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PROCEEDINGS ARTICLE

Sedentary behavior: target for change, challenge to assess

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Sedentary behavior is not a new topic, but trying to examine the direct links between sedentary behavior and health outcomes, independent of time spent in moderate- and vigorous-intensity physical activity, is a relatively new addition to the relationships between physical activity and health. Defining sedentary behavior as a risk factor and target for intervention opens up novel avenues for disease prevention and health promotion. The relationship between sedentary behavior and obesity is complex and not well understood, but the increased risk of disease due to sedentary behavior may be even greater in obese patients. Objective measurement of sedentary behavior is an important link in being able to understand the real effects of being sedentary, and a few measurement devices are described. Interventions targeting sedentary behavior should reduce total sedentary time, break long bouts of sitting with intermittent activity and encourage light-intensity activity throughout the day. New technologies can both measure and deliver an intervention aimed at reducing sitting time, the most common category of sedentary behavior. An optimal activity profile will include minimal amounts of sedentary behavior, in addition to regular physical activity and healthy sleep patterns.

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INTRODUCTION

Headlines in recent newspaper and magazine articles have proclaimed 'Sitting is Killing You', and ask 'Are You Sitting TOO Much'? This interest in sedentary behavior is justified, if exaggerated, by a growing body of evidence that points to a relationship between sedentary behavior and disease that is separate from the lack of moderate- or vigorous-intensity physical activity. Throughout history, it has been known that being inactive is unhealthy. Even traditional societies that promote spirituality over physical growth, as in ancient Hinduism, came up with a way of combating inactivity—Yoga. Because of the improvements in sedentary behavior measurement, we are now beginning to see the magnitude of the relationship between sedentary behavior and disease outcomes. The initial results are so compelling that researchers have decided that '… in the future, investigators should focus as much attention on the lower end of the activity intensity continuum as has traditionally been placed on the higher end of that continuum'.[1]

Increased interest in sedentary behavior stems from four different health-related trends taking place at the same time. First, Americans are increasingly relying on technology for our daily tasks, and therefore are more sedentary than they have ever been in the history of this country. Second, there is new physiological evidence of specific metabolic effects that are unique to being sedentary and detrimental to health.[2] Third, we now know how to better use objective measurement tools, such as accelerometers, to closely measure sedentary time throughout the day.[3] Finally, as it has proven to be difficult to motivate the population to do regular, vigorous bouts of physical activity, reducing sedentary behavior may be a promising alternative or complementary intervention area for disease prevention. The combination of light-intensity activity ('puttering around') and sedentary time makes up 96% of the average American's waking hours,[4] opening a large window of opportunity to make minor increases in activity intensity.

The definition of sedentary behavior has been a moving target for researchers in the past, but there is consensus building around certain aspects of the definition. Leading researchers in this field have defined sedentary behavior as a combination of sitting and low levels of energy expenditure;[5] anything with a sitting posture, unless it is an activity such as sitting on an exercise bike, qualifies as sedentary. These researchers and others have defined energy expenditures associated with sitting as less than 1.5 METs, or metabolic equivalents,[6,7] which seems to be an accurate assessment of the energy-expenditure level for sitting with very little movement. Unfortunately, this definition of sedentary would also include standing and other non-sitting activities.[8] The assessment of television viewing time is also considered a measure of a sedentary behavior,[9–13] but this will only give a description of leisure time behavior, not occupational behavior. In addition, accelerometers can provide objective measurement of the amount of time spent in low levels of activity.[4,7,14,15] However, the assessment of sedentary behavior with these latter two measures remains problematic in terms of the recent consensus definition, because neither of the measures directly assess either sitting or energy expenditure.

Reducing sedentary behavior, although seen as a promising avenue for interventions aimed at disease prevention, remains a difficult challenge given that validated measures have not been established. Therefore, it has been difficult to set guidelines as to what the goal of a sedentary behavior reduction intervention should be.

SEDENTARY BEHAVIOR, OBESITY AND HEALTH

Recent research has taken a novel approach to finding the health effects of sedentary behavior by changing the focus from a lack of exercise to exploring the balance between sitting and moving around in light-intensity activity. In this model, the analysis controls for time spent in moderate and vigorous physical activity

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(exercise) to separate the health effects of exercise from sedentary time as an independent predictor of health outcomes. Controlling for time spent exercising, a large study of Canadians showed a dose–response relationship between time spent sitting, and all-cause mortality and mortality from cardiovascular disease,[16] with the highest mortality rates being among the most sedentary and obese. In other studies, after controlling for exercise, sedentary behavior has been linked to a number of poor health outcomes, including metabolic syndrome,[17] abnormal glucose metabolism,[13] heart disease and obesity.[2]

Inactivity physiology, a term coined to describe the molecular study of sedentary behavior, has shown one important mechanism that may be at work during sedentary behavior, and its relationship with health outcomes. Regulation of lipoprotein lipase (LPL) is impaired during simulated sedentary behavior in rats, and simple standing motions are enough to reverse this effect.[18] Impaired LPL is associated with metabolic risk factors, and increasing light-intensity activity had a greater effect on LPL than the addition of exercise training, and the mechanism at work while being sedentary is different from the protective mechanism of exercise.[2] There is a need to understand the mechanism governing the relationship between sedentary metabolism, with and without excess of calories, and the active metabolism during light-intensity physical activity. Importantly, LPL has a role in metabolic disorders, energy balance and obesity.[19]

The plausibility of an association between sedentary behavior and obesity is obvious, but the directionality of the association is difficult to assess and may be bidirectional. When Ekelund *et al.*[20] studied the relationship between obesity and sedentary behavior, overweight subjects were more likely to be sedentary at a later time, but sedentary subjects were not more likely to be overweight at a later time. If confirmed, this relationship has several implications for sedentary behavior research and interventions. The strong link between obesity and sedentary behavior shows that in addition to an obesity epidemic in America, we most likely also have a 'sedentary epidemic' confirmed by the large amount of time in daily life Americans spend in sedentary behavior.[4] In addition, interventions aimed at reducing sedentary behaviors should be more intensely focused on an obese population.

OBJECTIVE MEASUREMENT OF SEDENTARY BEHAVIOR

Sedentary behavior measurement is difficult, because the mechanisms that lead to the detrimental health effects associated with sedentary behavior have not been defined. Is it reduced caloric expenditure? Is it impaired LPL activity? Is it sitting specifically or would standing still also be as bad for you? Is there something special about television viewing versus other sedentary activities? The answer to these questions would guide how sedentary behavior should be measured. Currently, there are either self-report questionnaires or objective measures of sedentary behavior. This discussion will focus on objective measures, and these measures are accelerometer- or motion-sensor-based devices. Accelerometers are quite common tools for measurement, but they are usually embedded in some other device. Smart phones all have accelerometers in them to play games and orient the screen correctly. Objective physical activity measurement in research also relies mostly on accelerometer-based devices, such as the Actigraph. Unfortunately, as sedentary measurement is relatively new, the standards have not yet been established for objective monitors.

Actigraph

The Actigraph has been used in a number of studies to measure sedentary behavior, but there are limitations with using the Actigraph that need to be understood when looking at the results of these studies.[4,15,21] First, until recently, the Actigraph had not been calibrated for sedentary behavior. Many investigators have used a cutoff point of $\leqslant$100 counts per min as their definition of sedentary behavior based on observation. Fortunately, recent calibration studies have shown that this was a reasonable and possibly an optimal sedentary cutoff point.[3] Second, the standard positioning of the Actigraph (attached near the hip) or any other hip-located accelerometer registers up to 100 counts per min while sitting, but there are similarly low counts for activities, such as standing in line, riding a stationary cycle, taking a nap, standing at a stand-up desk, or most other stationary activities that can be performed standing or lying down. It also does not directly measure energy expenditure, the other part of the recently established definition.[5] It estimates higher levels of energy expenditure with some accuracy (R^2 values are around 0.55 when including daily activities[22]), but it is not considered an acceptable measure for activities with lower energy expenditures. Despite these noted limitations, the use of the Actigraph has been widespread in epidemiological studies, and it is one of the few available approaches for scientists to control for or stratify populations based on time spent in sedentary behavior. The assumption that this device can be validly used to estimate sedentary behavior is reasonably sound, because most of the human activities are locomotion-based, and it does distinguish sitting activities such as sedentary and ambulation as active; however, there is still considerable room for improvement.

ActivPal

A newer device that is available for measuring sedentary behavior is the ActivPal. This device is an accelerometer worn on the thigh. The Actigraph and ActivPal have significant differences in measured sedentary time, with the Actigraph reporting a higher number of minutes in sedentary behavior.[23] The placement of the ActivPal is both a strength and a weakness for the device. In terms of assessing the 'sitting' component of sedentary behavior measurement, the ActivPal is the most accurate accelerometer-based device, because its orientation changes markedly when going from a standing to a sitting posture.[24] In terms of activity intensity measurement, the energy expenditure estimates with this device can produce a significant underestimation, and as the device is attached to the thigh with a sticker, getting people to wear the device can prove difficult for any sort of long-term measurement.[25] Therefore, the selection of the appropriate sedentary measurement device will depend on how sedentary behavior is defined—a lack of increased energy expenditure versus sitting.

Wockets

In the future, measurement of sedentary behavior and the interventions designed to reduce sedentary behavior will likely be mobile-phone-based systems. Collaboration between Northeastern University, Massachusetts Institute of Technology and Stanford University has produced the Wocket system. Wockets are two accelerometers worn on wrist and ankle that communicate via a wireless signal to a mobile phone. The positioning of the wockets on the wrist and ankle have three advantages: the ankle provides counts that are similar to the counts produced at the hip, focus groups have confirmed that wearing the devices at these locations will improve compliance to the protocol, and the wrist and ankle provide the best data for activity-recognition algorithms.[26] Activity data are recorded on the phone and delivered through the data network to a secure server, and access to the server can be made through any web browser. This is a powerful system, because there is no user burden to upload the data; the only requirement is to wear the accelerometers and keep the phone in normal use. It also allows real-time intervention either from the researchers accessing the data or directly through the phone. Currently, the system delivers feedback to the user via text messages that are generated from the server without researcher intervention. Given the unlimited possibilities of developing

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mobile phone applications that could deliver a tailored intervention targeted at the individual level, this system has the advantages of combining research in engineering, exercise and behavior. Wockets are being developed as an open-source technology, and thus, it is available to researchers to customize and use for measurement and feedback depending on their needs (http://wockets.wikispaces.com/).

SEDENTARY BEHAVIOR INTERVENTIONS

Preventive medicine focuses on several essential behaviors to protect the population from the burden of disease and to limit costs to the healthcare system. For example, the current model of preventing smoking, maintaining a healthy weight, consuming a healthful diet, regular exercise and appropriate medical care are considered optimal for disease prevention.[27] Given that the average American spends about 7.7 h per day in sedentary behavior, primarily sitting,[4] this opens up a large amount of time that is ripe for intervention when you consider inactivity as a separate risk factor. The specific goal(s) of an intervention to reduce sedentary behavior are still not well-defined. For example, increasing the frequency of breaks in sedentary behavior appears beneficial for reducing waist circumference, body mass index, 2-h fasting glucose and triglycerides.[6] However, because few, if any, studies have looked at the frequency, intensity and duration of 'breaks', further research is needed to define what is both practical and optimal for these breaks.

Another question needs to be answered to design an appropriate intervention: what mechanism makes sedentary behavior so detrimental to health? Currently, there are two leading hypotheses that could explain the relationship between sitting and disease. First, it could simply be that when humans are sedentary, we expend far less energy than when we are active. As proof, simply increasing energy expenditure without changes in weight or fitness will still improve metabolic risk.[7] As an alternative explanation, 'inactivity physiologists' propose that there is a different and detrimental metabolic mechanism at work when we sit, and it gets worse the longer we sit.[2] If the reason sedentary behavior is related to disease is because of one or the other of these explanations, an alternative hypothesis, or because of both of the above, then the intervention design would have the goal of either increasing energy expenditure or avoiding prolonged sitting and these are not actually the same thing. For example, the intervention to reduce sitting time might include getting out of your chair every 15 min, or standing instead of sitting. The other intervention might be more focused on increasing movement such as walking workstations, walking meetings and foot pedals under the desk to significantly increase energy expenditure.

An intervention on sedentary behavior may be easier to adopt than the typical intervention promoting moderate- and/or vigorous-intensity physical activity. In a study that compared adding exercise with reducing sedentary behavior in children, the sedentary group fared better for weight loss than the exercise group.[28] If we test the hypothesis that sitting is unhealthy because of the low energy expenditure, we can compare an intervention on sedentary behavior with an exercise intervention designed to expend the same amount of additional calories. If you consider an 80-kg person who wants to burn an extra 100 kcal a day, the calculation is presented in Figure 1. As you can see, a moderate exercise intervention of walking for 30 min is equivalent to a standing intervention of 2 h. An argument could be made for the difficulty in changing exercise behavior versus reducing sedentary behavior in this context.

FUTURE DIRECTIONS

Methodologies for objective measurement of sedentary behavior are still in the preliminary phase of development, including the calibration of accelerometers for the sensitive and specific measurement of sedentary time. However, as an alternative to assessing sedentary time through a questionnaire, objective measurement is a vast improvement. A benefit of using accelerometers for sedentary measurement is that they are used for a number of other measures, including physical activity and sleep. Currently, the Actigraph software is calibrated for physical activity (at the waist) and sleep (at the wrist), but not specifically sedentary time (cutoff points can be input in the software). The ActivPal is calibrated for physical activity and sedentary time (both on the thigh), but not sleep. The Wockets have the potential for calibration in physical activity, sleep and sedentary behavior (because of the wrist and ankle locations and the potential for 24 h measurement). There is room for great improvement in the calibration of accelerometers, including improving activity recognition and energy expenditure estimates from motion data. The Wockets system has the potential to improve this calibration because it is a multiple-sensor system (for activity recognition) and an open-source accelerometer allowing access to all features of the raw signal (for energy expenditure estimates).

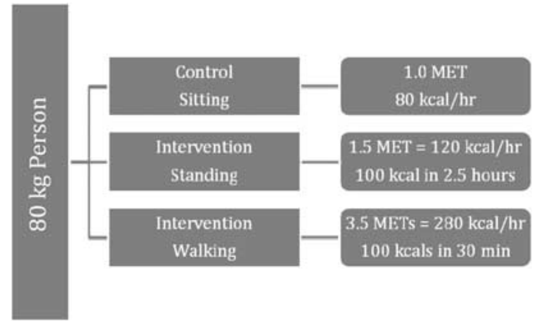

Figure 1. A comparison of interventions to expend an additional 100 kcals a day in an 80-kg person.

Given the relatively new ability to measure sedentary behavior, physical activity and sleep with one objective device, this is an exciting time to study the relationship between the entire activity spectrum and a number of health outcomes. The challenge for obesity researchers is now to consider the entire daily activity pattern when designing studies and planning interventions. Sedentary behavior alone will probably not prove to be the solution for preventing obesity, but a combination of daily exercise, decreasing sedentary behavior and adequate sleep will contribute to our understanding of treating and preventing obesity. New technology will also provide the potential to intervene in real time on all aspects of daily activity. The ability to collect data and provide feedback to the user through mobile devices, as with the Wockets, offers the opportunity to intervene at the time when the choice of activity is being made. For example, imagine a system that could prompt the user to take a break after so many minutes of sitting, inform the user before the end of the day when physical activity goals have not been met, and summarize unhealthy sleep patterns and strategies to improve them in the same week when the user really needs the sleep. In addition, all of this 24-h behavioral guidance comes from wearing a few small sensors with minimal additional input from the user.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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