THEORETICAL ESSAY

Sleep Science

The contribution of modern 24-hour society to the development of type 2 diabetes mellitus: the role of insufficient sleep

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ABSTRACT

Epidemiological studies since 1980 have shown significant increases in the incidence of type 2 diabetes mellitus (T2DM). The public health burden generated by the growing prevalence of T2DM, which, in its fully developed form, is a lifelong illness, has been associated with further social and economic costs in affected countries. Recent studies have suggested that chronic sleep insufficiency or disrupted or poor quality sleep could contribute to the development of T2DM. Although many research findings have now shown that sleep plays a key role in glucose metabolism, the full implications of these findings have not been translated into clinical programs for improving patients' sleep quality as a means for addressing the treatment of T2DM. The purpose of this brief overview is to focus on the clinical significance of sleep in the onset and treatment of T2DM. We suggest here that physician education should emphasize the importance of sufficient sleep for overall health, including the management of T2DM, and that steps should be taken to incorporate this perspective into clinical practice. The promotion of sleep hygiene techniques as a clinical intervention could improve the regulation of glucose metabolism and thus the longevity of T2DM patients. Moreover, it may prevent secondary complications accruing from the illness and consequently reduce the significant medical costs of treating T2DM patients.

Keywords: T2DM; Diabetes; Glucose metabolism; Life style; Sleep; Sleep hygiene; Type 2 diabetes mellitus.

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INTRODUCTION

Diabetes is one of the major non-communicable diseases (NCDs), the incidence of which has doubled in recent decades[1,2]. Although the exact causes of this increased incidence have not been fully determined, it is not unreasonable to infer that the growth of modern 24/7 lifestyles choices is a contributing factor. Across the globe, industrialized economies are increasingly introducing social changes that represent radical departures from the past.

These transformations include not only a movement away from traditional diets, but also the growing prevalence of shift work, longer working hours, workers taking on multiple forms and venues of employment, and the increasing availability of night-time entertainment activities. These changes have brought with them a reduction in concerns by many about the importance of getting an adequate amount of quality sleep.

Recent evidence demonstrates that the multiplicity of social and environmental pressures of modern lifestyles affects both the duration and quality of sleep, which in turn affect circadian rhythms, which are important to overall health[3]. When individuals are subjected to the above-mentioned lifestyle stressors for prolonged periods, their susceptibility to the number of disorders increase. Among these are psychiatric disorders[4], cancer,[5] dysregulation of immunological processes[6], and, most relevant to our present consideration, metabolic disorders, including type 2 diabetes mellitus (T2DM)[7-10]. There is considerable evidence that sleep has a restorative function, and is essential for the normal energy balance of the body[11]. Conversely, chronic sleep restriction produces stress and a number of aberrant clinical conditions, including T2DM.

The increased incidence of diabetes, which in the year 2017 reached an unprecedented level of 425 million cases or almost 9% of the global population[2], has contributed significantly to the expense of maintaining minimum public health standards. On a global basis, the economic cost of treating diabetes has amounted to around $727 billion[2]. The number of people who have died because of diabetes-associated difficulties now amounts to 4 million people[2]. As alarming as these trends may seem, they do not show signs of abatement. This evidence has led calls to explore as many options as possible for treating T2DM and to encourage contributions from multiple perspectives for managing its associated complications.

The World Health Organization (WHO) has concluded that despite many years of research, global efforts to manage T2DM in terms of public advocacy or policy revisions in the healthcare and educational sectors are still preliminary or mostly non-existent[1]. The heavy social and financial burden caused by T2DM obviously requires an urgent call for action for educating the public regarding the importance of hygienic sleep practices for overall health promotion. Despite the increasing amount of evidence that disturbed or inadequate sleep is highly disruptive to glucose metabolism there continues to remain only limited awareness among the general public regarding the significance of this association[7-10,12-14]. This knowledge gap also affects the agencies responsible for the promotion of public health and education, which similarly appear to be unaware of the effects of sleep on metabolic processes. Their relative ease of application and common sense nature usually provoke minimum resistance by patients and thus merit priority consideration by physicians for inclusion in an overall management strategy for T2DM. The purpose of this brief overview is to highlight the clinical significance of sleep in reducing the incidence of T2DM.

The effect of modern-day pressures on sleep quality

Epidemiological surveys have shown that the around-the-clock pressures of contemporary society have led to a substantial loss of more than 90 minutes a day in the average individual's duration of sleep[15]. One survey found that children are sleeping ~37 min less than the minimum recommended amount for healthful sleep[16]. Nearly 21% of the American people report sleeping less than 6 h in a 24- h period[9]. The emphasis on productivity of present-day society has meant that people in many countries are willing to voluntarily curtail the amount of time that they spend sleeping for the purpose of fulfilling their obligations for work or education[15,17].

It has been suggested that this type of work culture, in which individuals are expected to restrict their sleep in the service of other social or employment objectives, is a major causal factor in the long-term accumulation of sleep debt, i.e., the unfulfilled physiological need for sleep. The burden of this sleep debt, in turn, produces a chain of causation which ultimately disrupts circadian regulation and consequently increases the risk of acquiring T2DM[9]. Consistent with this suggestion has been the finding of public health studies in which the incidence of diabetes in the general population is associated with self-reports of reduced sleep duration[8]. It is known that melatonin secretion, the key neurohormone that facilitates circadian regulation, is suppressed by exposure to environmental light[18]. It has thus been suggested that the use of electronic devices involving visual stimulation, e.g., television, mobile phones, and computers, additionally contribute to the problem of reduced sleep length and quality. Children and adults using these devices have been shown to exhibit problems in their circadian clock[19], a difficulty, which further complicates their sleep propensity, i.e., their felt need and motivation to sleep. Additional physical health and psychological difficulties occur when this increased need for sleep remains unfulfilled due to the demands of their daily schedules[16].

Considering this evidence, it could be concluded that many in present-day society are living under a regimen of constant sleep debt, a biological burden that further affects their health status, and thus increases their risk of acquiring metabolic disorders such as T2DM.

Sleep and its role in glucose metabolism

Sleep is a fundamental biological need required for maintaining health status and normal lifespan[20]. Numerous studies have now shown that sleep has a major role in the regulation of metabolic processes including glucose homeostasis[7,9,10,12,13,21], hormones which control appetite[8,22,23], and insulin sensitivity[24,25].

Further, prolonged loss of sleep induces changes in a broad range of physiological processes[4-7], including the development of T2DM[8-10,12,13]. Studies of these processes have consistently shown that adequate sleep quality and sleep duration are fundamental requirements for maintaining control of insulin synthesis and sensitivity. Conversely, diminished sleep quality and duration are responsible for aberrant insulin-dependent processes which ultimately lead to the onset of T2DM[24-26].

Several research efforts have shown that sleep restriction or disturbance has a number of effects on metabolic functioning. Sleep restriction is strongly associated with reduced levels of leptin and elevation in ghrelin concentration, conditions that affect hunger regulation and lead to increases in appetite[23,27]. In one study, subjects whose sleep duration was restricted to 5 h showed diminished levels of leptin (15.5%) and elevated amounts of ghrelin (14.9%), abnormalities which did not occur when subjects were allowed to sleep for 8 h[27]. In another study of young women, it was found that restriction of sleep length for one night significantly lowered cortisol levels and enhanced the concentration of leptin[22]. In obese children aged 10-15, increased concentrations of leptin and ghrelin were observed in those who slept for less than 8 hours when compared to those who slept more than 10 hours[23].

Sleep insufficiency thus increases appetitive drive by stimulating the release of ghrelin, and this, in turn, leads to excessive nutrient intake and accumulation of adipose tissue[8]. An additional consequence of sleep loss is that glucose homeostasis is affected by the alteration in neuroendocrine function[8]. It has been found, for instance, that four hours of experimentally induced sleep deprivation over a period of five nights was sufficient to decrease glucose tolerance in human subjects up to 40% and produced a 30% reduction in insulin response[28]. In addition, elevated levels of cortisol synthesis was reported, thus suggesting that dysregulation of the HPA axis had occurred[28]. A considerable body of evidence has established an association between sleep perturbations and the development of obesity in both children and adults[29].

Close associations have been found between inadequate sleep and the development of fatty tissue and increases in body mass index[23,27,30]. These findings thus support the inference that total sleep time may be a vital regulator of adipogenesis. More broadly, it has been suggested that sleep is a process that is necessary for the uniform distribution of energy across the body, and that insufficient sleep is a disruptor of this essential balance, with increases in body weight being the final result[23,27,30]. The experimental findings that are reviewed above support a model in which sleep mediates glucose metabolism through multiple pathways, including the regulation of insulin synthesis and sensitivity, glucose utilization, food intake activity, adipogenesis, and through its stimulation of appetite-regulating neuroendocrine hormones. In summary, chronic sleep loss affects all the above-mentioned processes and is thus implicated as an important contributor to the development of T2DM.

The association between sleep duration and type 2 diabetes mellitus

The lines of evidence cited above thus support a model in which sleep deprivation and poor quality sleep contribute to the development of T2DM through the alteration of glucose metabolism, and several other mechanisms. It has been demonstrated that initiation of nighttime sleep is associated with a 30% increase in glucose concentration and enhancement of insulin synthesis up to a level of 50-60%[7]. Additionally, it has been observed that, compared to the general population, T2DM patients more frequently report having inadequate or disturbed sleep[31]. Inasmuch as the concentration of glucose utilization varies throughout the sleep/wake cycle, any postponement or restriction of the sleep process may alter the function of insulin and glucose variation in blood plasma[7].

One investigation demonstrated that drastic reductions occurred in the concentration of both plasma glucose and insulin following a 28-hour of continuous wakefulness[7]. Further, differential levels of glucose and insulin were observed during recovery sleep when compared with baseline sleep[7]. The increased duration of wakefulness resulting from sleep loss led to an elevated amount of nutrient intake, which further extended to the accumulation of body weight[23,27,30]. A recent investigation found a relationship between a prediabetic state and reduced sleep quality and duration[32], thus pointing to an association between disturbed sleep and the development of T2DM[33]. Comparatively high levels of HbA1c levels are observed in T2DM patients, with at least one sleep complication (as measured by the PSQI; the Pittsburgh Sleep Quality Index), when compared to T2DM patients without sleep complications[34]. In another investigation designed to study the role of sleep length and susceptibility to T2DM in children, a survey of 4525 subjects found that several indicators of metabolism were associated with the length of sleep duration[10]. In addition, the authors of the study found that the loss of one hour of sleep was correlated with a reduction in insulin resistance and a decrease in glucose concentration[10].

Artificial light is known to interfere with the induction of sleep. In particular, environmental light suppresses production of the hormone melatonin, resulting in increased alertness and a significant decrease in sleep propensity and quality[18,35]. It has been suggested that the widespread availability of electronic devices with illuminated viewing screens, such as computers, laptops, touchscreen tablet PCs (ipads), and mobile phones, has extended visual stimulation and mental activity into the nighttime hours, which in previous generations were restricted to the daytime.

Reading with the help of modern technological devices such as light-emitting diode (LED) electronic devices has been found to delay the synthesis of melatonin for 90 minutes when compared to using a printed version of the same reading material[36]. Light emission from artificial LED devices at inappropriate times has been found to alter the phase of the biological clock, thus underscoring the impact which technological devices have on sleep duration and quality[36].

It has been suggested that these forms of technological innovations (e.g. artificial lighting, light at night (LAN) combined with the excessive social and work demands of modern life (e.g. work culture, shift work, night time waking, etc.) have a significant impact on public health through their effects on melatonin synthesis, which in turn disrupts the circadian clock[18]. Circadian clock disruption further postpones, disturbs and alters the sleep/wake rhythm of the next day and, and those of subsequent days as well. The effects of another social trend, the increasing prevalence of shift work, have also been investigated. It has been found that those who engage in this type of employment have an elevated risk for the development of T2DM[37,38].

It has been observed also that shift workers often have difficulties in fully adapting to the sleep schedules of night-time work, with reports that they often slept no more than 5 h despite having been doing shift work for some time[39]. Not only do shift workers report having fewer hours of sleep, but the quality of sleep that they do get is also similarly reduced[39]. Further long-term studies are needed to establish the impact of sleep deprivation in the maintenance of glucose homeostasis. In summary, these findings point fairly consistently to the conclusion that sleep plays a crucial role in the maintenance of glucose balance, and, further, that prolonged loss of and reduction in the quality of sleep could accelerate the onset of T2DM.

Conclusion and future directions

Various technological innovations and social development practices of the modern-day society are responsible for undermining the perceived importance of sleep hygiene practices. Many lines of evidence suggest that social and cultural factors have contributed to the growing incidence of T2DM, but these are rarely considered in strategies for preventing or managing the problem[40]. In modern society, sleep insufficiency, sleep perturbations, inappropriate sleep/wake, and work schedules, early school start times, excessive time spent on weekends to compensate the sleep debt which is accumulated on the weekdays are frequently reported. An accumulating number of studies have dealt with the health effects of sleep loss across the human lifespan, starting from childhood to old age.

The resulting evidence has supported the conclusion that modern-day social schedules tend to restrict sleep and could be responsible for the onset of many disorders. The detrimental impact of modern 24h society on sleep quality and duration has unfortunately become accepted as the "new normal", and, further, has brought with it widespread increases in the incidence of T2DM. To a great extent, these phenomena are the result of pressures accruing from a limited recognition of the health consequences of working at night and of the hazards of electronic technology.

It is strongly recommended that these issues be addressed and discussed and that proper framework of policies is instituted to decrease the impact of these preventable risk factors of sleep. Further, the beneficial effects of sleep hygiene practices are often less appreciated by the medical establishment and have not been incorporated into public health policy. It has been noted that many countries and their health institutions do not include the contribution of personal health management in the development of clinical disorders. Further, there is even less appreciation for the contribution of social factors to personal health[40]. However, a growing number of studies showing the association between disturbed sleep and T2DM has underscored the importance of recognizing these linkages. These studies have set the stage for the next evolving transition in thinking about sleep. This expanded view regards appropriate sleep hygiene practice as a realistic and cost-effective strategy for dealing with the pandemic of T2DM.

It has been asserted that most nations and their health establishments have ignored the problems associated with the rising incidence of T2DM and the complications generated by it[40]. It has been suggested that relevant public policies, as well as actions taken to support these policies, should be undertaken immediately[40]. Numerous epidemiological surveys and laboratory studies have now provided evidence which strongly implicates sleep disturbance as a contributor to T2DM.

Further studies are needed however to characterize mechanisms behind the pathogenesis of abnormal glucose metabolism, and ultimately clinical studies will be needed to develop novel strategies for the prevention and treatment of T2DM. It is suggested that the use of animal models of sleep disturbance and clinical studies of how glycaemic control can be managed by improving sleep quality and duration could provide insights in this regard. Long-term studies with chronic sleep deprivation and disturbance in animal models are urgently needed to elucidate the clinical significance of sleep in the regulation of glucose homeostasis.

It is essential that clinical interviews with T2DM patients emphasize the importance of sleep hygiene practices for regulating glucose homeostasis. It is recommended that sleep therapy techniques be explored and studied as a means for managing disruptions to glucose balance. Levels of glucose utilization in various sleep states with respect to specific time periods should be analyzed across the general population and used as the basis for recommended sleep hygiene practice. Standardization of sleep hygiene therapy should be given equal importance to the pharmaceutical prescriptions given to T2DM patients[34]. There is now considerable evidence that an optimal quality and quantity of sleep are essential for neural development, hormonal regulation, and metabolism. Public policy should emphasize the importance of these linkages.

Further, specific policy initiatives should underscore the need for changes in physician training and in public education. In particular, these efforts should call attention to the adverse effect of sleep deprivation on glucose metabolism. The broader adoption of sleep therapy as a means for regulating glucose balance would provide advantages not only to individuals, but could also reduce the significant healthcare costs which T2DM represents to society generally. It is the opinion of the present authors that scientific investigations into the impact of sleep on the development of T2DM should be made known to relevant government agencies and to the general public. Such efforts would represent an important step in minimizing the global economic and social costs imposed by these human health burdens.

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