanding of the role of physical activity after a cancer diagnosis and assist practitioners and investigators in their efforts to improve the health and well-being of cancer survivors.

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Figure 1.
Choosing an appropriate objective monitoring strategy for research and clinical practice

Table 1

Randomized physical activity behavior change trials reporting the use of a pedometer or accelerometer

Lead investigator (trial name)	Primary study outcome	Sample	Intervention location, length, and goal	Behavioral counseling support	Accelerometer purpose (outcome reported)	Pedometer purpose	Results relevant to objective monitoring
Pinto (Moving Forward) ^{13, 39}	Physical activity behavior	86 breast cancer survivors; Stage 0-II; off adjuvant treatment; sedentary	Home-based; 12 weeks; 30 minutes, 5 days/ week; moderate intensity	One face-to-face counseling session followed by telephone counseling, print materials, periodic feedback sheets, and pedometer	Assessed adherence (caloric expenditure)	Motivation	Significant intervention effect on self-report but not accelerometer physical activity
Demark-Wahnefried (Fresh Start) ^{19, 25, 26, 37}	Physical activity behavior	543 breast and prostate cancer survivors; in situ, localized, or regional; <9 months since diagnosis; exercising <150 minutes/week	Home-based; 10 months; ≥150 weekly minutes; moderate intensity	Mail delivered print materials and pedometer; diet and physical activity counseling	Assessed adherence in a subsample of 115 participants (minutes)	Motivation	Significant intervention effect on self-report physical activity for original sample (n=573) but not on self-report or accelerometer in subsample (n=115). Change in self- report activity was greater compared to accelerometer
Mathews (Breast Cancer Walking Study) ¹⁴	Physical activity behavior	36 breast cancer survivors; Stage I-III; off adjuvant treatment; exercising <150 minutes/week	Home-based; 12 weeks; 30-40 minutes, 5 days/ week, walking	One face-to-face counseling session followed by telephone counseling; pedometer included	Assessed adherence (subsample = 23; steps and activity counts)	Motivation	Significant intervention effects on self-report walking and accelerometer counts and steps.
Rogers (BEAT) ^{22,29}	Physical activity behavior	41 breast cancer survivors; Stage I-IIIa; on hormonal therapy	Supervised and home-based; 3 months; ≥ 150 weekly minutes, moderate intensity	6 group and 3 individual counseling sessions; counseling with supervised sessions	Assess adherence (minutes, steps, activity counts)	N/A*	Significant intervention effect on accelerometer counts and minutes but not steps. Greater increase in self-report minutes but not statistically significant due to large standard deviations in self- report values.
Vallance (ACTION) ^{15, 36, 59}	Physical activity behavior	377 breast cancer survivors; Stage I-IIIa; off chemotherapy or radiation	Home-based; 12 weeks; 30 minutes, 5 days a week, ≥moderate intensity	Written materials and pedometer	N/A*	Motivation and adherence	Significant intervention effect on self-report physical activity and walking but no intervention effect on daily steps

* N/A = not applicable since device not reported as being used in the trial.

Table 2

Randomized trials of physical activity or non-physical activity intervention benefits reporting the use of a pedometer or accelerometer

Lead investigator (trial name)	Primary study outcome	Sample	Intervention location, length, and goal	Behavioral counseling support	Accelerometer purpose (outcome reported)	Pedometer purpose	Results relevant to objective monitoring
Demark-Wahnefried (STRENGTH) ¹⁸	Feasibility; physical activity benefits	90 breast cancer survivors; Stage I-IIIa; on chemotherapy; no exclusion based on physical activity behavior	Home-based; 6 months; aerobic ≥30 minutes, ≥3 days/week & strength training daily	Telephone counseling with print materials	Assessed adherence (caloric expenditure)	N/A *	No significant difference in intervention effect on self-report or accelerometer outcomes
Irwin (YES) ¹⁷	Feasibility; physical activity benefits	75 breast cancer survivors; Stage 0 - IIIa; 1 to 10 years since diagnosis; <90 weekly minutes of physical activity	1 group session and 2 home-based sessions per week; 6 months; 30 minutes, 5 days/week; moderate intensity	Pedometer, print materials, counseling during group exercise, and educational group meetings	N/A *	Motivation and assess adherence	Significantly greater physical activity in the intervention group based on log sheets and pedometer step counts
Nikander ¹⁶	Feasibility; physical activity	30 breast cancer survivors without metastasis	1 supervised session (step aerobics; circuit training) and 3 home-based sessions per week; 12 weeks; 30 to 40 minutes per session, vigorous intensity	None described but both study groups given pedometer for study duration	Mechanism of potential benefit [collected on subsample (n=3); relative ground forces]	Assessed adherence; unintentional motivation	Greater relative ground forces noted with step aerobics; ground forces achieved varied based on participant skill and preference for activity; pedometer steps increased in intervention group mid-intervention but statistical testing not reported
Maddocks ²⁰	Feasibility; benefits of neuromuscular electrical stimulation	16 lung cancer survivors; >4 weeks since chemotherapy	Neuromuscular electrical stimulation of the upper thigh 30 minutes daily	None	Benefit of a non-physical activity treatment modality (steps)	N/A *	Increase in daily steps in the intervention group that was not statistically significant
Mustian ²¹	Physical activity benefits	38 breast and prostate cancer patients; receiving radiation therapy	Home-based; 4 weeks; moderate intensity walking (10,000 steps/day); resistance bands daily	One face-to-face counseling session and print materials	N/A *	Motivation and assess adherence	Significantly greater increase in daily steps in intervention group. Used log to document resistance training

* N/A = not applicable since device not reported as being used in the trial.

Table 3

Registered but not completed randomized trials testing behavior change interventions related to physical activity or weight loss using a pedometer or accelerometer for physical activity assessment or motivation.

Identifier	Primary outcome	Cancer type	Intervention	Accelerometer purpose	Pedometer purpose
NCT00756795	Physical activity	Head and neck	12-week physical activity behavior change intervention; home-based exercise		Motivation
NCT00583726	Body weight	Breast; on chemotherapy	12-month, telephone delivered, motivational interviewing for exercise and diet behavior change (home-based exercise)		Motivation
NCT00533338	Intervention feasibility	Breast; on chemotherapy	Weight gain prevention; home-based exercise/ diet counseling	Assess adherence	Motivation
NCT00630591	Intervention feasibility and acceptability	Breast (survivors and daughters)	Partner-assisted, team-based physical activity and diet behavior change intervention	Assess adherence	Motivation
NCT01053468	Physical activity	Breast; on chemotherapy	Physical activity behavior change intervention		Motivation and assess adherence
NCT00095849	Physical activity	Breast (or at high risk)	3-month physical activity behavior change intervention		Motivation and assess adherence
NCT00732173	Body weight	Endometrial	6-month lifestyle behavior change intervention involving group and individual counseling		Motivation and assess adherence
NCT01133132	Physical activity	Colon	Lifestyle behavior change intervention using a mobile Comprehensive Health Enhancement Support System (Survivorship CHES)	Assess adherence	
NCT00633633	Intervention and study feasibility	Mixed; heart failure after chemotherapy	Lifestyle (including physical activity) behavior change intervention	Assess adherence	
NCT01147367	Physical activity	Breast; post- treatment	Physical activity behavior change intervention	Assess adherence	
NCT00929617	Physical activity	Breast	Physical activity behavior change intervention	Assess adherence	

Table 4

Registered but not completed randomized trials of physical activity or non-physical activity benefits using a pedometer or accelerometer for physical activity assessment or motivation.

Identifier	Primary outcome	Cancer type	Intervention	Accelerometer purpose	Pedometer purpose
NCT00868868	Androgen therapy side effects, quality of life	Prostate	Home-based exercise with pedometer and brief exercise coaching		Motivation
NCT00869804	Neuropathic symptoms	Breast; on chemotherapy	Home-based aerobic and resistance exercise		Motivation
NCT00740038	Medical Outcomes (SF-36)	Mixed; on chemotherapy	Stress management training versus home- based exercise training versus both		Motivation
NCT00405782	Physical functioning, fitness	Breast, metastatic	16 weeks, unsupervised, moderate- intensity exercise, 150 minutes/week		Motivation
NCT00985400	Neuropathic symptoms	Colon	Oncologist recommended home-based 16- week exercise program: resistance bands twice weekly; moderate-intensity walking; goal of 10,000 steps per day		Motivation
NCT00924651	Fatigue	Mixed; on chemotherapy	Home-based walking and resistance exercise		Motivation
NCT00153894	Fasting insulin levels	Breast; post- treatment	16 weeks; gym-based strength training and home- based aerobic exercise		Motivation
ISRCTN43801571	Fatigue, health service utilization, sick leave	Breast or colon	18-week supervised group exercise program; attendance twice per week encouraged		Assess adherence
NCT01136083	Exercise capacity	Non-small cell lung	Supervised high aerobic interval training for 30 minutes, 3 times weekly with home exercise twice weekly	Document home exercise	
NCT01108484	Fitness	Mixed	Supervised exercise $\pm$ diet $\pm$ psycho- emotional support	Assess adherence	
NCT00878995	Body composition, muscle strength, other biomarkers	Cervical	Amino acid supplement and/or testosterone	Benefits of non-physical activity treatment	
ISRCTN42944026	Adherence to neuromuscular electrical stimulation	Non-small cell lung; on chemotherapy	Neuromuscular electrical stimulation to thighs	Benefits of non-physical activity treatment	
NCT00424099	Fatigue	Mixed, advanced	Methylphenidate	Benefits of non-physical activity treatment*	
NCT00288795	Fatigue	Breast; on radiation	Polarity therapy or massage therapy	Benefits of non-physical activity treatment*	
NCT01005108	Hot flashes	Breast; on hormonal therapy	Acupuncture and gabapentin	Benefits of non-physical activity treatment	

* Note: Uncertain if physical activity or sleep is the actigraph outcome based on information provided with registration.

Table 5

The mean change in self-report and objective weekly minutes of $\geq$ moderate intensity physical activity (post-intervention minus baseline): exploratory, post hoc analysis from a randomized trial of a physical activity behavior change study.

Outcome used to calculate post- intervention minus baseline physical activity	Control group (n=18)		Intervention group (n=20)		P value ^c
	Mean $\pm$ SD ^a	95% CI ^b	Mean $\pm$ SD ^a	95% CI ^b	
Total minutes physical activity (accelerometer)	0.6 $\pm$ 96.8	-47.5 to 48.8	67.3 $\pm$ 100.0	20.5 to 114.17	0.04
Leisure minutes (self-report) ^d	62.8 $\pm$ 122.5	1.9 to 123.7	79.4 $\pm$ 87.9	38.2 to 120.5	0.63
Non-leisure minutes (accelerometer minus self-report)	-62.2 $\pm$ 173.4	-148.4 to 24.1	-12.1 $\pm$ 97.0	-57.5 to 33.35	0.29

^aSD= standard deviation

^bCI=confidence intervals

^cIndependent groups t-test used for comparison of the means of the difference scores.

^dGodin Leisure Time Physical Activity Questionnaire

Table 6

A comparison of the advantages and challenges of using pedometers and accelerometers

Characteristic	Pedometers	Accelerometers
Cost	↓	↑
Ease of use	↑	↓
Real-time accessible feedback of information on physical activity behavior	↑	↓
Measures physical activities that do not involve vertical, weight-bearing motion	↓	↔
Differentiates among varying physical activity intensities	↓	↑
Assesses sedentary time	↓	↑