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■ Review Article

Sedentarism and Chronic Health Problems

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Increased mechanization and technological advances have simplified our lives on the one hand and increased sedentary behaviors on the other hand, paving the way for emerging global health concerns, i.e., sedentarism, which could be the leading cause of all major chronic health problems worldwide. Sedentarism is a habitual behavior of choosing and indulging in low-energy expenditure activities (≤1.5 metabolic equivalents), such as chair-type (sitting, studying, traveling) or screen-type activities (TV, computers, mobile). With technological advancements, there is a significant transition in the lifestyles of people from being active (walking) to being more desk-bound (sitting). Prolonged sitting can have unintended consequences for health with sitting time >7 h/d, leading to a 5% increase in all-cause mortality with each additional hour spent sitting (i.e., +7 h/d), while considering physical activity levels. This review will highlight how sedentarism is emerging as a major risk factor for the rising incidence of non-communicable diseases, especially among young adults and adults. Chronic diseases, such as obesity, diabetes, coronary heart disease, and cancer, are the leading causes of death worldwide. Hence, there is an urgent need for collective action to mitigate the burgeoning public health crisis posed by sedentarism in the 21st century. This paper intends to set in motion a call for all policymakers and public health professionals placed nationally or internationally to reach a consensus on ending sedentarism and provide viable resolutions for effective management of excessive sedentary behaviors and healthy adoption and maintenance of active lifestyles among individuals of all age groups.

Keywords: Sedentary Behavior; Non-communicable Diseases; Sitting; Screen Time; Physical Activity; Technology

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INTRODUCTION

Since the Industrial Revolution, advancements in science and technology have revolutionized societies, leading to mechanization, urbanization, computerization, automation of household chores, and increased reliance on motorized transportation. This has fostered "technophilic" societies that prioritize physical comfort and prolonged sitting, a phenomenon at odds with the human body's need for physical activity.[1] Lack of physical activity is linked to numerous health issues, including cancer, insulin resistance, diabetes, hypertension, coronary and cerebrovascular diseases, overweight or obesity, metabolic syndrome, non-alcoholic liver disease, osteoporosis, respiratory diseases, dementia, depression, anxiety, and all-cause mortality.[2,3] Excessive sitting or sedentary behaviors have created space for the rise of new public health problems of sedentarism, i.e., indulgence in sedentary behaviors. The Sedentary Behavior Research Network defines sedentary behavior as "any waking behavior characterized by energy expenditure ≤1.5 metabolic equivalents (METs) while in a sitting, reclining, or lying posture."[4] Sedentarism encapsulates four key domains, namely occupation (including education), transport, leisure time, and household, which contribute to total sitting time. The spectrum of sedentarism is not merely limited to a lack or less of physical activity but marked by behavioral attributes and choices in which sitting or lying becomes the predominant posture.[1] This shift from active to predominantly sedentary lifestyles leads to a rise in non-communicable diseases (NCDs).

Physical activity has witnessed a "generational change," i.e., people are becoming increasingly sedentary generation after generation. Similarly, the disease pattern also changed. With the transition in every phase—health, nutrition, demographics, lifestyle, healthcare, technological, biological, environmental, social, and ecological—an "epidemiological transition" has taken place wherein there are changes in the pattern of health and, disease with a shift from infectious, parasitic, and deficiency diseases to NCDs.[5] This shift is characterized by human movement from underdeveloped to advanced levels of development and modernization.[6] Improvements in water, sanitation, and hygiene practices have reduced communicable diseases, but new health challenges have emerged.[5,6]

Researchers worldwide are studying the adverse effects of this comparatively new phenomenon on health and have discerned a positive relationship through a multitude of studies. Sedentarism has reached epidemic levels, contributing to the prevalence of NCDs like cardiovascular diseases, diabetes, cancer, and chronic respiratory diseases, which now account for 74% of global deaths.[7] The economic impact is significant, with a 0.5% reduction in annual economic growth for every 10% rise in NCD-related mortality.[8]

This narrative review aims to (1) summarize comprehensively the current state of knowledge on sedentary behaviors and their relationship with NCDs; (2) examine the mechanisms behind sedentarism's health impacts; (3) discuss intervention strategies to mitigate sedentarism's public health effects; and (4) identify research gaps and future directions. This review aims to inform policymakers, healthcare professionals, and stakeholders about the pressing need to address sedentarism and promote active lifestyles in contemporary society.

A comprehensive search of databases (PubMed, Scopus, Web of Science, Google Scholar) was conducted using keywords related to sedentary behaviors and public health. Peer-reviewed articles, systematic reviews and meta-analyses were screened for relevance. Key themes and findings were extracted and synthesized to provide a holistic understanding of sedentarism's implications and potential interventions.

This review highlights the serious medical and public health issues linked to widespread sedentarism, emphasizing its role as a major risk factor for NCDs such as obesity, diabetes, coronary heart disease, and certain cancers. Additionally, it provides a comprehensive overview of sedentarism, its global prevalence, and the transition from active to sedentary lifestyles driven by technological advancements. The review underscores the detrimental health effects of prolonged sitting and low-energy activities, presenting evidence-based literature on these impacts. To combat sedentarism, the review advocates for promoting physical activity through various intervention strategies at individual, school, workplace, healthcare, community, and policy levels. It calls for immediate action from international and national agencies, policymakers, and healthcare professionals to prioritize initiatives that encourage active lifestyles while balancing technological conveniences with overall health. The review serves as a resource for stakeholders to address sedentarism and improve public health in the 21st century.

EVOLUTION OF SEDENTARISM AND PHYSICAL INACTIVITY

Humans have a long evolutionary history dating back approximately 400 million years.[9] *Homo sapiens* have existed for nearly 2.4 million years, with modern *Homo sapiens* (the only surviving human species) emerging around 100,000 years ago in Africa.[10] Our ancestors evolved to lead highly physically active lifestyles, engaging in activities such as long-distance walking, hunting, digging, foraging, fishing, and running from threats, which kept them physically active.[10] However, with the onset of the Neolithic era approximately 10,000 years ago, marked by agricultural advancements, there was a notable shift towards settled lifestyles, replacing hunting with farming.[10] Despite the enduring link between food acquisition and physical activity, this connection weakened with the Industrial Revolution in the 19th century, which brought food to people's doorsteps.[11] Technological advancements replaced walking with motorized transportation, household chores with sophisticated appliances, active sports with electronics, and manual labor with machines.

Over the years, work-related physical activity has been in decline, as an increasing number of jobs are now based on mental tasks and, hence, are mostly chair-based. Currently, over 80% of occupations are sedentary, and only 20% offer physically active jobs.[12] A study conducted in the United States stated that over the last 50 years, there has been a decrease of over 100 calories in daily occupation-related energy

expenditure, favoring weight gain and obesity.[13]

This marked change in the lifestyle of people from active to inactive has given rise to a new public health concern, i.e., "sedentarism," which is "engagement in sedentary behaviors characterized by minimal movement, low energy expenditure, and rest."[14] This includes involvement in chair-type activities such as sitting, studying, talking, eating, traveling, and driving, or screen-type activities such as the use of computers, mobile phones, video games, television, and social media.

Sedentarism is a global issue affecting both developed and developing nations with long-term health implications across different age groups, including children and adolescents.[15,16] The recent coronavirus disease 2019 (COVID-19) pandemic has further exacerbated sedentary behaviors, with lockdowns, remote work, restrictions on outdoor movement, and home confinement limiting opportunities for physical activity and outdoor recreation.[17-20] Increased screen time for remote work, education, and leisure has contributed to a more sedentary lifestyle, especially among children.[20] A high screen-time increases the number of hours spent sitting. In their research on the effects of COVID-19 on physical activity and sedentary behaviors in children in the United States, Dunton et al.[20] found that school-related sitting time in children was approximately 90 minutes per day while sitting time for leisure activities (video games, TV, Internet, hanging out with family) was over 8 hours per day. These short-term changes in behavior and lifestyle adopted during the COVID-19 pandemic may have lasting effects on children with long-term health impacts, potentially contributing to an increased risk of obesity, diabetes, and cardiovascular disease as they grow older.[20]

IMPORTANT DEFINITIONS

As stated earlier, sedentarism is characterized by a low energy expenditure of ≤1.5 METs in a sitting, reclining, or lying posture. MET is the "resting metabolic rate, that is, the amount of oxygen consumed at rest, sitting quietly in a chair, approximately 3.5 mL O_2/kg/min[21]; hence, 1 MET is the energy expenditure at rest. The MET system can be effectively applied to estimate the energy cost of various activities as multiples of the resting metabolic rate. Thus, the MET value of an activity is defined "as the energy expenditure while performing an activity divided by the resting energy expenditure.[22] Sedentarism is the habitual behavior of choosing and indulging in low-energy-expenditure activities. Habitual behaviors are "automatic, largely subconscious, and fast, in contrast to a deliberative decision-making process."[23] These behaviors become part of the self, and the process of adaptation begins. Not all adaptations are healthy, and increasing immobility has led to many lifestyle-related disorders. Hence, sedentarism is a form of maladaptive behavior.

Physical activity is defined as "any bodily movement generated by the contraction of skeletal muscles that increases the energy expenditure above the resting metabolic rate. It is characterized by the modality, frequency, intensity, duration, and context of practice."[24] Physical activity is the most variable constituent of total daily energy expenditure, as it depends on several factors such as age, sex, occupation, culture, region, health and fitness, nutritional status, motivation, and climate. Exercise is a subcategory of physical activity that is "planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective."[24]

Sedentarism is often misunderstood as simply the absence of physical activity. However, it specifically refers to activities involving prolonged sitting, typically over 8 hours a day, while physical activity refers to meeting age-appropriate recommendations for movement.[25] An individual can be engaged in both sedentary and active behaviors within a single day. For instance, a software developer might exercise for 40 minutes each morning, but then sit for over 8 hours at work and spend additional hours sitting while commuting and watching TV.

Physical inactivity is another term usually confused with sedentary behavior. The World Health Organization (WHO) divides physical inactivity into two domains. Level 1 defines physical inactivity as "doing no or very little physical activity at work, at home, for transport, or in discretionary time."[26] The level 2 definition is "doing some physical activity but under 150 minutes of moderate-intensity physical activity or 60 minutes of vigorous-intensity physical activity a week accumulated across work, home, transport, or discretionary domains."[26] Hence, the definition accommodates two perspectives: very low energy expenditure due to low physical activity levels and not meeting physical activity recommendations. However, it is essentially not sedentarism, as sedentarism is primarily concerned with prolonged sitting hours. A person waiting in a queue or talking on the phone while standing is an explicit example of inactive physical activity that causes poor energy expenditure. Physical inactivity can range from low intensity (sitting, reduced steeping) to high intensity (certain medical conditions, e.g., spinal cord injury, surgery, bed rest, and physical frailty).[26]

PREVALENCE OF SEDENTARY BEHAVIOR

Despite various public health guidelines and the known health benefits of physical activity, people worldwide resort to sedentary behaviors, and their prevalence is increasing. This is supported by the assumption that humans have a natural propensity towards the conservation of energy (calories) and simultaneously avoid unnecessary laborious activities that demand energy expenditure.[27] Per the global estimate, approximately 27.5% of adults (i.e., one in four adults) and 81% of adolescents (more than 3 quarters) do not meet the WHO recommendations for daily physical activity, as outlined in the 2010 Global Recommendations on Physical Activity for Health.[28] There are sex variations, with women being more inactive than men.[29] Moreover, sedentarism is more prevalent in high-income countries than in low-income countries.[29]

According to an international study involving 20 countries, adults (18–65 years old) spend 3–8 hours sitting daily.[30] The median sitting time was 5 hours, and 25% of the participants reported sitting for at least 8 hours per day. Sitting for ≥7.5 hours per day is considered "high

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levels of sitting."[11] Bauman et al.[30] also reported that younger adults spend more time sitting than adults aged ≥40 years, reflecting higher technology use, sedentary education systems, and desk-based jobs. Globally, adolescents were found to be more inactive than adults, and it has been estimated that 80.3% of adolescents aged 13–15 years do not meet the recommendations of ≥60 minutes per day of moderate-to-vigorous physical activity.[29]

A decade-old report on the "physical activity levels of the world's population" stated that three out of every ten people in the world aged ≥15 years do not comply with the recommendations on physical activity, whereas in adolescents, the figures are even more threatening, with four out of every five adolescents not adhering to the guidelines.[29] The situation is even more alarming today, as the prevalence of physical inactivity is on the rise, and the levels are increasing year after year due to the increasing dependency on technology, modernization, reluctance towards lifestyle change, and changed workplaces.

Digital media is an integral part of the lives of adolescents. Social media, television, computers, mobiles, and video games dominate both recreational and work-related activities, hence, they are the highest contributor to total sitting time. High screen time is not limited to adolescents, but also to adults due to job-related demands. Various national and international organizations have recommended limiting screen time to no more than 2 hours per day for all age groups >2 years.[31] Excessive screen time, defined as over 2 hours per day, is prevalent among adolescents, with studies showing screen times as high as 7 hours daily.[32] A study in Brazil found the prevalence of excessive screen time in 79.5% of adolescents,[33] whereas in India, it was 68%.[34]

Children and adolescents spend approximately half of their after-school period sedentary.[35] Sedentary hours in children and adolescents have been positively correlated with increasing age or grade level in school.[36,37] A study conducted on 2,061 Austrian children and adolescents showed a steady increase in sitting time from 9 hours in the first grade to 12 hours in the eighth grade, corresponding to an annual increase of approximately 25 minutes per day in total sitting time.[36] Sedentary behavior during childhood and adolescence is considered a significant factor in the development of pediatric obesity, which in turn increases the risk of obesity and associated health issues in adulthood.[16] In a systematic review by Simmonds et al.,[38] the authors concluded that obesity during childhood and adolescence increases the risk of obesity in adulthood by 5 times compared with non-obese children. Highlighting the persistence of obesity in adulthood and the challenge of overcoming it once it is established during adolescence, the authors predicted that approximately 55% of children with obesity would remain obese during adolescence. Of these obese adolescents, approximately 80% will still be obese in adulthood, and approximately 70% will continue to be obese over the age of 30 years.[38]

Researchers have also studied the various other determinants of sedentarism. There is an inverse relationship between sedentarism and level of physical activity, meaning that physically active people are less likely to be involved in sedentary activities.[30,39] Furthermore, people with a high educational level have a long sitting time, which is mostly occupation-related and demands high volumes of sitting.[30,39,40] However, TV viewing time is lower in individuals with high education levels.[41] A systematic review conducted under the DEDIPAC (Determinants of Diet and Physical Activity) study on the determinants of sedentary behavior in older adults observed health to be an important determinant of sedentary behavior.[41] Health conditions such as obesity, cardiovascular disease, difficulty in standing, and functional limitations are significantly associated with greater levels of sedentary behavior in adults.[41]

Barriers to or a lack of opportunities for physical activity can also influence sedentary behaviors among individuals. Policy decisions related to the urban design and development of safe and walkable neighborhoods, i.e., cycle- and pedestrian-friendly neighborhoods with access to local amenities such as shops, services, and public transport, provide opportunities for residents to walk, thereby increasing their physical activity levels.[42-44] The lack of social support is a significant barrier to physical activity.[42,45] Accumulating evidence indicates that encouragement and support from family, friends, peers, teachers, or health professionals enhances people's participation in physical activity.[42,44,46] Physical activity levels are also stimulated by facilities and opportunities (e.g., parks, swimming pools, recreation facilities, gyms, sports complexes, and playgrounds) in the proximate environment of an individual, such as home, school, workplace, and other settings.[42,44,47] Certain intrapersonal factors, such as self-concept, lack of motivation, lack of time, and fatigue, are associated with physical activity levels.[44,45]

SEDENTARISM AND ADVERSE HEALTH OUTCOMES

"Sitting is the new smoking," a phrase coined by Dr. James Levine, is colloquial to describe the adverse health effects of sedentarism. This new addiction has barred no one and is entrenched in everyday life. Due to its vast prevalence, sedentarism has become one of the prime precursors of NCDs, including lifestyle-related disorders such as overweight and obesity, metabolic syndrome, and hypertension. Physical inactivity is responsible for approximately 9% of premature deaths worldwide,[48] and has been recognized as the leading preventable cause of death.[49] Sitting time >7 hours per day is hazardous to health, with a 5% increase in all-cause mortality with each additional hour spent sitting (i.e., +7 hours per day), taking into account physical activity levels.[50] Figure 1 represents the detrimental effects of sedentarism and the positive effects of physical activity.

1. Physiology of Sedentarism

Understanding the physiological mechanisms of health problems is important for planning interventions. Emerging evidence suggests that excessive sitting has pernicious effects on the body and is accompanied by numerous physiological changes. As soon as a person sits, the muscles become relaxed, and the electric activity in the leg muscles cuts off.[51] As physical activity is halted while sitting, the caloric

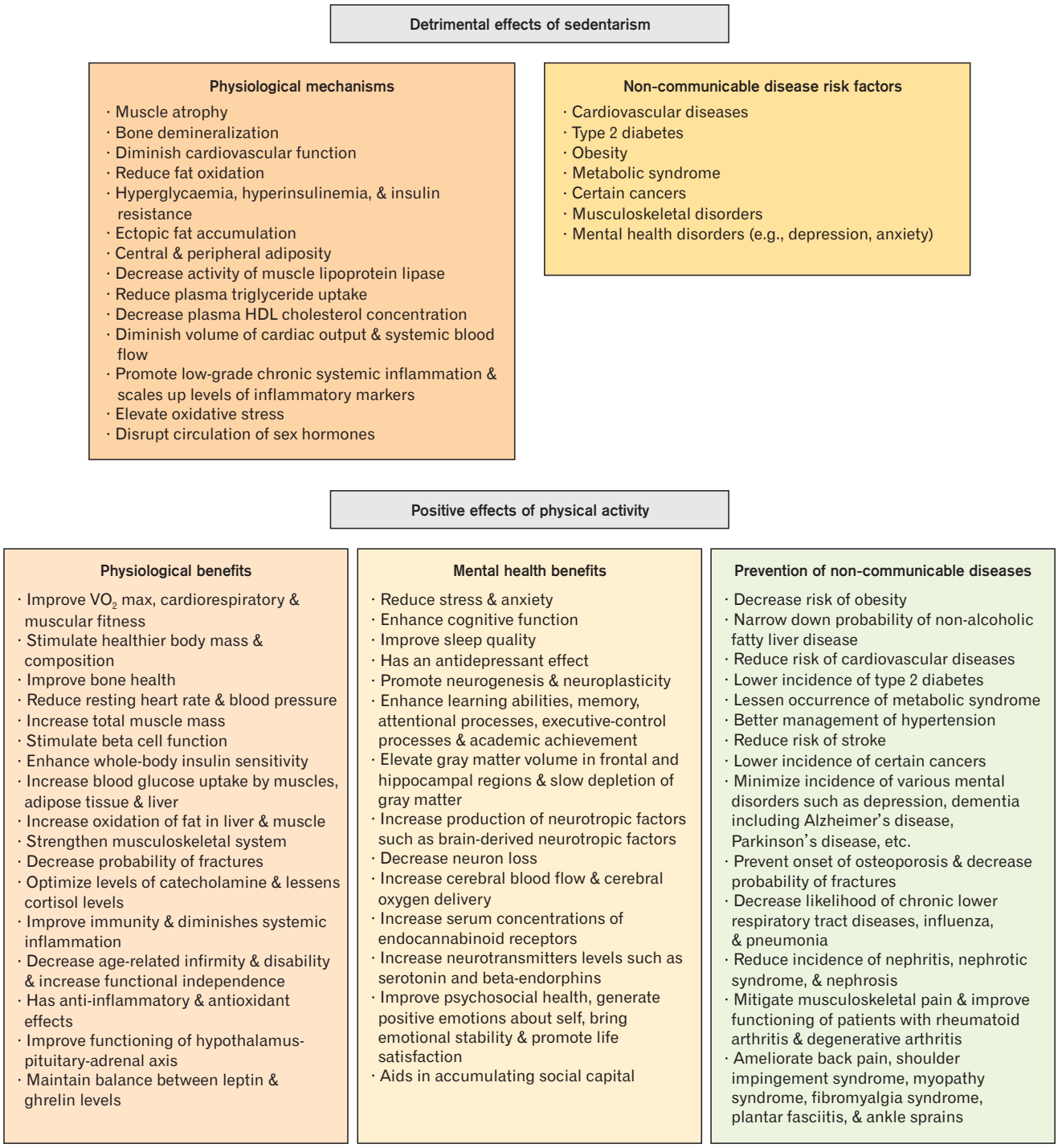

Figure 1. Detrimental effects of sedentarism and positive effects of physical activity. HDL, high-density lipoprotein; VO_2 max, maximal oxygen consumption.

burning rate decreases to 1 per minute, and the enzymes that break down lipids and triglycerides also decrease by 90%, favoring the deposition of fat in the body.[51] Physical inactivity can lead to muscle atrophy, bone demineralization, diminished cardiovascular function, reduced fat oxidation for the synthesis of adenosine triphosphate (ATP), a shift towards fast-twitch glycolytic muscle fibers (these fibers use anaerobic glycolysis, producing less ATP per cycle and becoming fatigued at a faster rate), skeletal muscle insulin resistance, ectopic fat accumulation, and a stimulated tendency for central and peripheral adiposity.[11] Sedentarism decreases the activity of muscle lipoprotein lipase (LPL), a key enzyme that regulates lipid metabolism.[52] Low levels of LPL have been correlated with reduced plasma triglyceride uptake, decreased plasma high-density lipoprotein (HDL) cholesterol concentration, and elevated postprandial lipid levels.[52] In a study con-

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ducted in rats, LPL levels began to decrease substantially after approximately 4 hours of inactivity.[53] Low LPL levels influence hypertension, diabetes-induced dyslipidemia, metabolic problems in elderly individuals, metabolic syndrome, and coronary artery disease.[53] LPL levels are increased during exercise, protecting against diet-induced adiposity and insulin resistance.[53]

Sedentariness reduces muscle glucose levels, reduces protein transporter activity, and impedes lipid and carbohydrate metabolism.[54] It stimulates the sympathetic nervous system, which diminishes the volume of cardiac output and systemic blood flow, eventually decreasing insulin sensitivity and vascular function while elevating oxidative stress and activating inflammatory factors.[54] It further causes metabolic alterations and leads to hyperglycemia, hyperinsulinemia, and insulin resistance; permeates the insulin-like growth factor axis; disrupts the circulation of sex hormones; promotes low-grade chronic systemic inflammation; and increases the levels of inflammatory markers such as C-reactive protein, adipokines, interleukin-6, leptin, and the leptin: adiponectin ratio.[54,55] These physiological changes are potential risk factors for cancer.[54] Understanding the physiology of sedentarism is an underexplored area, and more gainful insights and deeper knowledge are needed for a complete understanding of the mechanisms, pathways, and stages of progression to chronic diseases.

2. Chronic Health Problems

There is significant evidence that sedentarism has an insidious effect and has been positively associated with almost all chronic health problems that the world is facing today. A meta-analysis indicated that chronic sedentary behavior increases the risk of developing CVD by 34%, and among the various causal factors for CVD mortality, sedentary behavior has the strongest association.[56] Sedentary behavior, along with physical inactivity increases the risk of obesity in adults and older adults.[57] Biswas et al.[58] found a significant association between sedentarism and a high risk of all-cause mortality, CVD and CVD mortality, cancer and cancer mortality (breast, colon, colorectal, endometrial, and epithelial ovarian), and type 2 diabetes in adults. Total sedentary time, independent of physical activity, is positively linked to increased blood glucose, blood lipid, and adiposity.[59] Sitting for prolonged sitting can lead to the development of skeletal muscle insulin resistance, which in turn can cause metabolic syndrome, cardiovascular diseases, and type 2 diabetes.[26] Table 1 provides a summary of studies associated with sedentary behavior and outcomes of chronic diseases.

1) Cardiovascular diseases

Cardiovascular diseases (CVDs) have been the leading cause of death worldwide for decades. In 2021, over 500 million people were diagnosed with CVDs, leading to nearly 20.5 million deaths, approximately one-third of global fatalities.[60] CVDs encompass a range of disorders affecting the heart and blood vessels, including coronary heart disease (CHD), cerebrovascular disease, peripheral arterial disease, rheumatic heart disease, congenital heart disease, deep vein thrombosis (DVT), and pulmonary embolism.[61]

Sedentarism increases the risk of cardiovascular diseases, and there is a negative association between physical activity and the incidence of CHD and cardiovascular mortality.[62] The pioneering work by Morris et al.[63] provided the first evidence of this association in 1953 when they studied the effect of work-related physical activity on the development of CHDs. He observed that bus drivers who spent prolonged hours sitting, exhibited a higher risk than bus conductors who were constantly mobile and climbing the stairs of double-decker buses as part of their routine jobs.[63] CVD risk increases proportionally with the number of sitting hours. In a study, it was found that prolonged sitting raises CVD mortality risk by 2.7 times.[53] Television viewing, a common sedentary behavior, is linked to elevated risks of all-cause and CVD mortality, with each additional hour of viewing associated with an 11%–18% increase in risk.[59] Watching TV for 4 or more hours per day increases all-cause mortality risk by 46% and CVD mortality by 80%.[59]

DVT, a form of CVD characterized by blood clots in deep veins, is directly associated with prolonged sitting due to increased blood viscosity and decreased venous return.[11,53]

It has been recommended that an additional expenditure of at least 1,000 kcal per week on physical activity may prevent the incidence of CHDs.[62] Regular physical activity enhances cardiorespiratory fitness and lowers CVD risk by 20%–30% in leisure activities and by 10%–20% in occupational activities.[64] Exercise improves cardiovascular health by improving VO_2 max (maximal oxygen consumption), insulin sensitivity, and glycemic control; increasing HDL concentration; increasing the particle size of low-density lipoprotein (LDL) and HDL; and shrinking very low-density lipoprotein particle size.[65,66] Physical exercise regulates and modulates homeostasis in the endothelial arterial wall and ameliorates the endothelium-derived vasodilation by increasing the basal release of nitric oxide, which decreases the systemic vascular resistance and reduces the blood pressure, thus protecting the heart against atherogenesis and heart failures.[65,66] Exercise prevents thrombosis by decreasing both platelet adhesion and aggregation; therefore, exercise is recommended for improving chronic conditions such as DVT.[66]

Increasing non-exercise-related physical activity (household chores, shopping, and gardening) has a beneficial effect on the risk of CVD. A study performed on Chinese women reported an inverse relationship between all-cause mortality and non-exercise-related physical activity.[53] Findings from a recent study also support that non-exercise physical activity of moderate-to-vigorous intensity in short intermittent bouts, that is, lasting between 1 minutes and 5 minutes or 5 minutes and 10 minutes, performed as part of daily living, reduces the risk of mortality and major adverse cardiovascular events by 29%–44%.[67] Indulgence in intermittent lifestyle-related physical activity has special relevance for those who have time constraints and cannot devote dedicated time to structured exercise, and those who have functional limitations due to aging, medical conditions, or disability.

Table 1. Association of sedentary behavior with outcomes of chronic diseases

References	Country	Objective	Materials & method	Key findings & observations
CVD				
Morris et al.[63] (1953)	England	To study the effect of work-related PA on the development of CHDs	Participants: 31,000 men in the age group of 35–64 years were observed who were employed as bus, trams & trolleybus drivers & conductors, motormen & underground railway guards.	Bus drivers who were sedentary were at a higher risk for developing CHDs than bus conductors who were constantly mobile & were climbing the stairs of double-decker buses as part of their routine job. The annual incidence rate of CHD among bus drivers was 2.7 per 1,000 whereas it was 1.9 per 1,000 among bus conductors.
Hamilton et al.[53] (2007)	NS	To examine the role of SB, particularly sitting, on mortality & various health risks including MS, & T2DM, as well as examining the distinctive characteristics of inactivity physiology	The paper draws upon observational epidemiological studies, controlled laboratory studies, cohort studies, & literature reviews to analyze the impact of SB on health outcomes.	Prolonged sitting & SB are associated with increased risks of mortality, CVD, T2DM, MS, & obesity. Observational studies suggest a significant impact of inactivity on health outcomes, comparable to other risk factors—smoking, hypercholesterolemia. Sedentary time is associated with MS risk factors & T2DM. Inactivity physiology, (patterns of non-exercise activity & sitting time), is distinct from structured exercise. SB influences LPL activity, plasma TG clearance, & HDL-C responses. Molecular responses during inactivity suggest unique cellular mechanisms distinct from those triggered by exercise. DVT is caused by prolonged sitting.
Dunstan et al.[59] (2010)	Australia	To examine the associations of prolonged TV viewing time with all-cause, CVD, cancer, & non-CVD/ noncancer mortality in Australian adults	The study analyzed data from the AusDiab study involving 8,800 adults aged 25 years & above. TV viewing time & mortality outcomes (all-cause, CVD, cancer) were assessed over a median follow-up period of 6.6 years.	Each 1-hour increment in daily TV viewing time was associated with a 11% higher risk of all-cause mortality, 18% higher risk of CVD mortality, & 9% higher risk of cancer mortality after adjusting for age, sex, WC, & exercise. ≥4 h/d of TV viewing was associated with 46% increased risk of all-cause mortality & 80% increased risk of CVD mortality.
T2DM				
Vallance et al.[69] (2018)	NS	To summarize recent evidences on sitting & health	The paper provides an overview on existing evidence regarding sitting & smoking, reviewing meta-analyses & studies on SB & health outcomes. It compares risk estimates & absolute risk differences for mortality & prevalent chronic diseases associated with sitting & smoking.	High amounts of sitting (>8 h/d) have been hazardous for health & the greatest risk has been associated with T2DM with the HR of 1.91. Sitting has been negatively associated with all-cause mortality, cancer mortality, CVD mortality & the risk of depression. MVPA, 60–75 min/d, can diminish the risk of all-cause mortality associated with sitting. Role of mass media is outlined in shaping public perceptions & understanding of health-related issues. Both SB & smoking can have negative impacts on health but they are not equivalent in terms of the magnitude of risk they pose.
Hamilton et al.[70] (2014)	NS	To examine the associations between SB & risk for T2DM, MS as well as specific cardiometabolic risk factors	Review of cross-sectional & prospective studies examining SB & its relationship with MS & T2DM	An increase in the total number of sitting hours has been associated with the progression of T2DM & MS across the lifespan, independent of the level of PA, BMI status, & WC. Excessive sedentary time negatively impacts insulin sensitivity, glucose tolerance, TG levels, & 2-hour glucose levels. Findings from inclinometry suggest that the quartile range for weekly sedentary time is approximately 29 h/wk. It was observed that insulin-stimulated glucose uptake scaled down to 39% in subjects who sat for an entire day with energy expenditure ranging between 1.1–2.7 METs compared with subjects involved in LIPA, which included routine activities such as dishwashing, folding clothes, etc. The metabolism in slow-twitch oxidative skeletal muscle is highlighted as key for understanding the beneficial responses to LIPA. This suggests that even non-exercise activities like standing & light movement can have positive effects on health. Reductions in sedentary time may be achieved through increased LIPA, rather than solely relying on traditional exercise.
Obesity				
de Victo et al.[72] (2023)	Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, Peru, Venezuela	To associate different sitting time cut-off points with excess weight.	Participants: 7,995 (53.4% women), aged between 20 & 65 years; data from ELANS, a cross-sectional population-based survey conducted in 8 Latin American countries; sitting time categorized using different cut-off points (≥4, ≥6, & ≥8 h/d); excess weight measured by BMI, waist & neck circumferences	Sitting time ≥8 h/d associated with higher odds of excess weight, particularly observed in neck circumference. Different countries showed varied results.

(Continued on next page)

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Table 1. Continued

References	Country	Objective	Materials & method	Key findings & observations
Bullock et al.[73] (2017)	UK, USA, Germany, Spain, Italy, France, Portugal, Austria, & Switzerland	To examine the association between sitting time & obesity, while controlling for PA, in a large international sample.	Study design: cross-sectional survey; participants: 5,338 adults, 18 years & above. Self-reported total daily sitting time, PA, age, height & weight, BMI, total PA, & sitting time were derived. Logistic regression models explored the odds of obesity for each sitting time quartile.	Participants in the highest sitting time quartile (≥8 h/d) had 62% higher odds of obesity compared to the lowest quartile (<4 h/d) after adjustment for PA & other confounding variables. Sitting time was associated with obesity independent of PA. The study suggests that reducing high amounts of SB, defined as sitting for ≥8 h/d, could potentially decrease the associated odds of being obese.
Bakour et al.[74] (2022)	USA	To examine the association between screen time (TV, video games, computer, handheld devices) & BMI among U.S. adolescents, & the potential effect modification of these associations by sex, sleep duration, & PA.	Data obtained from the 2016–2017 NSCH, a nationally representative survey of US parents & caregivers. Participants: 29,480 adolescents aged 10–17 years; excluded those with certain medical conditions. Measures: BMI, screen time (TV/video games & computer/handheld device), sleep duration, PA, health status sociodemographic factors, etc. Statistical analysis: multinomial logistic regression	Watching TV/video games ≥1 h/d associated with increased odds of overweight/obesity. Computer/handheld device use associated with smaller increase in odds of overweight/obesity. Association stronger in adolescents not meeting PA guidelines. PA attenuated association between screen time & overweight/obesity, particularly in females. Sleep duration did not modify associations. Females showed stronger association between screen time & overweight/obesity compared to males.
Silveira et al.[57] (2022)	Multiple countries including USA, Sweden, Australia, Europe, UK, Germany, Brazil, Spain, Ireland, & Uganda	To investigate the prevalence/incidence of SB & physical inactivity, the association of SB & physical inactivity with obesity, & the measures, diagnostic criteria, & cut-off points used to estimate SB & physical inactivity in adults & older adults with obesity.	Study design: systematic review & meta-analysis; 23 studies were selected—5 were cohort & 18 were cross-sectional. Participants: 6,38,000 adults & older adults. Meta-analysis was done on 1,11,851 subjects who were suffering from obesity. Meta-analysis of random-effects model performed to estimate the combined prevalence of SB & physical inactivity & their association with obesity.	High prevalence of SB (31%) & physical inactivity (43%) found in individuals with obesity. Significant positive associations found between obesity & SB & physical inactivity.
MS				
Edwardson et al.[52] (2012)	NS	To quantify the association between SB & MS in adults using meta-analysis	Study design: meta-analysis. Inclusion criteria: cross-sectional or prospective design, adults ≥18 y, self-reported or objectively measured sedentary time, outcome measure of MS. Total 10 studies included; all were cross-sectional. Participants: 21,393. Analysis: used odds ratio & 95% CI for meta-analysis	Greater time spent sedentary increases odds of MS by 73%. However, no differences were observed in subgroups of sex, SB measure, MS definition, study quality, or country income. Sensitivity analysis suggested relationship between SB & MS independent of PA. SB may be an independent risk factor for MS, supported by experimental evidence. Implication: reduction in SB could be important for preventing MS, but longitudinal & intervention studies needed for clarification.
Dunstan et al.[75] (2005)	Australia	To analyze the associations of TV viewing & PA with the MS in Australian adults	Study design: population-based cross-sectional study. Participants: 6,241 adults aged ≥35 y, from AusDiab study; participants self-reported TV viewing (0–7, 7.01–14 & >14 h/wk) & PA time. Anthropometric assessment: WC, height, weight & BP. Demographic attributes, parental history of T2DM, smoking habits & educational attainment were assessed using an interviewer-administered questionnaire. Dietary intake was assessed using a self-administered validated FFQ.	Increased TV viewing (>14 h/wk) was associated with an increased risk of MS, insulin resistance, obesity, & dyslipidemia in both men & women. PA (≥2.5 h/wk) was associated with a reduced prevalence of MS, insulin resistance, dyslipidaemia, obesity, & hypertension. Population strategies should focus on reducing SB such as TV viewing & increasing PA.
Cancer				
Gilchrist et al.[79] (2020)	USA	To examine the association between accelerometer-measured SB (total volume & accrual in prolonged, uninterrupted bouts) & cancer mortality; To inform what type of activity (LIPA & MVPA) should be substituted for sedentary time to impart health benefit	Participants: recruited from the US middle-aged & older adults' cohort of the REGARDS study. 8,002 individuals with adherent accelerometer wear (≥4 d, ≥10 h/d) & follow-up mortality data. Actical accelerometers were used, secured to participants' right hip for 7 consecutive waking days. Activity levels: SB (0–49 counts/min), LIPA (50–1,064 counts/min), & MVPA (≥1,065 counts/min). Outcome: cancer mortality. Statistical analysis: HRs, isotemporal substitution modelling, sensitivity analysis	Greater time spent in SB & longer sedentary bout duration were associated with increased cancer mortality risk, even after adjusting for various covariates. Isotemporal substitution modelling showed that replacing sedentary time with either LIPA or MVPA was associated with lower cancer mortality risk. The association between SB & cancer mortality remained significant after adjusting for MVPA. The study suggests that reducing SB & increasing PA, even at modest levels, may improve cancer outcomes & promote health & longevity.

(Continued on next page)

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Table 1. Continued

References	Country	Objective	Materials & method	Key findings & observations
Hermelink et al.[80] (2022)	NS	To critically analyze existing systematic reviews & meta-analyses of SB in relation to the risk of various cancers & cancer mortality	Study design: systematic review & meta-analysis. Inclusion criteria: systematic reviews & meta-analyses published in English that investigated the association between SB & risk of cancer incidence or all-cancer mortality. 14 studies covering 17 different cancer sites from 77 original studies were included. Assessment of methodological quality using AMSTAR-2	Prolonged SB identified as an independent risk factor for various cancers, with varying strengths of association. Found significant positive associations between SB & cancer incidence for ovarian, endometrial, colon, breast, rectal, & prostate cancers, as well as all-cancer mortality. SB linked to obesity, insulin resistance, increased systemic inflammation, & hormone-related pathways, all of which can contribute to cancer risk.
MSD				
Cho et al.[82] (2015)	-	To determine the ideal sitting positions by measuring changes in LL & PP in various positions.	Study design: radiographic review of healthy volunteers. Participants: 30 males. Lateral lumbosacral radiographs obtained in standing & five sitting positions; LL & lumbar segmental lordosis measured using Cobb's method; PP measured on lateral radiograph. Statistical analyses: ANOVA & Pearson correlation	Sitting positions caused reduction in LL & sacral slope compared to standing. Sitting cross-legged resulted in significant lumbar kyphosis. Sitting on a chair with back support showed least change in LL. Strong correlation observed between decrease in LL & changes in sacral slope & pelvic tilt. Changes in LL & spinopelvic parameters observed in different sitting positions could contribute to spinal imbalance & chronic LBP.
Dubey et al.[83] (2019)	NS	To provide overview of improper designed workstations leading to consequences of vision & postures at work; To discuss possible problems, their effects on various body parts, proper positioning, & how to design ergonomically fit workstations.	Literature review, survey data analysis, ergonomic principles application	Prolonged sitting leads to various MSD—sitting posture affects disc pressure; lumbar support aids in maintaining posture; poor posture contributes to neck & back strain; slouching affects breathing. Prolonged sitting increases heart disease risk, affects breathing, contributes to varicose veins & carpal tunnel syndrome. Prolonged use of computer affects viewing & causes eye discomfort or strain. Ergonomic practices & adjustments mitigate musculoskeletal & vision-related problems. Ergonomic workstations decrease injury risk, increase productivity, promote healthier vision & joints, reduce tension & headaches, improve job satisfaction & morale.
Dzakpasu et al.[84] (2021)	NS	To examine evidence on the associations of SB with MSP conditions in observational & experimental/ intervention studies of adults.	Study design: systematic review & meta-analysis based on PRISMA guidelines. Inclusion criteria: quantitative study involving either an observational or intervention/ experimental design, adults ≥18 y, measure of any kind of MSP condition & clearly defined SB. 79 studies were included. Quality assessment: QualSyst checklist. Statistical analysis: pooled meta-analysis, sensitivity analysis	Significant association was found between full day SB & MSP including LBP, knee pain, arthritis, & general MSP. Computer time (≥4 h/d) associated with LBP, neck/shoulder pain, & general MSP. Reduction in sitting time correlates with reduction in LBP & neck/ shoulder pain.
Depression				
Huang et al.[90] (2020)	USA, Australia, Finland, Sweden, Denmark, Spain, & UK	To examine the association of SB with the risk of depression	Study design: meta-analysis of prospective studies based on MOOSE guidelines. Inclusion criteria: prospective cohort studies examining the relationship between SB & depression in average adults. 12 studies were included. Quality assessment: Newcastle-Ottawa scale. Statistical analysis: random-effect meta-analysis, subgroup analysis, meta-regression analysis, sensitivity analysis, assessment of heterogeneity, assessment of publication bias	Positive association between SB & risk of depression observed. Watching TV positively associated with depression risk, while using a computer was not significant. Mentally passive SB (such as watching TV) increased depression risk, while mentally active SB (such as using a computer) were non-significant. SB may hinder direct communication between individuals, leading to reduced social interaction & an increased potential for depression. SB also reduce the time spent on PA, which is known to be effective in preventing & treating depression. Additionally, depression itself may influence SB, as studies have shown that adults with depression tend to engage in low levels of PA & high levels of SB.

CVD, cardiovascular diseases; PA, physical activity; CHD, coronary heart diseases; NS, not specified; SB, sedentary behavior; MS, metabolic syndrome; T2DM, type 2 diabetes mellitus; LPL, lipoprotein lipase; HDL-C, high-density lipoprotein cholesterol; DVT, deep venous thrombosis; TV, television; AusDiab, Australian Diabetes, Obesity and Lifestyle Study; WC, waist circumference; HR, hazard ratio; MVPA, moderate-to-vigorous physical activity; TG, triglyceride; BMI, body mass index; MET, metabolic equivalent; LIPA, low-intensity physical activity; NSCH, National Survey of Children's Health; CI, confidence interval; BP, blood pressure; FFQ, Food Frequency Questionnaire; REGARDS, reasons for geographic and racial differences in stroke; LL, lumbar lordosis; PP, pelvic parameters; LBP, low back pain; MSD, musculoskeletal disorders; MSP, musculoskeletal pain; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; MOOSE, Meta-analyses of Observational Studies in Epidemiology.

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2) Type 2 diabetes

Type 2 diabetes, characterized by decreased insulin levels and elevated blood glucose, has reached epidemic proportions globally, prompting grave concerns among public health experts. An estimated 462 million individuals worldwide suffer from diabetes, with diabetes-related deaths reaching approximately 1 million in 2017, ranking it as the ninth leading cause of mortality.[68]

Sedentary behavior is a primary risk factor in type 2 diabetes onset and progression, chiefly due to its association with reduced insulin sensitivity. Excessive sedentary behavior can twofold increase the risk of developing type 2 diabetes.[69] Conversely, increased physical activity mitigates this risk.[62] Prolonged sitting correlates with diabetes progression independent of physical activity levels, body mass index (BMI), or waist circumference, negatively affecting insulin sensitivity, glucose tolerance, and triglyceride levels.[70] In a trial study, insulin-stimulated glucose uptake scaled down to 39% in subjects who sat for an entire day with energy expenditure ranging between 1.1–2.7 METs compared with subjects involved in low-intensity physical activity, which included routine activities such as dishwashing.[70] Emerging evidence shows that even short breaks of <5 minutes in small intermittent bouts of low-to-moderate-intensity physical activity between prolonged sitting improves glycemic control in healthy as well as overweight or obese individuals with interruptions like standing bouts proving beneficial.[11] These findings have significant relevance in the office environment, advocating for moderate-to-vigorous physical to manage the symptoms of diabetes. Even 30 minutes of daily walking can halve the risk of diabetes.[71] Exercise enhances insulin-sensitivity and glucose uptake, irrespective of exercise type (aerobic or anaerobic) or intensity (high or low) underscoring its therapeutic benefits in diabetes management.[66]

3) Obesity

Accumulating evidence has outlined the adverse association between uninterrupted sitting hours and obesity onset. High levels of sitting (i.e., ≥8 hours per day) and excessive screen time (i.e., ≥2–3 hours per day) are strongly associated with overweight and obesity among children, adolescents, and adults.[72-74] Sedentary behavior leads to low energy expenditure, resulting in overweight and obesity. A recent meta-analysis found that obese individuals have high prevalence rates of physical inactivity (43%) and 31% for sedentary behavior.[57]

Therefore, an active lifestyle, increased physical activity, and reduced sedentary behaviors, along with a healthy and nutritious diet, are indispensable for curbing obesity. Regular physical activity also influences appetite, that is, hunger and satiety perceptions, by regulating hormone levels, and has special implications in weight management. Physical activity has the potential to suppress ghrelin (appetite-stimulating hormone) levels, increase peptide YY (appetite-inhibiting hormone) levels,[11] and restore leptin (a hormone that regulates energy balance by suppressing hunger) sensitivity.[66]

4) Metabolic syndrome

Individuals with metabolic syndrome are at a high risk of developing diabetes, CVD, CHD, stroke, and all-cause mortality.[52] Sedentary behavior independently contributes to metabolic dysfunction, including reduced lipolysis and whole-body insulin sensitivity, regardless of physical activity levels.[52] Excessive sedentary behavior increases the odds of metabolic syndrome by 73%.[52]

There is mounting evidence linking excessive sitting to almost doubling the risk of metabolic syndrome.[53] Increased sedentary hours are associated with adverse metabolic changes, such as alterations in plasma triglyceride and HDL levels and waist circumference.[70] Dunstan et al.[75] reported that, with each additional hour of daily TV viewing raises the risk of metabolic syndrome in women by 26%.

A systematic review and meta-analysis of 16 studies has concluded that physical exercise benefits body composition, cardiovascular, and metabolic outcomes in patients with metabolic syndrome.[76] The authors observed these benefits with both aerobic and combined aerobic-resistance exercises.[76] For instance, combined exercises optimize changes in waist circumference (WC), systolic blood pressure (SBP), and peak VO_2 (peak oxygen consumption), while aerobic exercises primarily affect body mass and diastolic blood pressure (DBP).[76] Liang et al.[77] conducted similar research, exploring the impact of resistance exercise along with aerobic and combined exercises on metabolic syndrome. Their analysis suggests that a comprehensive exercise regimen incorporating both resistance and aerobic components maximizes benefits in managing metabolic syndrome, improving weight, WC, DBP, triglyceride and total cholesterol levels, glucose levels, and insulin levels, whereas resistance and aerobic exercises alone have limited impacts.[77]

5) Cancer

The most common cancers are breast, lung, colon, rectal, and prostate.[78] Over 50% of deaths due to cancer can be prevented by adopting healthy and active lifestyle choices, such as physical activity.[79] It is estimated that with an increase in physical activity, both the incidence and risk of death associated with cancer can be reduced.[79]

With the shift in lifestyle dominated by long sitting hours, the level of physical activity has decreased globally. A recent cohort study investigated the relationship between sedentary behavior and cancer. This finding indicates that sitting for long hours, especially in uninterrupted bouts, progressively increases cancer mortality irrespective of physical activity levels.[79] Furthermore, it was also highlighted that sedentary time, when replaced with physical activity (either low-intensity physical activity or moderate-to-vigorous intensity physical activity), has a diminished effect on cancer mortality. A recent systematic analysis reported statistically significant associations between sedentary behavior and the risk of developing ovarian, endometrial, colon, breast, rectal, and prostate cancers.[80] A plausible mechanism underlying the development of various cancers is that extreme sedentary behavior induces obesity, insulin resistance, and type 2 diabetes.[80]

6) Musculoskeletal disorders

Musculoskeletal disorders include over 150 disorders that affect the lo-

comotor system, and commonly occurring conditions are low back pain, neck pain, rheumatoid arthritis, osteoarthritis, and gout.[81]

Increased sitting hours due to work and leisure activities contribute significantly to low back pain, affecting both children and adults with a lifetime incidence rate of 50%–90%.[82] Prolonged sitting (especially for >8–9 hours) flattens the lumbar curve and increases pressure on the intervertebral disc, leading to strain in the back, neck, shoulders, and leg muscles.[82,83] Sedentary behavior, both occupational and non-occupational, has been positively linked to deteriorating musculoskeletal health, including low back pain, knee pain, arthritis, and neck/shoulder pain.[84]

Physical activity has been documented as an effective, safe, and cost-effective intervention for preventing and attenuating musculoskeletal disorders.[85,86] Exercise, particularly resistance training, stimulates muscle growth and strength gains by causing microtrauma to muscle fibers, leading to hypertrophy.[87,88] Resistance training further induces neural adaptations, improving motor unit recruitment and adaptation, whereas endurance exercise promotes metabolic adaptations that enhance the muscle's ability to utilize oxygen efficiently, increase mitochondrial biogenesis, and optimize energy source selection (e.g., using fat as a primary fuel source).[87,88] Regular exercise also reduces the risk of injury in individuals of all age groups by improving ligament and tendon strength and increasing collagen content.[87,88] Resistance exercise helps to delay osteoporosis by triggering favorable hormonal responses that can lead to bone remodeling, increasing bone mineral density, and slowing bone loss.[88]

7) Depression

Depression is the leading cause of global disability and negatively impacts the quality of life and productivity.[89] Researchers have demonstrated a significant link between sedentary behavior and increased risk of depression. Huang et al. conducted a meta-analysis of 12 cohort studies and found that sedentarism, especially those involving mentally passive activities (watching TV, chatting while sitting), is significantly correlated with the risk of depression, which increases exponentially with each incremental hour of sitting.[90]

Physical activity is efficacious in treating depression and depressive symptoms.[91-93] In a recent systematic review and meta-analysis by Noetel et al.,[94] a dose-response relationship was observed between the effectiveness of exercise and increased intensity; however, the beneficial effect of exercise was reported even with low-intensity exercises such as walking and yoga.[91] A review indicated that exercise could be as effective as antidepressant drugs, with some exercises having a superior impact.[94] Thus, exercise therapy may be a suitable alternative to drug therapy and can enhance the effectiveness of drug treatments.[91,94]

BREAKING THE CYCLE OF SEDENTARISM AND INCREASING PHYSICAL ACTIVITY

Humans constantly learn, evolve, and create limitless worlds for themselves. In this fast-paced era, technological advancements are undoubtedly a boon; however, one needs to adapt and absorb technology within a safe zone of health. Considering the increasing NCD burden, strategic interventions should be designed to prevent the onset and course of chronic illnesses. Moderate vigorous-intensity physical activity lasting for 60–75 min/d is necessary to diminish the risk of all-cause mortality associated with sedentary behavior.[68] Increased movement among the masses is a key strategy for attenuating chronic diseases.

People are entangled in modern lifestyle challenges, such as occupation-related stress, distractions from TV and mobile devices, and family responsibilities, which prevent them from dedicating time to exercise or physical activity. The rapid developments in research, science, and technology will likely increase dependency on machines and tools. Thus, integrating physical activity into daily life is a feasible solution to reduce sitting time and promote health and fitness globally. Therefore, national and international government agencies, policymakers, and public health professionals should develop practical and implementable recommendations that align with people's living and work patterns. Non-exercise activities such as walking as a means of recreation, active transportation such as walking, cycling, and climbing stairs should be promoted, and sensitization programs should be planned and organized accordingly, targeting each age group, especially children and youth, as they are the future building blocks of a bright nation.

Policy-level initiatives are scarce in this area[11] but are of paramount importance for increasing physical activity levels and decreasing sedentary time. The main areas of intervention were transportation, infrastructure and planning, environment, education, employment, healthcare, sports, and active recreation.[71] The various public health recommendations to counteract a sedentary lifestyle are summarized in Figure 2.

1. Urban Design, Environment and Transport Interventions

An explicit understanding of the physical environment, comprising both built and natural environments, can help governments plan prudent interventions. The built environment includes schools, workplaces, transport systems, neighborhoods, houses, and sports grounds.[71] Strategic city planning can encourage physical activity by promoting walking, cycling, and the use of public transportation, while limiting the use of private transport.[95] These interventions involve making destinations more accessible, ensuring an equitable arrangement of employment opportunities across urban areas, minimizing the availability and cost of car parking, building pedestrian- and bicycle-friendly infrastructure, optimizing household density, improving the accessibility of public transport, and increasing the desirability of active travel modes.[95] Research in four European cities found that residents of activity-supportive neighborhoods engaged in an additional 68–89 minutes of physical activity per week compared to those in less supportive areas.[96] In Paris, expanding and separating bike lanes from motorized traffic increased bicycle use by 54% between 2018 and 2019.[97]

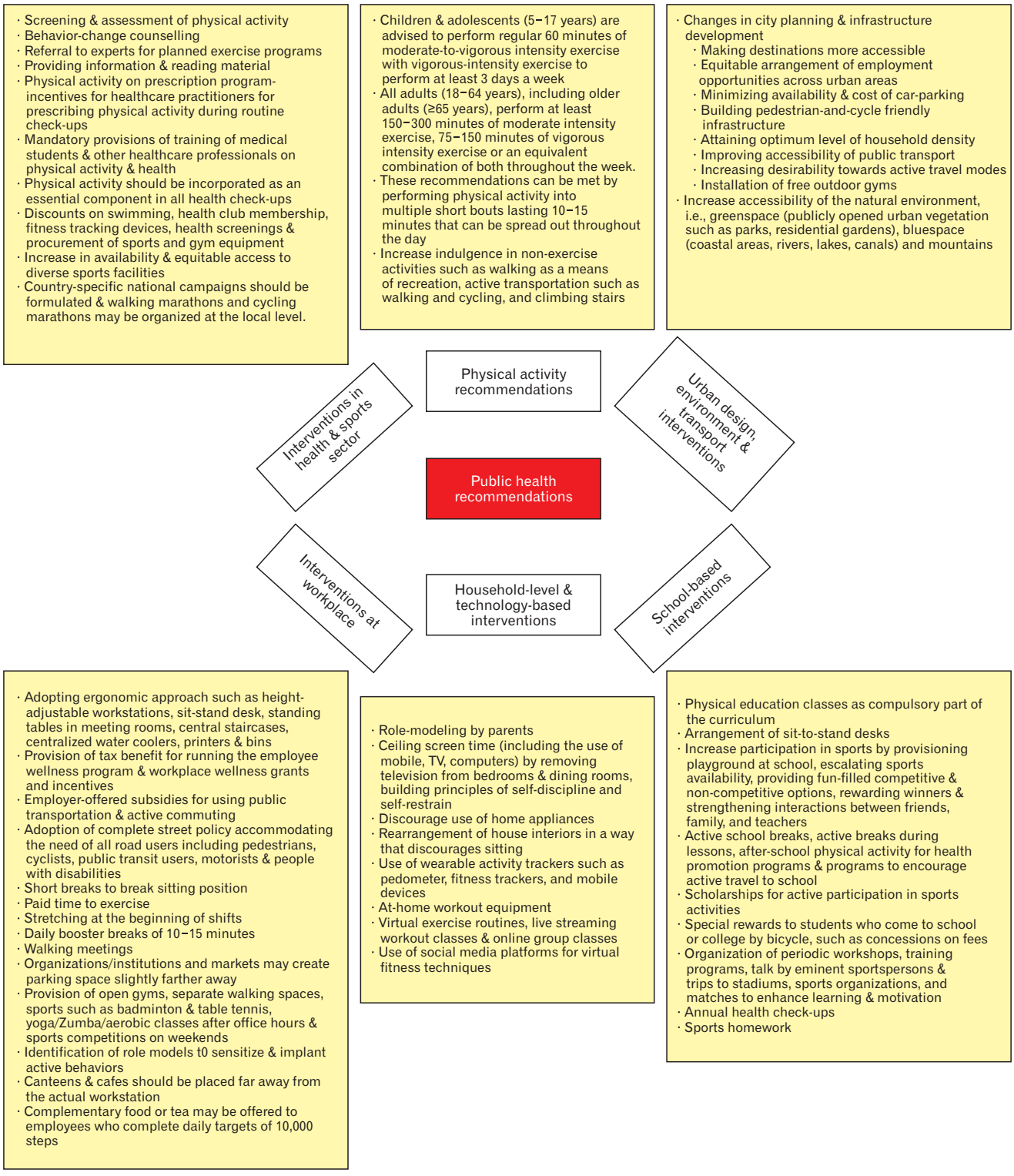

Figure 2. Public health recommendations to counteract sedentary lifestyles.

In Hungary, the government provides grants for purchasing electric bikes to encourage cycling as a means of transport.[98] The installation of free outdoor gymnasiums in parks is another viable option for increasing physical activity levels in the community, especially among socially vulnerable populations, including low-income individuals and families, minority groups, elderly individuals, children, homeless individuals, and socially isolated individuals.[99] Under the National Disability Program of Hungary (2015–2025), access to leisure-time

physical activity has increased for people with disabilities by improving infrastructure such as parks, playgrounds, tracks, and sports facilities with adequate equipment.[98]

Increasing the accessibility of natural environments, such as green greenspaces (urban vegetation like parks and residential gardens),[100] bluespaces (coastal areas, rivers, lakes, and canals),[101] and mountains, can improve physical activity levels among the masses. A recent systematic review concluded that physical activity is significantly high among residents living near or surrounded by bluespace.[101] Another review reported similar findings, indicating that better accessibility to greenspace can boost physical activity levels and reduce screen time.[102]

2. School-Based Interventions

Early education has a long-lasting imprint on young minds, and good habits formed during childhood are carried forward as a legacy into adulthood; therefore, policymakers worldwide should specifically focus on the education sector and school-going children to promote physical activity and reduce sedentary behavior.[103,104] Hence, physical education classes should be a mandatory and integral part of the curriculum rather than a neglected and optional subject, with marks/grades/scores included in the final score so that children are motivated to perform well on this subject. Children's high attendance in physical education classes positively impacts physical activity levels while decreasing sedentary behavior in both boys and girls.[105] In the Hungarian education system, physical education classes are mandatory for all students, both primary and secondary, 5 days per week.[98] Recently, in 2021, North Macedonia revised its law, whereby physical education teachers worked in tandem with teachers of other classes to enhance physical activity opportunities for students throughout the school day.[106]

Schools and colleges are ideal for promoting physical activity through exercise, yoga, dancing, and sports. Recess time should be longer in schools to promote physical activity among children.[11] In the European Union, various programs have been implemented to address sedentary behavior among children and promote a healthier lifestyle from an early age, such as active school breaks to incorporate physical activity into children's daily routines while they are at school through playground facilities and access to sports equipment and infrastructure; active breaks during lessons to integrate short bursts of physical activity into classroom lessons to break prolonged sitting hours; and after-school physical activity for health promotion programs to engage children in sports, fitness classes, or recreational activities outside of regular school hours and programs to encourage active travel to school, encouraging students to walk, cycle, or use other forms of active transportation instead of relying on motorized vehicles.[107]

Students spend many hours sitting while attending lectures at schools and colleges. To break this uninterrupted classroom sitting time, a study was conducted on a diverse sample wherein sit-to-stand desks were incorporated into the classroom and were effective in reducing the sitting time.[50] A review of 13 studies showed standing desks reduced sitting time by 44–60 minutes per day compared to traditional desks.[108] The UK's "Park & Stride" policy, which involves pick-up and drop-off points within a short walking distance from schools, has also been associated with decreased sedentary time.[103]

Children should be encouraged to participate in sports by providing playgrounds at school; escalating sports availability; providing fun-filled competitive and noncompetitive options; rewarding winners; and strengthening interactions between friends, family, and teachers.[109] In 2018, the Hungarian School Sports Federation launched the "Do60" campaign to foster 60 minutes of daily physical activity among children and students through social game activities.[98] Austria runs a program named 'Move Children Healthy 2.0' to provide children with the opportunity to participate in various age-appropriate exercise programs free of charge through collaboration between sports clubs and primary schools.[110] Schools should make participation in at least one sport mandatory and consider offering scholarships for active participation. Additional initiatives could include special rewards for cycling to school, periodic workshops, training programs, talks by sports figures, trips to stadiums, and monthly health assessments. Schools can conceptualize "health cards," wherein vital indicators such as weight, height, BMI, body fat percentage, lean muscle mass, bone mass, and hemoglobin levels are assessed and recorded monthly. Any anomaly can then be shared with parents/guardians for further consultation, and special classes may be planned for overweight or obese children. Hungary has a mandatory provision of annual health checkups for students in the 2nd, 4th, 6th, 8th, 10th, and 12th standards.[111] Schools can also assign weekly mandatory tasks involving moderate-to-vigorous physical activity to all children, which may be given as "sports homework." The Student Sports Club Program in Poland engages students in 60 minutes of physical activity twice a week by participating in various sports.[110] Government organizations should encourage daycare schools to teach discipline and physical education to children while reducing screen time.

3. Household-Level Interventions

Parents play a crucial role as role models in shaping their children's behavior, especially in terms of physical activity and sedentary habits. As the first teachers, children learn and mimic behavior observed in their surroundings, emphasizing the importance of parental influence. In a systematic review, parental influence on sedentary behavior in children was examined on six core themes: role modeling, parental support, home environment, access to play, and attributes of parents and children, and a significant association was found in all 15 studies.[112] Active parents tend to raise active children, creating a cycle of intergenerational health benefits.

Ceiling screen time (including the use of mobile, TV, and computers) is the foremost strategy to shrink total sedentary time at the household level by removing television from bedrooms and dining rooms, building principles of self-discipline and self-restraint, and creating rules for oneself to restrict the content, timing, duration, and location

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of screen media.[11,112] Policymakers can nudge people towards the adoption of non-sedentary behavior by encouraging less reliance on machines for daily chores, or the government can levy high taxes on home appliances to discourage their use. Rearranging household interiors to make sitting less appealing, such as repositioning televisions and removing sofas, can also contribute to this effort.[11]

4. Technology-Based Interventions

Technology can be employed anywhere, even to make people mobile, such as wearable activity trackers that can detect movements and generate reminders to achieve physical activity goals. The most commonly used device is the pedometer, which is user-friendly and provides feedback on the mobility of a person by counting the number of steps. Monitoring the step count can be effectively applied to break the cycle of uncertainty. Cut-offs for steps per day can be a useful tool to determine an individual's activity levels. One such step index was given by Tudor-Locke and Bassett in 2004, whereby people with <5,000 steps per day are classified as "sedentary"; between 5,000 and 7,499 steps per day as "low active"; between 7,500 and 9,999 steps per day as "somewhat active"; ≥10,000 to 12,499 steps per day as "active"; and ≥12,500 steps per day as "highly active."[113] From a public health perspective, people can be motivated and advised to achieve 10,000 steps per day to meet physical activity goals.[104,114] Various studies on physical activity interventions using pedometers have observed significant improvements in the physical activity levels of adults, youth, and children.[104] Apps for increasing physical fitness and stationary cycle-sharing platforms should be promoted.

Technology-based interventions have made significant contributions during the COVID-19 pandemic to sensitize people and increase their levels of physical activity. While gyms, parks, playgrounds, health and fitness centers, swimming pools, and aerobics and dance studios remained closed during the pandemic, a shift towards at-home workout equipment, virtual exercise routines, and online group classes was seen.[115] The study by Kaur et al.[116] in 2020 highlighted how people seek alternative ways to stay active and engage in physical activity during challenging times. Social media and live-streaming platforms offer new ways to access exercise training and foster a sense of community and accountability that can help individuals stay motivated and engage in fitness journeys.[115,116] Integrating fitness trackers and mobile devices into workouts provides valuable feedback that helps individuals stay motivated and monitor their progress.[115]

5. Interventions at the Workplace

As increasingly sedentary occupations are uprooted, employment/workplace has become an important intervention area. An ergonomic approach may be adopted to modify the workplace to decrease the ill effects of excessive sitting, such as height-adjustable workstations, standing tables in meeting rooms, central staircases, centralized water coolers, printers, and bins.[117] The use of a sit-stand desk is efficacious in diminishing workplace sitting time by an average of 100 minutes per day compared to a sit-desk.[118] Organizations can promote physical activity by creating parking spaces farther from the office, incentivizing active transportation like cycling, and providing facilities such as open gyms, separate walking space, and sports areas such as badminton and table tennis.[117] Placing canteens and cafes far from workstations and offering rewards for meeting daily step goals of 10,000 steps can also encourage movement. Initiatives such as walking meetings, walking during lunch breaks,[11] picking up calls away from the desk, yoga/Zumba/aerobic classes after office hours, and sports competitions on weekends can help drive inclination towards physical activity. Identification of role models to sensitize and induce active behaviors such as intermittent standing breaks.[117] The installation of small breaks (1–2 minutes after every half hour) can reduce the daily sitting time at work by an average of 40 minutes compared with long breaks (two breaks of 15 minutes duration per day at work).[118]

The Centers for Disease Control and Prevention have stressed various worksite policy level initiatives to improve physical activity levels of people at the workplace, such as the provision of tax benefits for running the employee wellness program, workplace wellness grants, and incentives for employers for institutionalizing training, programs, and other initiatives for employees to improve health; employer-offered subsidies for using public transportation and active commuting to encourage employees to use sustainable modes of transportation; and lastly, implementation of complete street policy accommodating the needs of all road users, including pedestrians, cyclists, public transit users, motorists, and people with disabilities.[119] Parallelly, employers can frame policies and norms at the workplace to promote and encourage physical activity and decrease sedentarism among employees, thereby improving their overall health and productivity. Among these are short breaks to break sitting positions; paid time to exercise, which allows employees to be physically active during office hours generating interest among employees and addressing the significant barrier of "lack of time"; stretching at the beginning of shifts; providing flexibility in time enabling employees to tune physical activity in their daily schedule while maintaining the total number of office hours; and daily booster breaks of 10–15 minutes for walking and walking meetings.[119]

6. Interventions in the Health and Sports Sector

Healthcare initiatives can be beneficial in preventing and managing chronic health problems. These include the screening and assessment of physical activity, behavior-change counseling, referral to experts for planned exercise programs, and provision of information and reading materials.[120] Healthcare practitioners can be provided with incentives to coalesce physical activity into routine protocols.[107,120] The physical activity on prescription program has been institutionalized by many countries, as is apparent in the Netherlands's combined lifestyle intervention and Sweden's prescription of physical activity programs.[110] Mandatory provision of training for medical students and other healthcare professionals on physical activity and health.[120] Physical activity should be incorporated as an essential component of all health check-ups.[120]

Governments can support physical activity by offering discounts on

swimming, health club memberships, fitness-tracking devices, and health screenings. An increase in the availability and equitable access to diverse sports facilities plays a significant role in promoting physical activity among individuals and communities, as is evident from Europe's sports club for health programs.[110] Sports-health houses are an initiative by the French government to promote physical activity and overall health by offering information, awareness sessions, and personalized support from health and sports professionals.[110]

In addition, sports and gymnasiums can be made available at subsidy rates. Early morning and evening hours may be utilized to indulge in active leisure time activities, such as cycling, biking, and swimming. Programs, such as walking and cycling marathons, may be organized at the local level to sensitize a larger group of people. Country-specific national campaigns should be formulated to educate and make the masses aware of the significance of physical activity and the adverse effects of sedentarism using appropriate mediums such as television, radio, newspapers, magazines, websites, and social media.[110] The elderly should be supported by jobs post-retirement to decrease their sedentary time and maintain physical activity levels. Additionally, special guiding exercises such as yoga should be programmed for older people to decrease frailty, increase strength, and improve functional capacity.

CONCLUSION

The 21st century is an era of "technological advancement" that has transformed human life in numerous ways. It has also been marked by a sudden surge in NCDs, hindering social and economic development worldwide. Humans constantly live in an environment that not only limits their physical activity but also makes them prone to various chronic diseases. Sedentarism was further exacerbated by the COVID-19 pandemic, such that its residuals are deeply ingrained in people, especially affecting children and adolescents. Excessive sitting is toxic to health and movement is the only antidote. The primary physiological change associated with excessive sedentary behavior is the development of insulin resistance, which may be a key element in the progression of metabolism-related chronic diseases.[61,69,121,122] To develop effective public health programs and policies, more insight is needed into the physiology of sedentarism and its progression to chronic diseases. Furthermore, limitations in measuring and quantifying sedentary activity should be overcome so that global consensus on recommendations on sedentarism can be achieved.

Adequate funding is essential for the success of public health programs, especially those aimed at preventive health measures such as promoting physical activity. Governments worldwide need to prioritize and allocate sufficient resources to support interventions that encourage active lifestyles and reduce sedentary behaviors. This may include funding for community-based programs, infrastructure development, educational campaigns, and policy initiatives aimed at creating environments conducive to physical activity. Continuous research is vital to understanding the complex patterns of physical activity and sedentary behavior among populations. The data will help identify trends, determinants, and barriers related to physical activity, as well as the health implications of sedentary lifestyles. By gaining a deeper understanding of these factors, public health professionals and policymakers can develop more effective interventions and policies to promote physical activity and improve the overall population's health.

It is essential to establish a strong policy framework to prioritize health and allocate resources to programs and infrastructure. Collaboration between multiple sectors, including healthcare, education, urban planning, transportation, technology, and recreation, is required to effectively address the pressing issues of physical inactivity and sedentary behavior among the masses of all age groups. The engagement of multiple and diverse stakeholders will ensure a holistic approach towards promoting physical activity and create opportunities for synergy and innovation. Physical activity initiatives often involve actions beyond the scope of public health such as urban planning, transportation policies, and recreational programming. Partnerships within these sectors are essential to create supportive environments that facilitate an active lifestyle.

Effective interventions should exert broad effects on large segments of the population. Surveillance systems are necessary to monitor trends in physical activity levels, assess the effectiveness of interventions, and guide future public health strategies. Evidence-based strategies must be adapted to suit the unique needs, cultures, and contexts of the communities. Tailoring interventions increase relevance, acceptability, and effectiveness, thereby fostering greater engagement and participation. Strong partnerships with policymakers, community leaders, advocacy groups, and private-sector stakeholders are crucial for securing sustained funding and political support for physical activity initiatives. Building coalitions amplifies the impact and visibility of public health efforts.

Addressing sedentarism requires a comprehensive and multi-faceted approach that integrates evidence-based strategies, community engagement, and collaboration across sectors. It is possible to create environments that promote active living and prevent noncommunicable diseases by prioritizing physical activity as a public health imperative and leveraging diverse partnerships and resources.

Although this global public health condition has created havoc in the lives of people, it comes with a simple and effective remedial solution, i.e., increasing the levels of physical activity and breaking the cycle of sedentarism, which is the only prescription known to date to ameliorate its adverse effects. Hippocrates (377 B.C.) in antiquity also believed in the merits of a physically active lifestyle and once said, "All parts of the body which have a function, if used in moderation and exercised in labors in which each is accustomed, become thereby healthy, well developed, and age more slowly, but if unused, they become liable to disease, defective in growth, and age quickly."[123] The human body is designed for movement, and when we engage in physical activity appropriate to our abilities and lifestyle, health, vitality, and resilience are promoted. Hence, a balanced approach needs to be adopted that leverages technology for convenience without compro-

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mising overall health, promoting an environment where technology coexists harmoniously with an active and healthy lifestyle.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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