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Relationship Between Sedentary Behavior and Cardiovascular Risk

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Abstract The majority of adults do not meet current guideline recommendations for moderate to vigorous physical activity. Recent research has linked a high amount of sedentary behavior with an increased risk of obesity, diabetes, the metabolic syndrome, cardiovascular disease, and death. This correlation with sedentary behavior even extends to individuals who meet recommended physical activity goals during the remainder of their day, which implies that sedentary behavior may represent a distinct cardiovascular risk factor that is independent of the overall amount of physical activity. During the past several years, there has been significant interest in identifying and understanding the mechanisms through which sedentary behavior affects cardiovascular health. In this review, we critically evaluate the literature pertaining to sedentary behavior and cardiovascular risk with an emphasis on studies published over the past year, and we suggest possible interventions that may help reduce sedentary behavior time.

Keywords Sedentary behavior · Cardiovascular risk · Physical activity · Lifestyle · mHealth

Introduction

Physical activity research has focused upon the relationship between moderate to vigorous intensity physical activity (MVPa) and health outcomes. Until recently, sedentary behavior has been largely overlooked. Part of the difficulty in assessing and studying sedentary behavior has been the need for standard definitions in the guidelines and literature [1]. Sedentary behavior is typically defined as any behavior resulting in less than 1.5 metabolic equivalents of task (METs), examples of which include most time spent in a seated or reclined posture (at a desk, in a car or bus, using a computer, or watching television) and generally exclude time spent asleep [2–4]. This is an important distinction from "physical inactivity" which has been used to describe the failure to meet a predefined MVPa threshold [5–9]. Quantifying sedentary behavior has typically been assessed by self-reported behaviors, and studies have often used surrogate markers like time spent watching television to measure sedentary behavior.

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Since this area of research is emerging, there are currently no US guidelines regarding sedentary behavior. The few international guidelines that exist provide limited recommendations for lifestyle changes. The Canadian Sedentary Behaviour Guidelines from the Canadian Society for Exercise Physiology recommend limiting recreational screen time to no more than 2 h per day and limiting "sedentary (motorized) transport, extended sitting, and time spent indoors" throughout the day [10]. Australia's Sedentary Behaviour Guidelines similarly recommend minimizing the amount of time spent in "prolonged sitting" and breaking up "long periods of sitting" as often as possible [11]. Until further evidence-based recommendations are available, it is reasonable to follow the above guidelines to the extent possible.

More recently, the growth of wearable technology has allowed more objective measurements through accelerometers or posture measures [12••]. It is important to note that people can, overall, be physically active (i.e., meet weekly exercise goals) while also engaging in high amounts of sedentary behavior. Several studies have shown that a high amount of sedentary behavior can be associated with increased morbidity and mortality regardless of an individual's MVPa [13–17]. Modern society is filled with opportunities for sedentary behavior in leisure, work, and commuting activities. Objective measurements have demonstrated that the average American adult spends more than 50 % of his/her waking hours in sedentary behavior [18].

Studies of US populations have found positive associations between increasing age and sedentary time, but relatively small variations among different gender and ethnic groups [19, 20]. In the Southern Community Cohort Study, Black women reported 45 min more viewing time than White women, and Black men reported 15 min more than White men in validated physical activity questionnaires [19]. However, overall sitting time as a proportion of overall awake time was similar between both races. Nearly 60 % of the participants' waking time was spent in sedentary behaviors, and no more than 25 % of participants followed the 2008 Physical Activity Guidelines for Americans, irrespective of gender or race.

Sedentary Behavior and Cardiovascular Disease

Even among those who are meeting the recommended physical activity time each week, researchers have hypothesized that some are still at an increased cardiovascular risk because they experience high amounts of sedentary time [12••]. Until recently, the independent association between sedentary behaviors and outcomes after adjustment for physical activity has been inconsistent. Since 2011, three studies from Scotland, the UK, and the USA have looked at the association between high sedentary time and cardiovascular disease (CVD) incidence. Stamatakis et al. followed 4512 individuals in the Scottish Health Survey from 2003 to 2007 for fatal and non-fatal CVD events [21]. With 215 CVD events, the covariate-adjusted hazard ratio for CVD events was 2.30 (95 % confidence interval (CI) 1.33–3.96) for participants reporting ≥4 h/day of screen time relative to <2 h/day. After adjusting for physical activity, the association was similar (hazard ratio (HR) 2.25, 95 % CI 1.30–3.89).

In another study from The European Prospective Investigation into Cancer and Nutrition, Wijndaele et al. studied 13,197 men and women free of known CVD for up to 11 years [17]. The HR for incident CVD based on sedentary time was 1.06 with a 95 % CI of 1.03–1.09. Also, each 1 h/day increase in television time was associated with increased risk of cardiovascular mortality (HR 1.07, 95 % CI 1.01–1.15; 373 deaths). Most recently in a study of the relationship of sedentary behavior and physical activity to incident CVD, Chomistek et al. followed 71,108 participants free of CVD at baseline from the prospective Women's Health Initiative [22••]. Sitting ≥10 h/day compared with ≤5 h/day was associated with increased CVD risk (HR 1.18, 95 % CI 1.09–1.29) in multivariable models including physical activity. Women were at highest CVD risk when they were inactive (≤1.7 MET task-h/week) and also sedentary (≥10 h/day of sitting). Interestingly, the associations between prolonged sitting and risk of CVD were stronger in overweight vs. normal weight women and in women older than 70 years of age. The results of these studies suggest that prolonged sitting time and sedentary behavior are associated with increased CVD risk among a relatively heterogeneous population.

In addition to the association between sedentary time and CVD incidence, several studies have also examined the relationship between sedentary time and CVD mortality. In 2012, Matthews et al. examined 240,819 adults without preexisting CVD from the NIH-AARP Diet and Health Study during an 8-year period [23]. Participants who reported the most television viewing (≥7 h compared with <1 h/day) were at greater risk of CVD mortality (HR 1.85, 95 % CI 1.56–2.20) after adjustment for MVPa. Additionally, among those adults with high levels of MVPa (>7 h/week) and high amounts of television viewing (≥7 h/day), there was an increased risk of CVD mortality (HR 2.00, 95 % CI 1.33–3.00) compared to those reporting the least television viewing (<1 h/day).

Kim et al. examined the association between various sedentary behaviors and CVD mortality [24]. In over 130,000 men and women 45–75 years of age, the multivariate HRs for ≥5 h/day vs. <1 h/day of sitting watching television were 1.20 (HR 1.20, 95 % CI 1.05–1.37) and 1.33 (HR 1.33, 95 % CI 1.14–1.55) for men and women, respectively. Most recently, Seguin et al. studied 92,234 women who participated in the Women's Health Initiative to evaluate the relationship between sedentary time and CVD and CVD-related mortality over a 12-year period [25••]. With self-reported sedentary time

≤4 h as the reference, women reporting the highest sedentary time (≥11 h) had increased risk of CVD (HR 1.14, 95 % CI 1.02–1.28) and CVD-related death (HR 1.32, 95 % CI 1.11–1.57) in models minimally adjusted for age, race, physical activities, and physical function score.

In 2014, five systematic reviews investigated the association between sedentary behavior and CVD in adults, two of which had conflicting results [16, 26, 27]. In two others that included meta-analyses, the results were consistent and showed a significant positive association between screen time (≥2 television hours/day) (HR 1.15 95 % CI 1.06–1.23) and sitting time (HR 2.47 95 % CI 1.44–2.24) and CVD risk, regardless of physical activity level [12••, 17]. Also, in 2012, Ford et al. reported that 2 h/day of sitting time and screen time were associated with an increase of 5 % (HR 1.05 95 % CI 1.01–1.09) and 17 % (HR 1.17 95 % CI 1.13–1.20) in CVD events, respectively [28].

Sedentary Behavior and Cardiovascular Risk Factors

Many reports in the literature have described the association between sedentary behavior and broader health outcomes of CVD, diabetes, and cardiovascular/all-cause mortality [29••]. The mechanisms through which sedentary behaviors lead to cardiovascular morbidity and mortality are underexplored in the literature but have been described to include defects in lipoprotein metabolism, early atherosclerosis, insulin resistance, and development of the metabolic syndrome. There are few studies that control for obesity or BMI, as it is thought to be a mediator between sedentary behaviors and the negative outcomes described.

Initial studies of cholesterol metabolism identified a reduction in lipoprotein lipase activity after prolonged sedentary behavior, and some studies suggested this as a pathway to increases in very-low-density lipoprotein, low-density lipoprotein (LDL), apolipoprotein B, total cholesterol, and triglycerides [29••, 30]. When looking at the entire body of published literature, however, the results may be less striking. A recent meta-analysis published in *Preventive Medicine* found an unfavorable link between sedentary behavior and triglyceride levels, but no evidence of an association with total or LDL cholesterol levels [31•].

Several studies have shown a strong and consistent relationship between sedentary time and diabetes [29••, 31•]. The exact physiologic mechanism is currently debated, but many studies suggest it is mediated through increased peripheral insulin resistance [30, 32, 33]. It has been well established that immobility rapidly leads to peripheral insulin resistance in both mouse and human studies. Genetic analysis has identified particular genotypes that predispose to adverse effects of sedentary behavior on glycemic regulation [34].

Studies linking sedentary behavior and metabolic syndrome (defined as the combination of abdominal obesity, raised triglycerides, reduced HDL-C, elevated blood pressure, and raised plasma glucose) have found a significant linear relationship between hours of daily sedentary behavior and risk of metabolic syndrome [35]. However, the composite nature of the metabolic syndrome makes it difficult to ascertain which components are most responsible.

The Effect of Positively Reallocating Sedentary Behavior Time

Given the benefits of habitual physical activity on CVD, it has been hypothesized that the CVD risk associated with sedentary behavior is due in large part to replacement of physical activity time. Several cross-sectional studies have assessed the effects of reallocating sedentary behaviors and examined the associations with CVD risk biomarkers. A recent study by Healy et al. found that displacing 2 h of sedentary time with standing improved several markers of glucose and lipid metabolism, with significant effects on BMI and waist circumference only seen when sedentary time was displaced with more active "stepping" time [36]. In one case, replacing 10 min of sedentary time with an equal amount of MVPa was associated with favorable effects on several risk factors, including hemoglobin A1c, body mass index, HDL cholesterol, and triglycerides [37].

In another study, beneficial associations ($p < 0.05$) with CVD risk biomarkers were seen when 30 min/day of sedentary time were replaced with an equal amount of either sleep (2.2 % lower insulin and 2.0 % lower homeostasis model assessment of beta-cell function), light-intensity activity (1.9 % lower triglycerides, 2.4 % lower insulin, and 2.2 % lower homeostasis model assessment of beta-cell function), or MVPa (2.4 % smaller waist circumference, 4.4 % higher HDL cholesterol, 8.5 % lower triglycerides, 1.7 % lower glucose, 10.7 % lower insulin, and 9.7 % higher homeostasis model assessment of insulin sensitivity) [38•]. These results not only highlight the health impacts of strictly increasing physical activity or reducing sedentary time, but they also suggest the additive value in displacing sedentary time with activity time. This lends additional support to evidence that shows that optimal sleep duration, less sedentary behavior time, and more time in active behaviors are associated with a reduced CVD risk profile.

Sedentary Behavior Despite an Active Lifestyle

It may be possible that one reaches their physical activity goals per guidelines but still has an abundant amount of sedentary behavior in their everyday life. The question then

becomes, does increased sedentary behavior increase one's risk of CVD despite adequate physical activity? Several prospective studies suggested that physical activity may not be enough to reduce the harms of increased sedentary behaviors [17, 39, 40]. Even in patients who performed at least 2 h of moderate activity per day, sedentary behavior still correlated with all-cause mortality in a dose-dependent manner [39].

More recent studies have shown similar trends. In a 2015 meta-analysis by Biswas et al., significant HRs were found with CVD mortality (HR 1.24 [95 % CI, 1.09 to 1.41]) and CVD incidence (HR, 1.14 [95 % CI, 1.00 to 1.73]) when adjusting for physical activity [12••]. However, these findings were more pronounced with lower amounts of physical activity than higher amounts. This study not only confirms the value of physical activity, but also suggests that it may not be sufficient. Similarly, in the Women's Health Initiative, which evaluated sedentary behavior in post-menopausal women with different levels of physical activity, women who sat greater than 10 h a day compared with those who sat <5 h a day had increased CVD risk (HR 1.18, 95 % CI 1.09 to 1.29) [22••]. In addition, women who engaged in 8.4 to 20 MET-h/week of physical activity (equivalent to 150 min/week of moderate-intensity exercise) were still at increased CVD risk if they reported prolonged sitting. It is important to note that women who exceeded 20 MET-h/week of physical activity did have clinically significant attenuation of CVD risk, as they were also the group that reported the lowest sitting time.

Evidence is emerging that breaking up sedentary time may be beneficial compared to uninterrupted sedentary time. Multiple studies in the literature have linked breaks in sedentary time with improved cardiometabolic biomarkers, but more prospective studies are needed to evaluate whether or not these improvements extend to reduced cardiovascular events [18, 41–46].

Intervention Strategies to Reduce Sedentary Behavior: Spotlight on Mobile Health and Built Environment

With ample opportunity to accumulate sedentary time while commuting, during work, at home, and in leisure activities, improvements in interventions aimed at reducing sedentary time are crucial in combating a growing public health issue [47]. A recent meta-analysis suggests that it may be easier to reduce sedentary time than to increase physical activity. The intervention components were aimed at increasing physical activity levels, reducing sedentary behavior times, and improving lifestyles, which had a focus on diet and nutrition, through various personalized protocols. In this meta-analysis, 34 studies were considered at low risk of performance bias (sedentary behavior was not the primary outcome), and on average, these studies showed a 22 min/day reduction in sedentary time for the intervention group (95 % CI −36 to −9 min/day). Specifically, lifestyle interventions aimed at both increasing activity and reducing sedentary behavior reduced sedentary behavior by 24 min/day (95 % CI −41 to −8 min/day) and interventions that only focused on reducing sedentary time reduced sedentary behavior by 42 min/day (95 % CI −79 to −5) [47]. While these results lend additional support to the possibility of helping individuals reduce sedentary behavior time, these studies and their interventions are limited by self-report and other methodological challenges, including intervention heterogeneity.

Mobile health or "mHealth" is used broadly to describe the intersection of mobile technology and the practice of medicine and public health. Miniaturization and wireless connectivity have allowed for dramatic gains in mHealth over recent years, including the use of smartphones as well as other "wearable" technology (pedometers, smartwatches, etc.) that can monitor a person's daily habits. Creative use of mHealth technology, which has the advantages of convenience, continuous monitoring, and patient engagement, holds promise for improving the current intervention models aimed at reducing sedentary behavior time. In fact, novel approaches of "prescribing" changes to sedentary behavior leveraging mHealth have been shown to reduce the risk of developing lifestyle-related chronic conditions [48].

While mHealth has emerged as an exciting potential option to help individuals increase physical activity and manage other cardiovascular-related risk factors, research investigating the effects of mHealth interventions on reductions in sedentary behavior at work and during leisure activity is limited. Most importantly, mHealth technologies help eliminate the inaccuracy of self-reported sedentary and physical activity time. Self-report is considered unreliable in a research setting due to individuals' tendency to underestimate sedentary time and overestimate active time. In addition, the growing acceptance among individuals to adopt wearable technology as a preventive and motivating measure to help promote increased levels of physical activity will also provide additional outlets to reduce sedentary time. Some wearable devices, for example, can be programmed to vibrate every 15 min–1 h if the individual has been sitting or still for too long. Ultimately, widespread use and adoption of ideas similar to this one will be dependent on future research studies to show its effectiveness.

In addition to mHealth, another (perhaps more far reaching) factor that can affect an individual's behavior is his or her "built environment." This term refers to the all the physical surroundings in a person's life, which include aspects relevant to sedentary behaviors including urban planning (i.e., sidewalks and parks) as well as workplace environment [49]. Changes to this built environment have been proposed as one strategy to reduce sedentary behavior (see Fig. 1). For

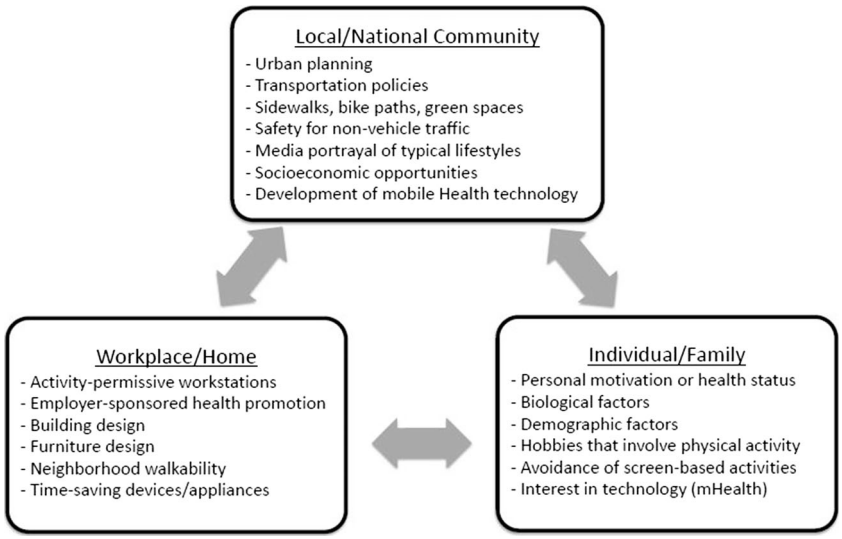

Fig. 1 Sedentary behavior domains of influence. Three domains for intervention in sedentary behavior. These levels of influence are highly interdependent and underscore the complexity of current sedentary lifestyles

example, the pooled effect of 38 studies that introduced activity-permissive workstations (i.e., standing desk and treadmill desk) into the work environment showed that individuals reduced their sedentary time by 77 min/8 h workday (95 % CI −120 to −35 min) compared to the control group [50•]. These results in conjunction with evidence of no detriment to work efficiency suggest that activity-permissive workstations can help reduce sedentary time during a workday without compromising long-term work performance.

Future Directions

Research into the impact of sedentary behaviors on health is an exciting field of study that is rapidly expanding in the literature. It has been historically difficult to accurately measure sedentary behavior, and many studies have used surrogate markers for sedentary behavior like "time spent sitting" or "time spent watching television" leading to increased heterogeneity of data. This may in part be due to the fact that there is no standardized definition of sedentary behavior. Much of the data is further weakened because it relies on self-reported behavior, which increases the risk of variability and bias [51]. Furthermore, sample sizes have been relatively small and underpowered to show benefit of reducing sedentary behavior or physical inactivity.

Yet, there has been tremendous growth in the number and quality of the studies on sedentary behavior. This is growing in parallel with the development and adoption of new wearable technology that allows for continuous and far more accurate measurement of behavior patterns. In addition to using objective measures in larger sample sizes, future studies should focus on the impact of how specific alterations in sedentary behaviors affect health. This includes further research into the ways in which time spent in sedentary behavior is replaced (with prior studies implying benefits if it is replaced with sleep, light exercise, or MVPa) or interrupted. We should also continue to study the development and impact of mHealth applications and built environment on behavior as well as health outcomes. Furthermore, it may be beneficial to investigate high-risk populations who would benefit the most from reduction in sedentary behavior.

Conclusions

The body of evidence that sedentary behavior leads to poor health outcomes has been steadily growing. The literature has shown a consistent link between sedentary behavior and CVD/mortality, as well as cardiovascular risk factors like diabetes and metabolic syndrome. There have been studies showing successful interventions to reduce sedentary time, and other studies have found that replacing sedentary time with other activities is associated with reduced CVD risk. Given that the average American spends more than half of their waking hours in some form of sedentary behavior, there is ample opportunity to make improvements in cultural lifestyle. There is still much work to be done, but taken as a whole, the current literature indicates that there is potential for significant public health gains by reducing sedentary behaviors.

Compliance with Ethical Standards

Conflict of Interest Robert V. Same, David I. Feldman, Nishant Shah, Mahmoud Al Rifai, and Haitham M. Ahmed declare that they have no conflicts of interest.

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