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REVIEW ARTICLE

A guide to assessing physical activity using accelerometry in cancer patients

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Abstract Increased physical activity (PA) has been associated with a decreased risk for the occurrence and recurrence of many cancers. PA is an important outcome measure in rehabilitation interventions within cancer and may be used as a proxy measure of recovery or deterioration in health status following treatment and in the palliative care setting. PA is a complex multi-dimensional construct which is challenging to measure accurately. Factors such as technical precision and feasibility influence the choice of PA measurement tool. Laboratory-based methods are precise and mainly used for validation purposes, but their clinical applicability is limited. Self-report methods such as questionnaires are widely used due to their simplicity and reasonable cost; however, accuracy can be questionable. Objective methods such as pedometers measure step count but do not measure intensity, frequency or duration of activity. Accelerometers can measure PA behaviour at both ends of the movement spectrum from sedentary to vigorous levels of activity and can also provide objective data about the frequency, intensity, type and duration of PA. Balancing precision with ease of use, accelerometry may be the best measure of PA in cancer-based studies, but only a small number of studies have incorporated this measurement. This review will provide a background to PA and an overview of accelerometer measurement as well as technical and practical considerations, so this useful tool could be more widely incorporated into clinical trial research within cancer.

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Introduction

The health benefits of physical activity (PA) have been universally acknowledged across many diseases, including cancer. PA promotes benefits throughout the cancer trajectory, and moderate levels of PA are specifically associated with reduced occurrence and recurrence [1–3] of several cancers. Post-diagnosis PA has been shown to reduce breast cancer deaths by 34 %, all-cause mortality by 41 % and disease recurrence by 24 % [4]. Moderate levels of PA have also been associated with a lower risk of death in colon cancer survivors [5, 6]. PA may also help to alleviate some side effects of treatment such as fatigue [7], and increasing PA has been shown to translate into an improvement in quality of life (QOL) [8, 9].

While the emphasis has traditionally been on the measurement of moderate and vigorous PA (MVPA), increasing focus has been directed at the effect of sedentary behaviour on health. Sedentary behaviour is generally referred to as low levels of activity, similar to resting levels (MET value of 1.5 METs or less [10, 11]), which corresponds to activities undertaken while sitting, such as watching TV or lying down. Standing activity (unless absolutely still) is considered non-sedentary. Sedentary behaviour is often incorrectly misconstrued as an absence of PA—this should be termed 'inactive' [12]. Although MVPA and sedentary behaviour are often thought of as two ends of a continuum, their independent effect on health [13] and the fact that they are poorly correlated [14] suggest that they are two distinct concepts or paradigms that require individual assessment. A number of studies suggest that those who engage in high amounts of sedentary behaviour can be at increased risk of mortality and

morbidity regardless of their level of moderate and vigorous intensity PA [15, 16]. Indeed, a recent study in a colorectal cohort [17] showed that longer leisure time spent sitting was associated with higher all-cause mortality. The exact mechanisms whereby sedentary behaviour might influence cancer pathogenesis and progression are not fully known at this time. Animal models of prolonged sedentary behaviour [18] have demonstrated modified biological effects on lipoprotein lipase activity, which may inhibit the breakdown of triglycerides. Importantly, the work of Potischman et al. [19] demonstrated a link between triglycerides and cancer development. Recent literature has also highlighted that light-intensity PA is also associated with health, independently of MVPA. For example, it has been reported [20] that the accumulation of light-intensity lifestyle activity measured using an accelerometer was independently associated with lowered cardiometabolic risk factors. Low levels of light activity have also been associated with development of the metabolic syndrome [21].

PA measurement may be a useful proxy measure of overall health [22], and as levels of PA reflect deconditioning and the effect of the disease process associated with cancer, or its management, PA may therefore be a feasible end point for cancer clinical trials, particularly those where quality of life and toxicity are important. As PA incorporates QOL and physical functioning dimensions, this patient-centred outcome may be important for tracking these trajectories in advanced cancer [23, 24], and to this end, accelerometry may be a useful tool in cancer cachexia studies [22, 25–27]. The accurate measurement of PA is also important to identify correlates, determinants and potential mediators and to evaluate the efficacy of interventions to increase PA levels within cancer-based studies.

PA, however, as a multi-dimensional construct incorporating frequency, time, type and duration is difficult to measure accurately. There are a number of PA measurement methods. Gold standard techniques such as doubly labelled water, room calorimetry and indirect calorimetry are expensive and difficult to replicate in real-life settings. Subjective or self-report methods are useful for population monitoring and have traditionally been used in epidemiological studies. Objective methods are more useful for individual monitoring and provide more accurate information than self-report measures. These consist of HR monitoring, direct observation, accelerometers and pedometers. The choice of PA measurement tool is based on the research question, precision and a number of factors related to feasibility and participant burden. With minimal wearer burden, accelerometers can estimate some or all of the following: the number and length of activity bouts, breaks in sedentary time, energy expenditure, adherence to activity guidelines and postural transitions. Thus, accelerometry may be the best measure of PA in cancer-based studies, but only a small number of studies within cancer have incorporated this measurement.

PA measurement using accelerometry may be a more accurate assessment of changes in PA behaviour than traditional questionnaire usage in longitudinal studies and thus a better evaluation of the efficacy of interventions to increase PA levels in cancer studies. It has been proposed that accelerometry may be a useful adjunct to routine clinical assessment, although the technical precision and data processing time may preclude the widespread integration of accelerometers into routine clinical practice [23] at this time. It is possible that deteriorations in physical and cognitive health in advanced disease may preclude the ability to comply with accelerometer use although accelerometer use (ActivPAL) has been successfully carried out in palliative patients [26]. Accelerometers were initially used in smaller studies but are now more widely used in large epidemiological studies [28] and within large cancer-based studies [9], and this trend appears to be accelerating. For example, the Alberta Moving Beyond Breast Cancer (AMBER) study [29], a large longitudinal, prospective study which will enrol 1,500 breast cancer survivors and assess various health outcomes at baseline (within 90 days of surgery) and at 1-year and 3-year follow-up, incorporates the use of accelerometer measurement (Actigraph GT3X). In our centre, we have experience of using accelerometry in oesophageal [30], breast [31] and mixed cancer populations [32].

The aim of this article is to provide an overview of the measurement of PA, focusing on the use of accelerometers. This is not an exhaustive review of all aspects related to and types of accelerometers. There is a large body of literature pertaining to PA measurement using accelerometry; the reader is referred to a useful series of articles in *Med Sci Sports Exerc* from Jan 2012 vol. 44 (S1) and 2005 vol. 37 (S1) and also to individual studies detailing the reliability and validity and to the user manual of each monitor. This review will provide a user's guide, which may be particularly useful for new users of accelerometers, and will include the key conceptual issues as well as aspects of feasibility and practicality with specific regard to the cancer setting.

The measurement of physical activity

PA is defined as any 'bodily movement produced by skeletal muscles which results in energy expenditure' [33]. Although the terms PA and exercise are often used interchangeably, the distinct difference between these two concepts is that exercise involves 'planned, structured, repetitive bodily movements' with the objective of improving or maintaining components of physical fitness [33]. The term PA therefore not only includes energy expended during exercise but also encompasses the energy cost of activities of daily living, fidgeting, spontaneous muscle contraction and maintaining posture.

PA, as a complex multi-dimensional construct, is difficult to measure accurately. In addition, PA as a behaviour is not

stable and is prone to daily and weekly variation, as well as variations throughout the year. The measurement of PA in oncology includes some special considerations. Measurement techniques used to quantify PA in normal populations should theoretically be transferable to cancer populations as patients with cancer are generally not expected to show any abnormal movement patterns. However, for those with a significant disease burden and extreme fatigue or those undergoing intensive treatment, it would be important for any measurement tool to be sensitive enough to discriminate between sedentary and very low levels of activity.

PA measures lie along a continuum with precision of measurement at one end and ease of use at the other (Fig. 1). The selection of an assessment tool should be closely linked to the research hypothesis and study design. Direct measures such as room calorimetry and doubly labelled water are considered the gold standard for measuring energy expenditure, but are complex, expensive techniques, which are not feasible for use in population-based studies.

Self-report measures, which have traditionally been used in PA research, including in cancer population, lie at the opposite end of the continuum. These measures have the advantage of ease of use and minimal cost per assessment but are considered crude measures and are subject to bias [34]. Recall bias may be particularly high amongst older people or some metastatic groups, where memory or recall may be affected. Nonetheless, self-report measures have provided sufficient broad evidence to establish the preventative role of PA in the occurrence and recurrence of post-menopausal breast cancer [1, 2] and colon cancers [35]. They are also useful for assessing different domains of PA (such as occupational, recreational and transport-related activity) as well as sedentary behaviour (such as television viewing and computer use). More precise measures, however, are required for answering the next generation of questions relating to dose–response relationships, the effect of PA patterns on health, and for exploring the effectiveness of PA interventions [36].

Heart rate (HR) monitoring is an objective method of measuring daily energy expenditure (EE) based on the principle of a linear relationship between heart rate and EE over a wide range of activity levels [37]. There are, however, a number of potential sources of error associated with this technique, namely the non-linearity of HR during sedentary and light activities [38] and the inter-individual variations between HR and EE [39]. HR variability may also be increased in patients with cancer as a result of the latent effect of chemotherapy treatment on autonomic function [40], which may influence the accuracy of this method in cancer settings. Direct observation involves the observation of PA by the naked eye or from video observation. This can be intrusive, does not measure intensity of activity and is generally not suitable in home-based settings.

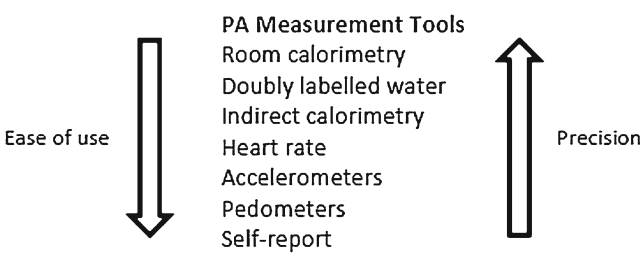

Fig. 1 Precision and ease of use of physical activity measurement tools

Motion sensors such as pedometers and accelerometers present as objective and feasible methods of measuring PA in population-based studies. Pedometers are quick and easy to use and are effective motivational tools [41]. They are also suitable to integrate into the clinical setting to enhance or encourage the daily PA of patients along with PA counselling [42]. Pedometers, however, only provide an output in steps/day and therefore have limited ability to assess intensity, sedentary time or duration of PA bouts. In addition, pedometers may not be suitable in certain cancer settings, for example in very deconditioned patients or in palliative settings, as accuracy can be reduced at slow speeds [22]. Obesity may also lead to inaccuracies in pedometer measurement, which limits the precision of this measure within some cancer groups such as endometrial and breast cancer [43].

Accelerometers

There are many commercially available accelerometer models, with a body of literature relating to the validity and reliability of each which should be accessed prior to choosing an accelerometer, as well as referring to the user manual of each model. A summary of the details of the most commonly used models is presented in Table 1, updated from previous reviews [41, 44]. Further details on the technical specifications of the different generations of Actigraph accelerometers and Actical are presented elsewhere [45].

The majority of accelerometers measure the magnitude of the body's acceleration to provide data in terms of 'counts' per unit time. Acceleration can be measured in one (uniaxial), two (biaxial) or three (triaxial) planes, and accelerometers are usually placed as close as possible to the body's centre of mass or on the hip in the mid-axillary line. There are a number of attachment options with the newer accelerometers, e.g. the Actical can be attached at the wrist, waist or ankle. Accelerometers are powered by coin cell batteries, or some of the newer generation of monitors are rechargeable such as the Actiwatch 2, the Actiwatch spectrum, Actigraph GT3X and ActivPAL.

Individual monitors have their own specifications, but many accelerometers are 'cantilever beam' accelerometers. With these accelerometers, a piezoelectric element bends in proportion to the acceleration detected [46] and records a voltage signal, which converts the mechanical motion into

Table 1 List of commonly used commercially available accelerometer models

Name	Manufacturer	Type	Technical specifications	Placement	Memory capacity	Features/what it provides
Actical	Phillips Respironics, (Bend, OR, USA; www.philips.com/actical)	Omni-directional	2.9×3.7×1.1 cm, 16 g, frequency response 0.5–3.0 Hz	Wrist, hip or ankle	32 MB	Activity counts Step counts Energy expenditure Total activity within intensity ranges
Actigraph GT1M	Actigraph LLC, (Pensacola, FL, USA; www.actigraphcorp.com)	Biaxial	3.8×3.7×1.8 cm, 27 g, frequency response 0.25 to 2.5 Hz	Hip or waist	1 MB	Activity counts Step counts Energy expenditure Sleep quality
Actigraph GT3X	Actigraph, (Pensacola, FL, USA; www.actigraphcorp.com)	Triaxial	3.8×3.7×1.8 cm, 27 g, frequency response 0.25–2.5 Hz	Waist or wrist	16 MB	Activity counts Steps Energy expenditure
Actigraph GT3X+	Actigraph, (Pensacola, FL, USA; www.actigraphcorp.com)	Triaxial	4.6×3.3×1.5 cm, 19 g, frequency response 30–100 Hz	Waist or waist	256 MB	Activity counts Steps Inclinometer Light
ActivPAL™	PAL Technologies Ltd. (Glasgow, UK; www.paltech.plus.com)	Uniaxial	5.3×3.5×0.7 cm, 15 g, sampling frequency 10 Hz	Anterior thigh placement	4 MB	Records periods spent sitting, standing, walking, sit-to-stand transitions Step count Cadence
ActivPAL^{3TM} VT	PAL Technologies Ltd. (Glasgow, UK; www.paltech.plus.com)	Uniaxial or Triaxial	5.3×3.5×0.7 cm, 15 g, sampling frequency 20 Hz	Anterior thigh placement	16 MB	Records periods spent sitting, standing, walking, sit-to-stand transitions Step count Cadence
Actitrac	IM Systems (Arnold MD, USA; www.imsystems.net)	Biaxial	5.6×3.8×1.3 cm, sampling frequency 40 Hz	Wrist	48 KB	Measures acceleration Records ambient light
Actiwatch AW16 or AW64	Phillips Healthcare (Andova, MA, USA; Best, The Netherlands; www.healthcare.philips.com)	Uniaxial Omni-directional	2.8×2.7×1.0 cm, frequency response 0.5–7 Hz	Hip or wrist	AW16 16 K, AW64 64 K	Activity counts Sleep quality
Actiwatch Spectrum	Phillips Healthcare (Andova, MA, USA; Best, The Netherlands; www.healthcare.philips.com)	Uniaxial; Omni-directional	4.9×3.7×1.4 cm, 29.8 cm	Wrist	1 Mbit	Activity counts Sleep quality Ambient light
Actiwatch 2	Phillips Healthcare (Andova, MA, USA; Best, The Netherlands; www.healthcare.philips.com)	Uniaxial; Omni-directional	4.4×2.3×1 cm, 16.1 g, frequency response 0.35–7.5 Hz	Wrist	2 Mbit	Activity counts Sleep quality

Table 1 (continued)

Name	Manufacturer	Type	Technical specifications	Placement	Memory capacity	Features/what it provides
						Ambient light
						Coloured light
Biotrainer Pro	IM Systems (Arnold, MD, USA; www.imsystems.net)	Biaxial	7.6×5×2.2 cm, 51.1 g, movements sampled at 40 per second	Hip	Records up to 22 days of data when using 1-min epochs	Physical activity 'g' units or kilocalories expended
GENEActiv	Activinsights (Cambridgeshire, UK; www.geneactive.co.uk)	Triaxial	4.3×4.0×1.3 cm, 16 g, frequency 32.77 Hz	Wrist, thigh or ankle	0.5 Gbit	Sedentary time, as well as time spent walking, running and in household activity
						Temperature sensor
RT3-Triaxial Research Tracker	Stayhealthy Inc. (Monrovia, CA; www.stayhealthy.com)	Triaxial	7.1×5.6×2.8 cm, 65.2 g, frequency response 2.0–10 Hz	Hip or waist	Records up to 21 days, 1-min epochs	Activity counts
						Energy Expenditure
Sensor-wear Pro Arm band	BodyMedia, Inc. (Pittsburgh, PA, USA; www.sensewear.bodymedia.com)	Tri-axial	5.5×6.2×1.3 cm, 45.4 g	On upper arm	10 days steady use	Energy expenditure
						Steps
						Physical activity
						Sleep On/off body time

an electric signal [47]. It is advised that when using cantilever beam technology, a calibration protocol should be in place to ensure that they remain within the calibration specifications set by the manufacturer before and/or after testing [48]. IC chip accelerometers have a piezoelectric element and a seismic mass, which detect acceleration, but the sensor is enclosed in a package attached to an electronic circuit board, which improves the durability and repeatability of monitors [41].

Using an internal clock, acceleration units are accumulated over a discrete, user-specified epoch or time-sampling interval which is then written to the device memory [44] as counts. The count output provided by traditional accelerometers is a meaningless value unless translated into a more interpretable unit [49]. It is conventional to apply count thresholds or 'cut-points' to accelerometer counts in order to express raw data in terms of minutes per day spent in specific or combined activity intensities, e.g. sedentary, light, moderate or vigorous, or as time spent in activity/sedentary behaviour as a percentage of total waking hours. Due to differences in how raw data is collected, processed and filtered, scaled counts cannot be directly compared across devices [47]. Individual calibration of appropriate cut-points is therefore required for each make and version of accelerometer.

Another method of interpreting accelerometer data is to convert counts into EE with the use of proprietary algorithms. While many EE equations have to be externally applied to the raw data, some monitors, such as the RT3 accelerometer, provide direct outputs of EE with the use of inbuilt equations. A disadvantage is that linear regression models to predict EE associated with activities can be inaccurate, especially at high levels of expenditure [50] such as running, although this may not be largely relevant in the cancer setting. Also, there may be an increase in EE and decreased fat mass in cachectic patients [51], which may limit the accuracy of predictive algorithms. A disadvantage of hip-worn accelerometers is that EE associated with free-living activities is also often underestimated [52, 53]. The assessment of EE may aid in planning suitable nutritional support for patients with cancer. Recently developed advanced accelerometry-based devices use pattern recognition technology to assess PA, which may provide a more accurate estimate of EE in this population. These devices use inputs from multiple sources and provide different outputs such as information on body positions, activity domain and EE. The Sensewear Pro Armband is an example of such devices. This accelerometer is worn on the upper arm and integrates information from heat-related channels with accelerometry data to predict EE. There may be limitations, however, to the use of this device in some breast and gynaecological cancers due to hot flashes related to chemotherapy-induced premature menopause [54].

A useful feature of some accelerometers is the ability to distinguish between different body postures. For example, the ActivPAL uses the inclination output from the accelerometer

(the acceleration due to gravity) to determine thigh position. By using both inclination and dynamic acceleration, the ActivPAL is able to classify basic posture by distinguishing sedentary activities from upright and quantify dynamic stepping activities. The Actigraph GT3X also provides inclinometer output, which specifies if the individual is not wearing the monitor (number 0), standing (number 1), lying (number 2) or sitting (number 3). Use of the inclinometer function of the Actigraph model in isolation mandates caution, however, as a recent study [55] reported that the correct anatomical position was identified in only approximately two thirds of the time during sedentary activity, although this function was found to be more accurate during light-intensity activity (71.8–85.1 % percent agreement).

As well as providing objective, precise PA data, the wearer is normally blinded to the activity output of accelerometers, and monitor data is therefore free from random and systematic errors introduced by respondents and interviewers [56]. There are a number of limitations associated with accelerometers, however, such as the lack of consensus on data processing and cut-points, which limits comparability between studies and a lack of standardised data analysis strategies. Further limitations of accelerometers are their inability to provide contextual information related to the setting and type of activity. Accelerometers are also unable to accurately detect the intensity of cycling and activities involving the use of upper extremities; this also applies to arm-worn monitors [34, 57, 58]. Wrist-worn accelerometers are not as accurate at classifying activity and sedentary behaviour as hip-worn accelerometers [59], and the measurement of isometric muscular contraction such as weight lifting and activities such as carrying a load, pushing, skating and rowing can also be problematic. The majority of traditional accelerometers are not waterproof and therefore cannot capture the activity associated with swimming and water sports. Although, some of the newer monitors are splashproof and some are submersible such as the GENEActiv and Actigraph GT3X+, enabling the recording of water-based activities such as swimming. All accelerometers are likely to be sensitive to exposure to impact forces such as being dropped. Most newer monitors are encased in a hard polycarbonate plastic casing such as the Actigraph GT1M and GT3X models—even for these models, it is not known whether exposure to repeated drop forces would cause monitors to lose calibration [45].

Accelerometer measurement: technical aspects

There are a number of considerations in accelerometer choice, and these are outlined in Table 2. When using accelerometers, the researcher must initialize the monitor—that is, prepare it for use. Researchers must first programme a date and time to begin recording data. Some monitors commence recording data as soon as the monitor is removed from the docking station, e.g. ActivPAL accelerometer, while others can be self-commenced by the participant, e.g. RT3 accelerometer. Generally, epoch length is specified during initialization of the device pre-wearing, but in newer generation accelerometers (e.g. ActiGraph GT3X+), raw acceleration data is recorded, and accelerometer epoch can be specified post data collection. Shorter epoch lengths provide more detailed data over shorter time periods, but this may reduce the memory capacity or battery life [60]. Most monitors record activity in 1-min or 1-s epochs, although some only provide data over total wear time. As movements are not expected to be sporadic or intermittent in cancer populations, a 1-min epoch is frequently chosen. This also allows a direct comparison of data to PA guidelines.

There is no firm consensus on the minimum number of valid days of monitoring required. The time span chosen should not be overly burdensome for the individual or for available resources but should be sufficiently long to reflect the individual's habitual level of activity [44]. Firstly, a 'valid' day must be defined. Values of 10 h or 60 % of waking hours have been proposed [61], although more recent work [62] proposes that at least 12 h per day monitoring time is more optimal. It is possible that patients on treatment and/or with advanced disease may rest longer at night and may experience restlessness and periods of wakefulness and activity at night, which could also be assessed using accelerometry if required. Conservative estimates of 3 to 7 valid days [61] or 3 to 5 days [44] have been reported as acceptable, with 2 valid days of measurement considered as the minimum number of necessary days to assess PA in daily life [63]. Other literature would recommend 6-day monitoring [44, 64] to ensure that habitual levels of activity are reflected, and this time frame has also been reported in a study by Maddocks et al. in a cancer population [22]. It has been suggested that weekend days and weekdays need to be sampled [65], although it is not clear if sufficient variability exists between weekdays and weekend days in cancer populations.

Screening of accelerometer data should also be carried out to minimise the influence of non-wear time or spurious data on reported outcomes. An important aspect of accelerometer choice is whether very low levels of activity can be discriminated from non-compliance, e.g. lying very stationary resting versus true non-wear time as it is possible that very low levels of activity may be sub-threshold, which may be important particularly within the palliative context. A solution is to combine accelerometer output with a concurrent self-report PA diary and adjust results accordingly [56]. Definitions of non-compliance vary, from bouts of 10 min of motionless data (10 consecutive '0' counts using 1-min epochs) up to 60 min [28]. It is likely though that non-voluntary movements generated during resting would register as counts >0, as opposed to non-compliance which would generate consecutive series of 0. Little is known about wearer compliance in cancer patients; however, an excellent compliance rate of 98 % has been

Table 2 Patient-related and technical considerations in choosing an accelerometer for use

Technical considerations
What are the reliability and validity of the monitor?
What is the direct cost of the monitor per unit and if bought in bulk?
What is the cost of monitor replacement if lost?
What are the indirect costs (software, belts, docking station, maintenance/repair)?
Can the monitor be tampered with—is there a reset button or visual display?
Is the accelerometer operated by a coin cell battery or rechargeable battery? What is the battery life?
Is the primary outcome total PA, time spent in specific activity domains (such as sedentary, light, moderate or high) or EE?
What is the primary purpose of monitoring compliance with PA guidelines, motivation, assessing adherence?
What are the cut-off points for PA or algorithms for EE?
Can the monitor differentiate between sedentary and light levels of activity?
What epoch length will be chosen?
Does data need to be cleansed and reduced? How much data manipulation is required?
Can the data be easily downloaded from the monitor?
What is the rate of monitor malfunction?
What is the memory capacity of the monitor?
Can you differentiate between very low levels of activity and non-compliance with monitor wearing?
How will non-compliance be defined?
Can data generated be compared to other studies?
How will missing data be dealt with?
What constitutes a valid day wearing the monitor?
How many days of valid monitoring are required?
Does the monitor measure acceleration in one, two or three planes of movement?
Does the accelerometer have a 'stop date' so excess days beyond the study period are not recorded?
How will the monitor be delivered to and retrieved from participants? Face-to-face, or mail?
Is a face-to-face meeting necessary or can the monitor be mailed to participants?
If the monitor is to be mailed, what is the cost of delivery to the participant and return?
Will express and/or registered post be used?
Has the cost of mailing been included in the study budget?
Can the monitor be initialised by the participant at home?
How will the monitor be returned to the study centre?
Is there a pool of other accelerometer users to troubleshoot if problems occur?
Is the accelerometer software user-friendly?
Is technical and software backup available?
Patient-related considerations
Is the monitor feasible for use in clinical settings?
What are the monitor size and weight?
What are the durability and sturdiness of the monitor?
Is this a 'usual week' of activity?
Have participants been instructed not to change their activity patterns?
What is the participant burden?
Will incentives be used for monitor return?
Does the monitor have to be removed during water-based activities?
Should the monitor be removed at night?
Where should the monitor be placed, and on right or left side of body?
Can the monitor be tampered with?
Will the participant keep a diary to document on and off time of the monitor and activities which would not be recorded by the monitor such as stationary cycling and swimming?
Will the participant be contacted to encourage compliance (e.g. phone or SMS)?
Will instructions be provided on how to use the monitor?
Will a practical demonstration be given on accelerometer use?
Will a contact number be provided should the participant have questions or difficulties?

reported [22] in an advanced cancer population, and similar high levels of compliance were found in a recent study carried out in our centre [66]. Newer generation of measurement tools such as the combined heart rate and movement sensor Actiheart may be useful for identifying non-wear time, as the absence of concurrent HR measurement would signify non-compliance with accelerometer use. Skin/heat sensors in the Sense Wear arm band, Actiwatch Spectrum and GENEActiv (Table 1) also overcome the problem of non-wear time as heat sensors are integrated into this product, resulting in better detection of non-wear time versus time spent sedentary [50].

Practical considerations when using accelerometer measurement

As evident from this review, there are a number of accelerometry-based devices commercially available. Although advances in accelerometry technology have potentially improved the accuracy of PA research, the influx of new monitors on the market and the constant updating of models make monitor selection an intimidating task. When choosing a monitor, it is therefore important to weigh up the accuracy of the monitor with its feasibility. Factors that should be considered in addition to validity are the financial cost of monitors, staff time to process and analyse monitors [67] and variability in terms of technical reliability [68].

From our experience, an initial pilot study to evaluate the feasibility and measurement properties of two or more accelerometer models can be useful to aid in accelerometer choice. Trost et al. (2005) also suggested doing a small cost–benefit analysis. Some practical challenges we faced with accelerometer measurement were forgetfulness, which is a well-recognized limitation, and unwillingness to wear the device due to the monitor being conspicuous on special events [69].

Also, a number of accelerometers will be subject to accelerometer failure, some will be lost by participants and others will be returned with insufficient data. This means that a number of participants may be requested to re-wear the monitor. A number will return their accelerometers late, and some will have to be contacted multiple times for the monitor to be returned.

Strategies to improve wearer compliance include the completion of an activity monitoring log, reminder calls, SMS reminders, providing tips or lists of frequently asked questions about accelerometer wearing, displaying written material to prompt monitor wearing and providing an incentive, e.g. monetary, to promote monitor wearing [44].

We found a face-to-face meeting useful to explain monitor setup, and generally, the device was returned by pre-paid envelope. The envelope should have sufficient padding and strength to prevent monitor damage. Trost et al. suggested that X-ray screenings associated with mailing may adversely affect data storage, which should be checked, and encourage several 'practice mailings' before committing to a mail-based distribution collection protocol.

Prior to commencing a study, it would be useful to determine the number of monitors needed. This is determined by the maximum number of participants in the study in a given measurement period; the speed with which the monitors can be distributed, worn, retrieved and prepared for next usage; and the number of monitors that are mislaid or fail. A useful example of this is given in the paper by Matthews et al. [60].

The future of accelerometry measurement

Combined newer generation tools incorporating HR monitors and movement sensors as well as multi-unit monitors which combine multiple accelerometers, inclinometers or physiological sensors may be the future of PA measurement, although these remain untested in free-living settings and their feasibility due to their analytic complexity has not been widely established. The future is also likely to be the miniaturization of these combined devices and advanced computation methods such as the wireless capacity of the Actigraph GT3X and the integration with smart phone technology, which is already available. There are cheap commercially available accelerometers, but they have not as yet been validated in clinical or research settings. Further research is required into the validity of these monitors in larger samples and different cancer types, however.

Conclusion

As evident from this review, PA remains a challenging construct to measure. We propose that balancing precision and practicality, accelerometers offer exciting possibilities for the measurement of PA within cancer settings. There are a large number of commercially available models, and when choosing an accelerometer, factors such as the research question, technical precision and a number of feasibility issues such as cost, participant burden as well as issues specific to cancer research require careful consideration. More comparability studies between accelerometers are required, as well as further studies to access the validity and reliability of these devices among cancer populations. It is hoped that the information in this review may aid in increasing the accuracy of measuring PA with cancer settings.

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References

1. Irwin ML, Smith AW, Mc Tiernan A, Ballard-Barbash R, Cronin K, Gilliland FD, Baumgartner RN, Baumgartner RN, Bernstein L (2008) Influence of pre- and postdiagnosis physical activity on mortality in breast cancer survivors: the Health, Eating, Activity and Lifestyle Study. J Clin Oncol 26(24):3958–3964. doi:10.1200/JCO.2007
2. Holmes MD, Chen WY, Feskanich D, Kroenke CH, Colditz GA (2005) Physical activity and survival after breast cancer diagnosis. JAMA 293:2479–2486. doi:10.1001/jama.293.20.2479
3. Holick CN, Newcomb PA, Trentham-Dietz A (2008) Physical activity and survival after diagnosis of invasive breast cancer. Cancer Epidemiol Biomarkers Prev 17:379–386. doi:10.1158/1055-9965.EPI-07-0771
4. Ibrahim EM, Al-Homaidh A (2011) Physical activity and survival after breast cancer diagnosis: meta-analysis of published studies. Med Oncol 28(3):753–765. doi:10.1007/s12032-010-9536-x
5. Meyerhardt JA, Giovannucci EL, Holmes MD, Chan AT, Chan JA, Colditz GA, Fuchs CS (2006) Physical activity and survival after colorectal cancer diagnosis. J Clin Oncol 24:3527–3534. doi:10.1200/JCO.2006.06.0855
6. Meyerhardt JA, Heseltine D, Niedziecki D, Hollis D, Saltz LB, Mayer RJ, Thomas J, Nelson H, Whittom R, Hantel A, Schilsky RL, Fuchs CS (2006) Impact of physical activity on cancer recurrence and survival in patients with stage III colon cancer: findings from CALBG 89803. J Clin Oncol 24:3535–3541
7. Dimeo F (2002) Radiotherapy-related fatigue and exercise for cancer patients: a review of the literature and suggestions for further research. Front Radiat Ther Oncol 37:49–56
8. Irwin ML, Crumlet D, Mc Tiernan A (2003) Physical activity levels before and after a diagnosis of breast carcinoma: the Health, Eating, Activity (HEAL) study. Cancer 97(7):1746–1757
9. Lynch BM, Cerin E, Owen N, Aitken JF (2007) Associations of leisure-time physical activity with quality of life in a large, population-based sample of colorectal cancer survivors. Cancer Causes Control 18:735–742
10. Pate RR, O' Neill JR, Lobelo F (2008) The evolving definition of "sedentary". Exerc Sports Sci Rev 36(4):173–178
11. Owen N, Bauman A, Brown W (2009) Too much sitting: a novel and important predictor of chronic disease risk? Br J Sports Med 43:81–83

12. Lynch BM (2010) Sedentary behavior and cancer: a systematic review of the literature and proposed biological mechanisms. Cancer Epidemiol Biomarkers Prev 19(11):2691–2709. doi:10.1158/1055-9965.epi-10-0815
13. Stamatakis E, Hamer M, Tilling K, Lawlor DA (2012) Sedentary time in relation to cardio-metabolic risk factors: differential associations for self-report vs accelerometry in working age adults. Int J Epidemiol 41(5):1328–1337. doi:10.1093/ije/dys077
14. Carson V, Janssen I (2011) Volume, patterns, and types of sedentary behavior and cardio-metabolic health in children and adolescents: a cross-sectional study. BMC Public Health 11:274. doi:10.1186/1471-2458-11-274
15. Grontved A, Hu FB (2011) Television viewing and risk of type 2 diabetes, cardiovascular disease, and all-cause mortality: a meta-analysis. JAMA 305(23):2448–2455. doi:10.1001/jama.2011.812
16. Thorp AA, Owen N, Neuhaus M, Dunstan DW (2011) Sedentary behaviors and subsequent health outcomes in adults a systematic review of longitudinal studies, 1996–2011. Am J Prev Med 41(2): 207–215. doi:10.1016/j.amepre.2011.05.004
17. Campbell PT, Patel AV, Newton CC, Jacobs EJ, Gapstur SM (2013) Associations of recreational physical activity and leisure time spent sitting with colorectal cancer survival. J Clin Oncol 31(7):876–885. doi:10.1200/jco.2012.45.9735
18. Marshall SJ, Ramirez E (2011) Reducing sedentary behavior: a new paradigm in physical activity promotion. Am J Lifestyle Med 5(6): 518–530
19. Potischman N, McCulloch CE, Byers T, Houghton L, Nemoto T, Graham S, Campbell TC (1991) Associations between breast cancer, plasma triglycerides, and cholesterol. Nutr Cancer 15(3–4):205–215
20. Camhi SM, Sisson SB, Johnson WD, Katzmarzyk PT, Tudor-Locke C (2011) Accelerometer-determined moderate intensity lifestyle activity and cardiometabolic health. Prev Med 52(5):358–360. doi:10.1016/j.ypmed.2011.01.030
21. Kim J, Tanabe K, Yokoyama N, Zempo H, Kuno S (2013) Objectively measured light-intensity lifestyle activity and sedentary time are independently associated with metabolic syndrome: a cross-sectional study of Japanese adults. Int J Behav Nutr Phys Act 10:30. doi:10.1186/1479-5868-10-30
22. Maddocks M, Byrne A, Johnson CD, Wilson RH, Fearon KCH, Wilcock A (2010) Physical activity level as an outcome measure for use in cancer cachexia trials: a feasibility study. Support Cancer Care 18:1539–1544
23. Maddocks M, Wilcock A (2012) Exploring physical activity level in patients with thoracic cancer: implications for use as an outcome measure. Support Care Cancer 20(5):1113–1116. doi:10.1007/s00520-012-1393-z
24. World Health Organization (1979) WHO handbook for reporting results of cancer treatment. Geneva
25. Fearon KC (2008) Cancer cachexia: developing multimodal therapy for a multidimensional problem. Eur J Cancer 44(8):1124–1132. doi:10.1016/j.ejca.2008.02.033
26. Dahele M, Skipworth R, Wall L, Voss A, Preston T, Fearon K (2007) Objective physical activity and self-reported quality-of-life in patients receiving palliative chemotherapy. J Pain Symptom Manag 33(6): 676–685
27. Mantovani G, Madeddu C, Serpe R (2010) Improvement of physical activity as an alternative objective variable to measure treatment effects of anticachexia therapy in cancer patients. Curr Opin Support Palliat Care 4(4):259–265. doi:10.1097/SPC.0b013e32833b35c0
28. Matthews C, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, Troiano RP (2008) Amount of time spent in sedentary behaviours in the United States, 2003–2004. Am J Epidemiol 167: 875–881
29. Courneya KS, Vallance JK, Culos-Reed SN, McNeely ML, Bell GJ, Mackey JR, Yasui Y, Yuan Y, Matthews CE, Lau DC, Cook D, Friedenreich CM (2012) The Alberta moving beyond breast cancer (AMBER) cohort study: a prospective study of physical activity and health-related fitness in breast cancer survivors. BMC Cancer 12:525. doi:10.1186/1471-2407-12-525
30. Feeney C, Reynolds JV, Hussey J (2011) Preoperative physical activity levels and postoperative pulmonary complications post-esophagectomy. Dis Esophagus 24(7):489–494. doi:10.1111/j.1442-2050.2010.01171.x
31. Guinan E, Hussey J, Broderick JM, Lithander FE, O'Donnell D, Kennedy MJ, Connolly EM (2013) The effect of aerobic exercise on metabolic and inflammatory markers in breast cancer survivors—a pilot study. Support Care Cancer. doi:10.1007/s00520-013-1743-5
32. Walsh JM, Hussey J, Guinan E, OD D (2010) 'Pragmatic randomized controlled trial of individually prescribed exercise versus usual care in a heterogeneous cancer survivor population': a feasibility study PEACH trial: prescribed exercise after chemotherapy. BMC Cancer 10:42. doi:10.1186/1471-2407-10-42
33. Caspersen CJ, Powell KE, Christensen GM (1985) Physical activity, exercise and physical fitness. Definitions and distinctions for health-related research. Public Health Rep 100:126–131
34. Prince SA, Adamo KB, Hamel ME, Hardt J, Gorber SC, Tremblay M (2008) A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. Int J Behav Nut Phys Act 5 (56). doi:10.1186/1479-5868-5-56
35. Je Y, Jeon JY, Giovannucci EL, Meyerhardt JA (2013) Association between physical activity and mortality in colorectal cancer: a Meta-analysis of prospective cohort studies. Int J Cancer. doi:10.1002/ijc.28208
36. Colbert LH, Schoeller DA (2011) Expending our physical activity (measurement) budget wisely. J Appl Physiol 111(2):606–607. doi:10.1152/japplphysiol.00089.2011
37. Christensen C, Frey HM, Foenstelien E, Adadland E, Refsum HE (1983) A critical evaluation of energy expenditure estimates based on individual O2 consumption/heart rate curves and average daily heart rate. Am J Clin Nutr 37:468–472
38. Spurr GB, Prentice AM, Murgatroyd PR, Goldberg GR, Reina JC, Christman NT (1988) Energy expenditure from minute-by-minute heart-rate monitoring: comparison with indirect calorimetry. Am J Clin Nutr 48:552–559
39. Leonard WR (2003) Measuring human energy expenditure: what have we learned from the flex-heart rate method? Am J Hum Biol 15:479–489
40. Pujol JL, Quantin X, Chakra M (2009) Cardiorespiratory fitness in patients with advanced non-small cell lung cancer: why is this feature important to evaluate? Can it be improved? J Thorac Oncol 4(5):565–567. doi:10.1097/JTO.0b013e3181a0d761
41. Murphy SL (2009) Review of physical activity measurement using accelerometers in older adults: considerations for research design and conduct. Preventative Med 49:108–114
42. Bassett DR, Mahar MT, Rowe DA, Morrow JR (2008) Walking and measurement. Med Sci Sports Exerc 40(7S):S529–S536
43. McClung CD, Zahiri CA, Higa JK, Amstutz HC, Schmalzried TP (2000) Relationship between body mass index and activity in hip or knee arthroplasty patients. J Orthop Res 18(1):35–39. doi:10.1002/jor.1100180106
44. Trost SG, McIver KL, Pate RR (2005) Conducting accelerometer-based activity assessments in field-based research. Med Sci Sports Exerc 37(11 Suppl):S531–543
45. John D, Freedson P (2012) ActiGraph and Actical physical activity monitors: a peek under the hood. Med Sci Sports Exerc 44(1 Suppl 1):S86–89. doi:10.1249/MSS.0b013e3182399f5e
46. Mathie MJ, Coster ACF, Lovell NH (2004) Accelerometry: providing an integrated, practical method for long-term, ambulatory monitoring of human movement. Physiol Meas 25:R1–20
47. Chen KY, Bassett DR Jr (2005) The technology of accelerometry-based activity monitors: current and future. Med Sci Sports Exerc 37: S490–S500

48. Welk GJ (2005) Principles of design and analyses for the calibration of accelerometry-based activity monitors. Med Sci Sports Exerc 37(11 Suppl):S501–511
49. Troiano RP (2006) Translating accelerometer counts into energy expenditure: advancing the quest. J Appl Physiol 100(4):1107–1108. doi:10.1152/japplphysiol.01577.2005
50. Johannsen DL, Calabro MA, Stewart J, Franke W, Rood JC, Welk GJ (2010) Accuracy of armband monitors for measuring daily energy expenditure in healthy adults. Med Sci Sports Exerc 42(11):2134–2140
51. Suzuki H, Asakawa A, Amitani H, Nakamura N, Inui A (2013) Cancer cachexia—pathophysiology and management. J Gastroenterol 48(5):574–594. doi:10.1007/s00535-013-0787-0
52. Lyden K, Kozey SL, Staudenmeyer JW, Freedson PS (2011) A comprehensive evaluation of commonly used accelerometer energy expenditure and MET prediction equations. Eur J Appl Physiol 111(2):187–201. doi:10.1007/s00421-010-1639-8
53. Howe CA, Staudenmayer JW, Freedson PS (2009) Accelerometer prediction of energy expenditure: vector magnitude versus vertical axis. Med Sci Sports Exerc 41(12):2199–2206. doi:10.1249/MSS.0b013e3181aa3a0e
54. Mar Fan HG, Houede-Tchen N, Chemerynsky I, Yi QL, Xu W, Harvey B, Tannock IF (2010) Menopausal symptoms in women undergoing chemotherapy-induced and natural menopause: a prospective controlled study. Ann Oncol 21(5):983–987. doi:10.1093/annonc/mdp394
55. Carr LJ, Mahar MT (2012) Accuracy of intensity and inclinometer output of three activity monitors for identification of sedentary behavior and light-intensity activity. J Obes 2012:460271. doi:10.1155/2012/460271
56. Matthews CE (2005) Calibration of accelerometer output for adults. Med Sci Sports Exerc 37(11):S512–S522
57. Kozey SL, Lyden K, Howe CA, Staudenmayer JW (2010) Accelerometer output and MET values of common physical activities. Med Sci Sports Exerc 42(9):1776–1784
58. Jakicic JM, Marcus M, Gallagher KI, Randall C, Thomas E, Goss FL, Robertson RJ (2004) Evaluation of the SenseWear Pro Armband to assess energy expenditure during exercise. Med Sci Sports Exerc 36(5):897–904
59. Rosenberger ME, Haskell WL, Albinali F, Mota S, Nawyn J, Intille S (2013) Estimating activity and sedentary behavior from an accelerometer on the hip or wrist. Med Sci Sports Exerc 45(5):964–975. doi:10.1249/MSS.0b013e31827f0d9c
60. Matthews CE, Hagstromer M, Pober DM, Bowles HR (2012) Best practices for using physical activity monitors in population-based research. Med Sci Sports Exerc 44(1 Suppl 1):S68–76. doi:10.1249/MSS.0b013e3182399e5b
61. Masse LC, Fuemmeler BF, Anderson CB, Matthews CE, Trost SG, Catellier DJ, Treuth M (2005) Accelerometer data reduction: a comparison of four reduction algorithms on select outcome variables. Med Sci Sports Exerc 37(11 Suppl):S544–554
62. Herrmann SD, Barreira TV, Kang M, Ainsworth BE (2012) Impact of accelerometer wear time on physical activity data: a NHANES semisimulation data approach. Br J Sports Med. doi:10.1136/bjsports-2012-091410
63. Pitta F, Troosters T, Spruit MA, Probst VS, Gosselink R (2005) Characteristics of physical activities in daily life in chronic obstructive pulmonary disease. Am J Respir Crit Care Med 171:972–977
64. Ward DS, Evenson KR, Vaughn A, Rodgers AB, Tropano RP (2005) Accelerometer use in physical activity: best practices and research recommendations. Med Sci Sports Exerc 37:582–588
65. Gretebeck RJ, Montoyne HJ (1992) Variability of some objective measures of physical activity. Med Sci Sports Exerc 24(10):1167–1172
66. Broderick JM, Guinan E, Kennedy MJ, Hollywood D, Courneya KS, Culos-Reed SN, Bennett K, O'Donnell DM, Hussey J (2013) Feasibility and efficacy of a supervised exercise intervention in deconditioned cancer survivors during the early survivorship phase: the PEACH trial J Cancer Survivorship. doi:10.1007/s11764-013-0294-6
67. Dale D, Welk GJ, Matthews CE (2002) Physical activity measurement for health and research. Methods for assessing physical activity and challenges for research. Human Kinetics, Champaign
68. Esliger DW, Tremblay MS (2006) Technical reliability of three accelerometer models in a mechanical setup. Med Sci Sports Exerc 38:2173–2181. doi:10.1249/01.mss.0000239394.55461.08
69. Rogers LQ (2010) Objective monitoring of physical activity after a cancer diagnosis: challenges and opportunities for enhancing cancer control. Phys Ther Rev 15(3):224–237. doi:10.1179/174328810x12814016178872