Chapter 28
Limitations in Sedentary Behaviour Research and Future Research Needs

Daniela Schmid, Carmen Jochem, and Michael F. Leitzmann

Abstract This section discusses limitations and uncertainties in sedentary behaviour research and briefly presents future research needs in the field. These include but are not limited to better understanding the association between sedentary behaviour and health, increasing the validity and reliability of measuring sedentary behaviour, more clearly identifying the determinants and correlates of sedentary behaviour, devising appropriate interventions to reduce sedentary behaviour, and effectively translating research findings aimed at decreasing extended periods of sitting into practice. Specifically, there is a need for prospective studies using objective measures of sedentary behaviour to determine how long people should maximal sit per day and how often they should interrupt their daily sitting to prevent the harmful effects of prolonged sitting. The combined use of self-report and accelerometer-derived measures is needed to enhance the validity and comprehensiveness of existing sedentary behaviour assessments. Future studies should also expand their exposure assessments to include sedentary behaviours in the transportation and household domains. To formulate personalized disease prevention strategies, enhanced research efforts are needed for certain population subgroups, such as persons with chronic diseases or disabilities, overweight/obese individuals, the elderly, socially disadvantaged individuals, and ethnic/racial minorities. In addition, additional future mechanistic and experimental work is required to identify the aetiologic pathways through which sedentary behaviour impacts upon the aetiology of chronic diseases.

Mounting epidemiologic evidence suggests that sitting for long periods of time poses risk for developing chronic diseases and preterm death [1–3]. Although considerable progress has been made in sedentary behaviour research over the past years, numerous uncertainties and limitations remain that require further attention. Evidence linking sedentary behaviour to health-related outcomes largely bears on observational studies, which do not allow interpretation of causal

D. Schmid • C. Jochem • M.F. Leitzmann (✉)
Department of Epidemiology and Preventive Medicine, University of Regensburg, Regensburg, Germany
e-mail: daniela.schmid@ukr.de; carmen.jochem@ukr.de; michael.leitzmann@ukr.de

M.F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, DOI 10.1007/978-3-319-61552-3_28

relationships. Confirmatory evidence from intervention and experimental studies is sparse. Understanding the underlying biologic mechanisms and identifying factors that influence sedentary behaviour is crucial to further our knowledge about the role of sedentary behaviour in disease prevention and to devise appropriate public health guidelines.

Research in the field of sedentary behaviour epidemiology describes a dynamic process continuously creating new knowledge about the influence of sedentary behaviour on health. Although we believe that the available scientific evidence base is sufficient to explain a pivotal role of prolonged sedentary time for the development of chronic diseases, knowledge in this relatively new research discipline needs to further grow to facilitate effective public health interventions. A number of public health organizations expanded their physical activity guidelines to recommend avoiding sedentary behaviour, which is an important step in thwarting the rapid increase in a sedentary lifestyle (see Chap. 3). However, the available scientific evidence base does not allow specific recommendations beyond broad formulations to "reduce sedentary time" or to "break up prolonged sitting time frequently".

Briefly worded, there is a line of inquiry that needs to be resolved before we can take the next step in informing effective disease prevention strategies. In the following section, we will discuss limitations and uncertainties in sedentary research, followed by a presentation of future research needs in this field. We will use the *behavioural epidemiology framework* proposed by Sallis et al. [4], which specifies a sequence of five research phases regarding health-related behaviours. These five phases are (1) establishing relationships between the behaviour and health outcomes, (2) developing behaviour measures, (3) identifying influences on the behaviour, (4) evaluating interventions to impact the behaviour, and (5) translating findings into practice [4]. This framework was recently adapted to sedentary behaviour epidemiology [5]. For further detail on the behavioural epidemiology framework, please refer to Chap. 15.

1. What do we know about the relationship between sedentary behaviour and health-related outcomes?

A large proportion of studies reporting on harmful associations of prolonged time spent sedentary with disease outcomes and mortality argue that sedentary behaviour independently affects health [2]. That conclusion is primarily based on studies that showed consistent findings from models that were adjusted for physical activity and those that were not adjusted for physical activity. The method of comparing adjusted and unadjusted effect estimates, however, represents a rather crude approach to exploring independent effects. Numerous prospective studies investigating the joint effects of sedentary behaviour and moderate-to-vigorous physical activity on mortality risk [6–12] presented inconsistent findings. A recent meta-analysis [13] revealed that 1 h of moderate physical activity spread over the day was sufficient to oppose the adverse effect of sitting for more than 8 h. In contrast, the detrimental association of sitting with mortality persisted for TV viewing, regardless of the physical activity level [13].

Future studies are needed to resolve whether and to what extent physical activity can alleviate the deleterious health consequences associated with prolonged sitting time. It is worth noting that previous studies largely relied on self-reported measures of sedentary behaviour, which are prone to measurement error resulting from recall and reporting biases and, thus, likely under- or overestimated the true effect of sedentary behaviour on health-related outcomes. As such, future studies using objective measures of sedentary time are desirable to confirm the findings from previous reports.

Clearly, sedentary behaviour and physical activity describe distinct behaviours, yet both represent co-dependent elements of daily energy expenditure during a finite number of waking hours, that is, spending time in one activity behaviour ultimately replaces time spent in another activity behaviour. Recent studies employed isotemporal substitution models to explore the effect of substituting time spent in one activity behaviour for the same amount of time spent in another activity behaviour [14]. That approach may help guide people in optimizing their daily activity behaviour aimed at replacing sedentary time with ambulatory movement [14]. For example, using data from the National Health and Nutrition Examination Survey (NHANES) 2003–2006, we found that replacing 30 min per day of objectively measured sedentary time with an equal amount of light activity or moderate-to-vigorous activity was associated with 14% and 50% reduced risks of all-cause mortality, respectively [15]. Recent substitution analyses of the NHANES 2003–2006 [16] and Whitehall II epidemiological cohorts [17] further indicated that reallocations of sedentary time to moderate-to-vigorous physical activity were associated with improved levels of triglycerides [16, 17], high-density lipoprotein (HDL) cholesterol [16, 17], insulin [16], homeostasis model assessment of insulin sensitivity [16], and adiposity [17]. A novel statistical avenue in sedentary behaviour research includes compositional data analysis, which enables a comprehensive investigation of the proportional distributions of daily time spent in sedentary behaviour and other activities in relation to health outcomes [18].

While the vast majority of sedentary behaviour research has focused on the general population, little is known about whether sedentary behaviour differently impacts upon health among population subgroups. Persons with chronic diseases or disabilities, overweight/obese individuals, the elderly, socially disadvantaged individuals, and ethnic/racial minorities are at increased risk of exposure to high volumes of sedentary behaviour and may face several barriers to overcome physical inactivity. Thus, enhanced research in population subgroups represents an important step forward in devising personalized disease prevention interventions.

Another question that remains insufficiently answered concerns the physiologic mechanisms linking sedentary behaviour to health-related outcomes. Although experimental studies on sedentary behaviour in humans are accumulating, such as investigations of the metabolic consequences of interruptions to prolonged sitting (see Chap. 5), little is known about the precise aetiologic pathways through which sedentary behaviour affects health-related outcomes. Important insights into the biologic consequences of sedentary behaviour have been obtained from animal experiments conducted by Hamilton and colleagues [19, 20], who found that

reduced contractile activity localized to the two hindlimbs of mice led to the suppression of skeletal muscle lipoprotein lipase (LPL) activity, which is crucial for triglyceride uptake and production of HDL cholesterol. We do not know whether similar physiologic consequences of sedentary behaviour on LPL activity occur in humans. Previous studies of interruptions of sitting time on blood lipids in healthy adults revealed inconsistent findings [21, 22]. Discrepancies between study results may have arisen from variation in study populations, sample sizes, study duration, initial metabolic state, and type of intervention. Yet, experimental studies on interrupted sitting regimens may deliver important information about how long individuals should maximally sit per day and how often extended periods of sitting time should be interrupted to improve metabolic function and other health-related conditions. For example, a recent study found that breaks in sitting resulted in improvements of postprandial glucose and insulin responsiveness, and the beneficial effect was greater in individuals who frequently interrupted prolonged sitting by short activity bouts than in those who interspersed a single bout of continuous physical activity between a long period of sitting [23].

While most experimental studies in humans examined the effect of extended sitting time and interruptions of sitting time on glucose and lipid metabolism, there is a paucity of data on other biomarkers that may be operative in the development of chronic diseases, such as adipokines (e.g. leptin, adiponectin), pro-inflammatory cytokines (e.g. interleukin (IL)-6, tumour necrosis factor (TNF)-α), and insulin-like growth factor (IGF) and insulin-like growth factor-binding protein (IGFBP) (e.g. IGF-I, IGFBP-III).

2. How can we validly and reliably measure sedentary behaviour?

Existing data on sedentary behaviour are limited by the heterogeneity of methods used to assess sedentary behaviour and the poor to modest validity of self-reported sedentary behaviour measures (see Chap. 2). Inconsistencies in study findings may stem from misconception and misclassification of the term “sedentary behaviour” in the individual studies. In our understanding, sedentary behaviour is defined as “any waking behaviour characterized by an energy expenditure $\leq$1.5 METs while in a sitting or reclining posture” [24]. A plethora of epidemiologic studies used mixed categories of sedentary behaviour and physical activity in the sedentary behaviour context and, thus, may have introduced some degree of misclassification error [25]. High levels of sedentary time may coincide with high levels of physical activity [25]. For example, office workers spending hours sedentary at their desks may accumulate an appreciable amount of moderate-to-vigorous exercise in the gym after work. Comparing a high sedentary behaviour level with the “most physically active” category as the referent would neglect the coexistence of high amounts of both sedentary behaviour and physical activity [25]. In addition, inferring occupational sitting from job titles represents a potential source of exposure misclassification [25]. To obtain comparable and valid results, future studies of sedentary behaviour should be consistent in their terminology and measurement structure.

Most studies to date evaluated sitting time based on self-report measurements. Self-reported methods are widely used because they are feasible in large population studies, and they capture important information about the type of sedentary behaviour (e.g. TV watching) occurring in a specific domain (e.g. recreation, household, occupation, transport). However, they are prone to measurement error, resulting in potential distortion of the true relationship [26–28]. Advances in measurement technology now deliver affordable objective methods such as accelerometers and inclinometers that help overcome the limitations of self-report assessments [26]. To date, only a small number of studies have used objective activity monitors to measure sedentary time accumulated throughout the day. Device-based measurements have been demonstrated to more accurately assess total sedentary behaviour than self-report measurements [26–28]. Moreover, they enable assessment of total sedentary time across the day and provide important information about patterns of sedentary behaviour accumulation, e.g. durations of sedentary bouts and interruptions in sedentary time [28]. Advanced activity monitoring using the activPAL allows different postures such as sitting/lying and standing to be distinguished [29]. However, device-based measurement does not discriminate between different types and domains of sedentary behaviour. In addition, there are several methodologic issues with regard to accelerometer measurements (e.g. definitions of epoch length, wear time, non-wear time, cut-points for sedentary behaviour, number of valid wear days) that have not yet been resolved and require further study.

Combining self-reported measures with objectively derived data has been recommended to improve the comprehensiveness and accuracy of sedentary behaviour measurements [26, 28]. A recent study utilizing data of around 10,000 adults aged $\geq$20 years from the NHANES 2003–2006 provides an example of how a more comprehensive measure of sedentary behaviour can be achieved from the combinatorial use of self-reported and objective instruments [28]. The descriptive epidemiology of sedentary time determined by self-reported measures and accelerometer-derived measures was compared [28]. The major results indicated that both self-reported measures and accelerometer-derived measures identified women to spend more time in sedentary pursuits than men, and the self-reported measures were able to uncover the prevalence of TV viewing, computer use, and screen time to be lower in women than men. Moreover, domain-specific variation in sedentary time across different race/ethnicity groups could be identified by self-reported measures. For example, non-Hispanic whites and non-Hispanic blacks were more likely to be sedentary than Mexican Americans according to all sedentary behaviour measures, with the exception of TV viewing time [28]. Stratifying sedentary behaviour by both race/ethnicity and life span, self-reported measures detected significant differences in women, while important differences in men were noted using accelerometer-based measures [28]. Future measurements should extend beyond self-reported measures of sedentary behaviour to allow for a more valid objective measurement of sedentary behaviour accumulated throughout the day.

The vast majority of sedentary behaviour studies are limited in that they evaluated sedentary time at a single point in time, typically the time at study entry. Repeated measurements allow extraction of information about diverse patterns and changes of sedentary behaviour over time and identification of specific time periods in life that are sensitive to prolonged sedentary time. For example, a recent study utilizing data from the National Institutes of Health (NIH)-AARP Diet and Health Study evaluated change in TV viewing time between 1994–1996 and 2004–2006 in relation to death occurring until 2011 [30]. High versus low amounts of TV viewing at both time points were related to a statistically significant increased risk of mortality, but the hazardous relation tended to be most marked at the second time point [30]. Moreover, the above-mentioned study [30] was able to discover important findings related to change in TV viewing and mortality risk. Specifically, an increase in TV viewing between the two measurement points was related to an increased risk of mortality, and a decline in TV viewing was associated with a reduction in mortality risk [30]. Another study found that hourly increments of change in TV viewing over a 5-year period were associated with increases in biologic markers (body mass index, waist circumference, fasting insulin, and insulin resistance) of postmenopausal breast cancer risk [31]. The sedentary lifestyle of an individual does not remain constant over the lifetime, but rather, it alters during the life course, with the elderly usually spending more time in sedentary activities than young- or middle-aged adults [28]. Likewise, hormonal and metabolic changes occur over the life span [32, 33] leading to potential different biologic responses to sedentary behaviour among various age groups. Thus, the exploration of sedentary behaviour at different life stages may provide important insights into time-sensitive effects of sedentary behaviour on disease outcomes and aetiology.

3. What are the determinants and correlates of sedentary behaviour?

Sedentary behaviour scientists have been extensively engaged in research on the effect of sedentary behaviour on various health-related outcomes. In future research, more emphasis should be placed on the study of factors that drive sedentary behaviour. There are numerous potential factors that may influence sedentary behaviour including demographic, psychological, social, and environmental factors. Identifying correlates and determinants of sedentary behaviour at a multilevel represents an important step in designing appropriate interventions programmes aiming to reduce sedentary behaviour. Ecologic approaches in correlates research may help navigate through the numerous possible influences of sedentary behaviour and identify important interactions across levels that are relevant for being targeted in sedentary behaviour interventions (see Chap. 15). To understand why persons are inactive and others are not, research into correlates should expand beyond the study of individual factors to identify the potential of changes in contextual and environmental factors for preventing non-communicable diseases. In this regard, understanding environmental correlates of transportation and recreational activity in low-income and middle-income countries has been formulated as a research priority to support the development of contextually tailored interventions aiming to reduce the rapid proliferation of inactivity brought

about by increased urbanization, passive entertainment, and motorized commuting [34].

4. What are feasible interventions to reduce sedentary behaviour?

To determine which specific public health initiatives to pursue, results from intervention programmes aiming to change sedentary behaviour are essential. Intervention studies designed to reduce sedentary behaviour have proliferated during recent years, and while some intervention programmes are aimed at changing an individual's behaviour, others have directed their attention towards environmental factors. Several intervention studies have focused on alterations in the work environment and have introduced sit-to-stand desks to combat the dangers of several hours sitting in the office [35]. Findings of numerous studies showing prolonged sedentary behaviour to harmfully affect health-related outcomes led public health scientists to the logical conclusion that replacing hours being seated by standing would be a feasible alternative to produce a healthy working environment. The creation of 'movement-friendly' places for working includes computer-based prompts and personal motion assessment devices, placement of toilets and kitchens on different floors, promotion of stair use, and standing meetings [35]. However, there is a need for future prospective studies and randomized controlled trials to evaluate standing and light activity interventions in real office environments [35] taking into account the feasibility, acceptability, sustainability, and safety of the interventions. Moreover, exploration of the long-term effects of such interventions on health-related outcomes requires further research attention.

The efficiency of interventions for reducing time spent sitting in the household and transportation domains is largely unexplored. There is likely to be value in future intervention studies aiming to reduce sitting during transportation. Self-reported data from the USA, Australia, and Belgium [36] revealed that adults spent on average 326.7–478.6 min per week in motorized transportation. People would meet the physical activity recommendations of 150 min per week of moderate-intensity activity [37] if they replaced half of the time spent in a car or bus for commuting by moderate-intensity pursuits of walking or bicycling.

The majority of intervention studies published to date involved only healthy adults, and thus studies of understudied population groups such as individuals with chronic disease or disabilities, ethnicity/race minorities, elderly, or overweight/obese individuals are a research priority. Such groups are at an increased risk for high levels of sedentary time and subsequent negative health consequences and may particularly benefit from effective intervention programmes aiming to reduce sedentary behaviour. The development of intervention programmes with particular attention paid to these subgroups is suggested to inform personalized disease prevention strategies.

5. How can research findings be effectively translated into practice?

In a final step, public health initiatives need to be informed by evidence from the preceding phases. The design of an intervention programme that has proven efficiency in the study scenario may be unwise if it cannot be effectively applied

to a real-life setting. Implementation issues are complex, and they have a host of barriers in that multiple aspects need to be taken into account including feasibility, acceptability, cost-effectiveness, and other environmental, organizational, and political factors. The last phase deals with questions about how we can properly disseminate, implement, and maintain effective interventions. Clearly, more research is needed to ensure successful translation of evidence-based intervention programmes into real-life settings. This important area of future research will require mobilizing transdisciplinary collaboration.

28.1 Summary

Although a considerable amount of knowledge has been accomplished in the field of sedentary behaviour epidemiology over the past decades, further progress in sedentary behaviour research is needed to inform effective intervention programmes aiming to reduce long periods of sitting. Future prospective studies using objective measures (e.g. accelerometers) are needed to confirm the findings from self-report studies on the relationships between sedentary behaviour and a variety of health-related outcomes. The combined use of self-report measures and accelerometer-derived measures may represent a valuable future approach to enhance the comprehensiveness and validity of sedentary behaviour measurements. While previous studies have predominantly focused on TV viewing or total sitting time, future studies should place more emphasis on other domains such as transportation and the household to expand the potential for interventions. Enhanced research efforts are suggested for population subgroups to allow personalized disease prevention strategies. Moreover, future mechanistic and experimental studies are needed to identify the biologic pathways through which sedentary behaviour affects the aetiology of various disease outcomes. Equally important are studies to explore for how long people should maximal sit and how often they should interrupt their sitting to prevent the harmful effects of prolonged sitting on health. Such data are needed to build a stronger basis for sedentary behaviour recommendations. Moreover, research into correlates should expand beyond factors at the individual level to identify different social and environmental contexts that can be targeted in future intervention programmes. Finally, efforts to implement and disseminate intervention programmes need to be evaluated to ensure the successful implementation of evidence-based research findings into real-life settings.

References

1. Schmid D, Leitzmann MF. Television viewing and time spent sedentary in relation to cancer risk: a meta-analysis. J Natl Cancer Inst. 2014;106(7) doi:10.1093/jnci/dju098.
2. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. Ann Intern Med. 2015;162(2):123–32.
3. Grontved A, Hu FB. Television viewing and risk of type 2 diabetes, cardiovascular disease, and all-cause mortality: a meta-analysis. JAMA. 2011;305(23):2448–55.
4. Sallis JF, Owen N. Physical activity and behavioral medicine. Thousand Oaks, CA: Sage; 1999.
5. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev. 2010;38(3):105–13.
6. Katzmarzyk PT, Church TS, Craig CL, Bouchard C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med Sci Sports Exerc. 2009;41(5):998–1005.
7. Patel AV, Bernstein L, Deka A, Feigelson HS, Campbell PT, Gapstur SM, et al. Leisure time spent sitting in relation to total mortality in a prospective cohort of US adults. Am J Epidemiol. 2010;172(4):419–29.
8. Matthews CE, George SM, Moore SC, Bowles HR, Blair A, Park Y, et al. Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. Am J Clin Nutr. 2012;95(2):437–45.
9. Kim Y, Wilkens LR, Park SY, Goodman MT, Monroe KR, Kolonel LN. Association between various sedentary behaviours and all-cause, cardiovascular disease and cancer mortality: the multiethnic cohort study. Int J Epidemiol. 2013;42(4):1040–56.
10. Pavey TG, Peeters GG, Brown WJ. Sitting-time and 9-year all-cause mortality in older women. Br J Sports Med. 2015;49(2):95–9.
11. Van der Ploeg HP, Chey T, Korda RJ, Banks E, Bauman A. Sitting time and all-cause mortality risk in 222 497 Australian adults. Arch Intern Med. 2012;172(6):494–500.
12. Schmid D, Ricci C, Leitzmann MF. Associations of objectively assessed physical activity and sedentary time with all-cause mortality in US adults: the NHANES study. PLoS One. 2015;10(3):e0119591.
13. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. Lancet. 2016;388(10051):1302–10.
14. Mekary RA, Willett WC, Hu FB, Ding EL. Isotemporal substitution paradigm for physical activity epidemiology and weight change. Am J Epidemiol. 2009;170(4):519–27.
15. Schmid D, Ricci C, Baumeister SE, Leitzmann MF. Replacing sedentary time with physical activity in relation to mortality. Med Sci Sports Exerc. 2016;48(7):1312–9.
16. Buman MP, Winkler EA, Kurka JM, Hekler EB, Baldwin CM, Owen N, et al. Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005–2006. Am J Epidemiol. 2014;179(3):323–34.
17. Hamer M, Stamatakis E, Steptoe A. Effects of substituting sedentary time with physical activity on metabolic risk. Med Sci Sports Exerc. 2014;46(10):1946–50.
18. Chastin SF, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: a novel compositional data analysis approach. PLoS One. 2015;10(10):e0139984.
19. Zderic TW, Hamilton MT. Physical inactivity amplifies the sensitivity of skeletal muscle to the lipid-induced downregulation of lipoprotein lipase activity. J Appl Physiol (1985). 2006;100(1):249–57.
20. Bey L, Hamilton MT. Suppression of skeletal muscle lipoprotein lipase activity during physical inactivity: a molecular reason to maintain daily low-intensity activity. J Physiol. 2003;551(Pt 2):673–82.

21. Cooper AR, Sebire S, Montgomery AA, Peters TJ, Sharp DJ, Jackson N, et al. Sedentary time, breaks in sedentary time and metabolic variables in people with newly diagnosed type 2 diabetes. Diabetologia. 2012;55(3):589–99.
22. Bailey DP, Locke CD. Breaking up prolonged sitting with light-intensity walking improves postprandial glycemia, but breaking up sitting with standing does not. J Sci Med Sport. 2015;18(3):294–8.
23. Peddie MC, Bone JL, Rehrer NJ, Skeaff CM, Gray AR, Perry TL. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. Am J Clin Nutr. 2013;98(2):358–66.
24. Barnes J, Behrens TK, Benden ME, Biddle S, Bond D, Brassard P, et al. Letter to the Editor: Standardized use of the terms "sedentary" and "sedentary behaviours". Appl Physiol Nutr Metab. 2012;37(3):540–2.
25. Lynch BM, Boyle T. Distinguishing sedentary from inactive: implications for meta-analyses. Br J Cancer. 2014;111(11):2202–3.
26. Matthews CE, Moore SC, George SM, Sampson J, Bowles HR. Improving self-reports of active and sedentary behaviors in large epidemiologic studies. Exerc Sport Sci Rev. 2012;40 (3):118–26.
27. Celis-Morales CA, Perez-Bravo F, Ibanez L, Salas C, Bailey ME, Gill JM. Objective vs. self-reported physical activity and sedentary time: effects of measurement method on relationships with risk biomarkers. PLoS One. 2012;7(5):e36345.
28. Healy GN, Clark BK, Winkler EA, Gardiner PA, Brown WJ, Matthews CE. Measurement of adults' sedentary time in population-based studies. Am J Prev Med. 2011;41(2):216–27.
29. Lyden K, Kozey Keadle SL, Staudenmayer JW, Freedson PS. Validity of two wearable monitors to estimate breaks from sedentary time. Med Sci Sports Exerc. 2012;44(11):2243–52.
30. Keadle SK, Arem H, Moore SC, Sampson JN, Matthews CE. Impact of changes in television viewing time and physical activity on longevity: a prospective cohort study. Int J Behav Nutr Phys Act. 2015;12(1):156.
31. Wiseman AJ, Lynch BM, Cameron AJ, Dunstan DW. Associations of change in television viewing time with biomarkers of postmenopausal breast cancer risk: the Australian diabetes, obesity and lifestyle study. Cancer Causes Control. 2014;25(10):1309–19.
32. Roberts SB, Rosenberg I. Nutrition and aging: changes in the regulation of energy metabolism with aging. Physiol Rev. 2006;86(2):651–67.
33. Roth GS. Hormone action during aging: alterations and mechanisms. Mech Ageing Dev. 1979;9(5–6):497–514.
34. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW, et al. Correlates of physical activity: why are some people physically active and others not? Lancet. 2012;380 (9838):258–71.
35. Buckley JP, Hedge A, Yates T, Copeland RJ, Loosemore M, Hamer M, et al. The sedentary office: an expert statement on the growing case for change towards better health and productivity. Br J Sports Med. 2015;49(21):1357–62.
36. Van Dyck D, Cerin E, Conway TL, De Bourdeaudhuij I, Owen N, Kerr J, et al. Associations between perceived neighborhood environmental attributes and adults' sedentary behavior: findings from the U.S.A., Australia and Belgium. Soc Sci Med. 2012;74(9):1375–84.
37. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc. 2011;43(7):1334–59.