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TECHNICAL REPORT

Insufficient Sleep in Adolescents and Young Adults: An Update on Causes and Consequences

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KEY WORDS
adolescents, caffeine, car crashes, media use, obesity, sleep loss, sleepiness

ABBREVIATIONS
REM—rapid eye movement

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abstract

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Chronic sleep loss and associated sleepiness and daytime impairments in adolescence are a serious threat to the academic success, health, and safety of our nation's youth and an important public health issue. Understanding the extent and potential short- and long-term repercussions of sleep restriction, as well as the unhealthy sleep practices and environmental factors that contribute to sleep loss in adolescents, is key in setting public policies to mitigate these effects and in counseling patients and families in the clinical setting. This report reviews the current literature on sleep patterns in adolescents, factors contributing to chronic sleep loss (ie, electronic media use, caffeine consumption), and health-related consequences, such as depression, increased obesity risk, and higher rates of drowsy driving accidents. The report also discusses the potential role of later school start times as a means of reducing adolescent sleepiness. *Pediatrics* 2014;134:e921–e932

INTRODUCTION

Since the publication of the American Academy of Pediatrics technical report on excessive sleepiness in adolescents in 2005,[1] there have been a considerable number of articles published pertaining to sleep. These articles expand on many of the topics raised in the original report and add a number of new important health issues not previously or minimally discussed (ie, short sleep and its association with obesity, caffeine/stimulant use). The previous technical report provided an overview of the profound changes in sleep–wake regulation and circadian biology occurring during adolescence, outlined factors (ie, parental influence, school start times) contributing to insufficient sleep in adolescents, and summarized consequences such as negative impacts on mood, attention, and school performance. It also focused in particular on clinical sleep disorders such as insomnia, narcolepsy, and restless legs syndrome contributing to daytime sleepiness in adolescents. The new material in the present report adds to what is known about the extent of sleep restriction in the adolescent population and reinforces the importance of recognizing insufficient sleep both as a key public health issue and one that is immediately relevant to pediatric practice.

The focus of this updated technical report is on insufficient sleep, specifically as a consequence of voluntary sleep restriction. It should

be noted that such terms as insufficient sleep, inadequate sleep, short sleep duration, sleep loss, and sleep restriction are used interchangeably and as generic descriptive terms only and do not imply specific amounts but rather "less sleep than needed."

Insufficient sleep in adolescents was recognized as a serious health risk in 2010 in a jointly sponsored American Medical Association/American Academy of Sleep Medicine resolution acknowledging the problem.[2] Furthermore, objectives for Sleep Health, a new topic in Healthy People 2020,[3] specifically includes reducing adolescent sleep loss: "SH-3: Increase the proportion of students in grades 9 through 12 who get sufficient sleep" (defined as ≥8 hours).

A second focus of the present report is on unhealthy sleep behaviors (ie, poor "sleep hygiene") in teenagers, including irregular sleep–wake patterns, electronic media use in the bedroom, and excessive caffeine use. A third focus is on the myriad of potential consequences of inadequate sleep in adolescents, including depression/suicidal ideation, obesity, car crashes attributable to drowsiness, and poor academic performance.

EPIDEMIOLOGIC STUDIES OF SLEEPING ADOLESCENTS

Epidemiologic studies of sleep typically rely on self- or parent-reported questionnaire data to document adolescent sleep patterns and the factors affecting them. The key advantage of this method is the ease of assessment of large sample sizes. As a result, epidemiologic studies can determine sleep patterns across the full adolescent age range with less potential sampling bias than smaller case-control studies. Consistent with other methodologic approaches, the consensus finding across epidemiologic studies is that both younger[4–6] and older[4,7–11] adolescents are not getting enough sleep. It is important to note that studies comparing self-reported sleep duration with objectively measured sleep amounts (ie, with actigraphy) suggest that self-reports of sleep often overestimate actual sleep duration, signifying that the problem of chronic sleep loss in adolescents may be even greater than the data indicate.[12]

US-based[4,13] and international studies[5,6,14] revealed that as students get older, sleep durations decline. The National Sleep Foundation Sleep in America Poll[4] found that by the 12th grade, 75% of students self-reported sleep durations of less than 8 hours of sleep per night compared with 16% of sixth graders. Furthermore, although 30% to 41% of sixth through eighth graders were getting 9 or more hours of sleep, only 3% of 12th graders reported doing so. Adolescents often attempt to address the accumulated weekday sleep debt during the weekend, when oversleep (the difference between weekday and weekend sleep durations) of up to 2 or more hours is commonly reported.[4,7,8,15,16]

Comparisons with other countries show similar patterns of decreased sleep durations with increasing age among adolescents. For example, in Northern Taiwan,[5] Germany,[14] and India,[17] average sleep duration dropped to below 8 hours for high school–aged students. The most precipitous drop was reported in 2005 for more than 1400 South Korean adolescents, for whom the average duration of sleep was 4.9 hours.[6] In general, studies have demonstrated similar weekend sleep durations across countries, but weekday sleep durations tend to vary greatly.[5,9] In contrast, Australian adolescents seem to do comparatively well, with students 17 years and older reporting average sleep durations between 8.5 and 9.1 hours.[18] The difference between weeknight and weekend sleep durations also was not large, with weekend durations reported at 9.3 hours. Interestingly, although data on school start times in the Australian study were not presented, the average reported wake times on school days was 7:00 AM or later, suggesting that the schools these students attended did not start before 8:00 AM.

A number of studies have indicated that sleep health disparities exist and that adults,[19] children, and adolescents[20–22] from families with low income or of racial or ethnic minorities may be at even greater risk of poor-quality and insufficient sleep. For example, in a recent study of middle school students, appropriate timing and consistency of both weeknight and weekend sleep schedules were inversely correlated with low socioeconomic status and specific household/neighborhood variables (eg, overcrowding, noise levels, safety concerns).[23] This relationship may have important health implications. For example, a recent study suggested that less sleep was a predictor of obesity risk in African-American adolescents but not in white adolescents.[24] "Missed" sleep was also reported to be an important factor in asthma morbidity, especially in Latino children.[25] However, higher socioeconomic status is not necessarily protective because studies have also shown that youth from households with higher socioeconomic status have shorter sleep durations.[16,26]

For older adolescents, additional environmental factors, such as after-school employment,[16] striving for good grades,[5,6,12] socializing,[27,28] participation in sports and other extracurricular activities, and lack of parental monitoring or rules about bedtimes, can further interfere with sleep durations.[6,29,30] School start times are reviewed later in the present report.

In summary, short sleep durations, coupled with evidence of daytime sleepiness (eg, increased self-reported sleepiness ratings,[5,6,11,31] daytime napping,[5,14,26] weekend oversleeping,[6,10,14,32] need for assistance in waking[6]), as well as increased use of fatigue countermeasures

(eg, excessive caffeine consumption[4,5,15]), all indicate that adolescents are sleeping fewer hours than they need. The clear and consistent message is that middle and high school students are not getting enough sleep and that this issue is a chronic problem worldwide. In addition, the health and behavioral outcomes linked to restricted sleep, as further detailed in the following sections, are alarming. These outcomes include increased risk of car crashes,[4,33] delinquent behaviors,[27] depression,[8,10,34] and psychological stress.[35]

FACTORS CONTRIBUTING TO INSUFFICIENT SLEEP IN ADOLESCENTS

Influence of Biological Processes on Adolescent Sleep

The association of early adolescent development/pubertal onset and a more evening-type circadian phase preference (ie, preferred timing of sleep and wake as well as daytime activities) has been documented since the 1990s.[36] The behavioral result of this biological process is most clear in the timing of sleep, particularly for weekends. For example, Roenneberg et al[37] measured the midpoint of weekend sleep in European schoolchildren and revealed a marked linear delay of 2 (girls) to 3 (boys) hours across the second decade, roughly 12 to 18 minutes later with each year of age. The reversal of this delayed weekend sleep pattern may be a "biological marker for the end of adolescence."

Recent data have indicated that another process involved in regulating sleep timing seems to be altered to favor late nights across adolescent development. This process, called sleep–wake homeostasis, can be thought of as the system that accounts for greater pressure to sleep as one stays awake longer. Data collected with 2 different paradigms to estimate the rate of buildup of sleep pressure in prepubertal versus postpubertal adolescents indicate that more mature adolescents accumulate this sleep pressure at a slower rate.[38,39]

Maturational changes to these 2 bioregulatory processes begin in adolescents as young as middle school and present a major challenge for young people to fall asleep in the early evening and to wake refreshed/restored in the early morning to attend school. The most prominent factors in this regard are evening and nighttime screen use and social networking, both of which have increased markedly in the 21st century.[40] Going to bed later and waking later on weekends than on weekdays reflects the biology of circadian rhythm and is also a response to insufficient weekday sleep. Later sleep timing and catch-up sleep on the weekends further delay the signal for the biological night (ie, melatonin production) and dissipate residual sleep pressure.[41] In summary, the combination of biologically driven processes with modern lifestyles and social obligations minimize the opportunities for adolescents to obtain adequate sleep.

Electronic Media and Sleep

Today's adolescents and young adults have grown up in an electronic age. According to the National Sleep Foundation's 2006 Sleep in America Poll, almost all adolescents had at least 1 media electronic device in their bedroom.[4] Among the devices reported were televisions (57%), music players (90%), video game consoles (43%), computers (28%), and phones (64%). A more rigorous study of subjects recruited from a pediatric office in a Philadelphia suburb showed that of the 100 adolescents ranging in age from 12 to 18 years, two-thirds had a television in their bedroom, almost one-third had a computer, almost 80% had a digital music player, and 90% had a cellular phone in their bedroom.[42] The teenagers engaged simultaneously in an average of 4 electronic activities after 9:00 PM.

It is not surprising that several studies in adolescents have demonstrated that electronic exposure in the evening potentially disrupts sleep. The use of multiple electronic devices at the same time has been associated with less sleep at night and a greater degree of sleepiness during the daytime.[4,15,31,42,43] Having a television in the bedroom (or even out of the bedroom) has been associated with later bedtimes on weekdays, longer sleep latencies, shorter total sleep times, later wakeup times on the weekends, and more daytime sleepiness in adolescents.[44–46] In the Children in the Community Study in 1976,[47] adolescents who were watching 3 or more hours of television not only experienced difficulty falling asleep and frequent awakenings but also had a risk of having difficulties with their sleep later in adolescence and young adulthood. The use of computers before bedtime has also been shown to have the same effect, and this finding has been demonstrated in a wide range of countries and cultures.[45,46,48–51]

Engaging in a greater number and range of sleep-interfering activities before going to bed has also been associated with less nocturnal sleep and more daytime sleepiness in adolescents.[45] Several mechanisms have been postulated about how media disrupts sleep.[40] One is that the use of media directly displaces sleep; an adolescent or young adult may simply stay up later enjoying whatever media he or she is using. In addition, electronic media allow for greater interaction between friends. Early data suggested that peer-to-peer interaction did not have a major influence on school-night bedtime but rather had a more significant influence on a teenager's sleep on weekends.[52] These findings may no

longer hold now that there are enhanced ways for adolescents to communicate electronically. Calamaro et al[42] found that after 9:00 PM, 34% of adolescents in the study sample were text messaging, 44% were talking on the phone, 55% were online, and 24% were playing computer games. In another study of Belgian teenagers, 62% of the subjects used their phones after the lights were turned off, and phone use at this time was associated with increased daytime tiredness the next day.[53]

Another possible mechanism for the detrimental effect of electronics use on sleep is that the light produced by electronic devices may disrupt circadian rhythms by suppressing melatonin, resulting in the inability to fall asleep at a reasonable time.[40] Recent studies have demonstrated that exposure to relatively low-intensity light can alter circadian rhythms[54,55] and suppress nocturnal melatonin secretion.[56]

Finally, media use may cause increased sleep-disrupting mental, emotional, and physiologic arousal.[40] One study found that subjective sleepiness was lower, sleep latency was longer, and rapid eye movement (REM) sleep was shorter in subjects after playing video shooting games, independent of the brightness of the screen used.[56] Another study that compared playing an interactive computer game with watching a movie on television in the evening[51] found a decline in verbal memory performance, prolonged sleep latency, and an increase in light sleep in the computer game cohort.

School Start Times

As has been described elsewhere in the present report, a multitude of changes occur over the course of adolescence that can affect the quality and quantity of sleep in adolescents and young adults. One of the most salient and arguably most malleable is that of school start times, a systemic countermeasure. There are clearly a number of practical implications and/or challenges that schools might face when considering altering school start times, such as changes in athletic schedules, effects on after-school activities, and transportation issues.[57] Despite these hurdles, a small yet increasing number of school districts over the last 15 years have responded to research reports regarding the prevalence of inadequate sleep among middle and high school students by delaying school start times. Research on the effects of delaying the start times of middle and high schools for adolescents' sleep and daytime functioning is discussed in this section, and a more detailed discussion is available in the American Academy of Pediatrics policy statement on school start times.[58]

In one of the first studies to assess the effect of school start times on adolescents,[59] a 65-minute earlier school start time in the transition from grade 9 to grade 10 resulted in fewer than one-half of 10th graders obtaining an average of 7 hours or more of sleep on school nights and physiologic levels of daytime sleepiness ordinarily seen in patients with narcolepsy. A large prospective longitudinal study of delays in school start times in both an urban and a suburban school district found improvements in attendance rates and an increase in the percentage of high school students continuously enrolled in the district or the same school, although grades did not show a statistically significant improvement.[60] Similar to what has been reported in subsequent studies,[55] bedtimes did not change with the delay in start times, but morning wake times were significantly later, resulting in the students obtaining nearly 1 hour more of sleep on school nights. Other studies have also reported increases in sleep duration and decreased daytime sleepiness associated with delayed school start times,[61] as well as increased satisfaction with sleep and motivation and significant declines in self-reported depressed mood, health center visits for fatigue-related complaints, and first-period tardiness.[62]

Research on the effects of early versus delayed school start times for young adolescents has resulted in strikingly similar findings. Students at later-starting middle schools report later rise times, more total sleep on school nights, less daytime sleepiness, less tardiness, fewer attention/concentration difficulties, and better academic performance compared with middle school students at earlier-starting schools.[63,64] In addition, middle school students with a delayed start time of 1 hour for just 1 week performed better than the earlier-starting comparison group on tests requiring attention.[65] Undoubtedly, delaying the start of middle school allows early adolescents, similar to their older high school–aged peers, to obtain sufficient sleep and to perform better in school.

Danner and Phillips[33] demonstrated that delaying school start times in 1 community in Kentucky decreased the average crash rate for teenaged drivers by 16.5%, while the state as a whole increased by 7.8% in the same time period. In another recent study conducted in 2 adjacent, demographically similar cities, there were significantly increased teenaged (16- to 18-year-olds) crash rates over a 2-year period in the city with earlier high school start times.[66]

Taken together, it is clear that when middle and high schools (schools designed for adolescents) institute the countermeasure of delaying the start time of school, students obtain more sleep and there are associated improvements in behaviors pertinent to academic success (attendance and school performance) and safety.

Caffeine

Use of caffeine has been understudied in adolescents and children; however, current research has raised important questions regarding the complex interrelationship between caffeine use and sleep patterns during this developmental period.[67–70]

Similar to studies of adult caffeine use, higher caffeine intake as early as 12 years of age is associated with shorter sleep duration, increased sleep onset latency, increased wake time after sleep onset, and increased daytime sleepiness.[68,69,71] High school students who report a moderate to high intake of caffeine versus very low intake were nearly 2 times more likely to have difficulty sleeping and to report morning sleepiness.[71] High and regular caffeine users seem to develop a cycle in which disrupted sleep attributable to caffeine use leads to sleepiness, which then leads them to increase their caffeine consumption.[72] Moreover, caffeine reduces the percentage of time spent in slow-wave or "deep" sleep in a dose-related manner and alters the temporal organization of REM/non-REM sleep.[70,72,73] This outcome is particularly important because of the critical role that both slow-wave sleep and REM sleep play in learning and memory consolidation.

Researchers are beginning to examine adolescents' expectancies regarding caffeine use. Reported expectancies for caffeine users were for energy and mood enhancement and to counteract the effects of sleep disturbances. Other studies have found that adolescents report using energy drinks for the energy boost or "buzz" and that these beverages make them "feel more energetic."[74] In comparing different types of users, "mixed" caffeine product users (ie, soda, coffee, energy drinks) reported higher levels of withdrawal and/or dependence, energy and mood enhancement, appetite suppression, and performance enhancement expectancies than either the high-soda or low-caffeine use groups. A higher percentage of mixed users compared with high-soda users reported that the reasons for their caffeine use were related to getting through the day, experimentation, and recreation.[68]

Regardless of the reasons adolescents use caffeinated substances, there are clear consequences. Adolescents experience tolerance and withdrawal symptoms; however, in general, caffeine dependence in adolescents is poorly understood.[75,76] Female high school students were more likely to report withdrawal/dependence caffeine expectancies as well as appetite suppression expectancies compared with their male peers.[68] Although adolescents may consume excessive caffeine in an attempt to mitigate daytime sleepiness, this action not only further compromises the quality and quantity of sleep, but high caffeine users may also be at risk for other substance use and/or abuse as well as other risk-taking behaviors.[68,75,77–79] Consumption of caffeine is linked to nicotine use in adolescents,[80] which in turn may further disrupt sleep[81] and perpetuate the cycle of sleep fragmentation/daytime sleepiness coupled with stimulant use. Not surprisingly, increased caffeine use frequently coexists with other behaviors that negatively affect sleep, such as adolescents' late-night, multifaceted technology use. For example, a recent study[42] found that high school–aged adolescents who reported the highest levels of multitasking with media-related electronic products also consumed the most caffeine.

The correlation between caffeine consumption and daytime sleepiness is, in turn, inversely correlated with academic achievement. For example, 1 study of over 7000 adolescents reported that a significant proportion of the variance that occurs in academic achievement was found to be attributable to caffeine use.[82] The authors further postulated that daytime sleepiness might be an important mediator of the negative impact of not only caffeine but also alcohol use and cigarette smoking on academic success. Caffeine use may also serve as an affect modulator, particularly when it comes to adolescents with excessive daytime sleepiness or insufficient sleep. For example, studies have suggested that adolescents may use caffeine as a means of regulating mood and/or helping to alleviate depression.[75,83]

Undoubtedly, there is growing evidence that caffeine use is increasing among adolescents, with negative implications for sleep and other behaviors. Significant questions, however, remain regarding the direction of this complex relationship. Are adolescents turning to caffeine because of insufficient and inconsistent sleep patterns, or does increased caffeine use exacerbate sleep problems for developing adolescents? These findings document the need for more extensive health education about caffeine use during adolescence. Furthermore, with the dramatic and potentially dangerous rise in the consumption of energy drinks in combination with alcohol (particularly on college campuses), researchers and physicians need to carefully investigate the implications for adolescents across the developmental spectrum.[84]

Other Factors Affecting Sleep in Adolescents

A number of other factors have been related to reduced sleep durations across the adolescent age range, such as chronic medical illnesses, mental health issues (ie, anxiety/stress), and prescribed psychotropic medications.[10,15] Chronic respiratory illnesses, such as asthma, and pain conditions, such as migraines, may contribute to truncated and disrupted sleep. Although obesity

does not necessarily lead to poor sleep per se, it is an increasingly important risk factor for obstructive sleep apnea in adolescents, which in turn results in poor-quality sleep and daytime consequences. Moreover, although the evidence is still largely anecdotal, the use of stimulants (particularly those typically prescribed for the treatment of attention-deficit/hyperactivity disorder) as a "countermeasure" to sleepiness and/or as academic "performance enhancers" seems to be an increasingly common phenomenon across college campuses.[85,86] Future investigations need to assess the extent and context of "diversion" of legitimately prescribed stimulant medications as well as the use and abuse of increasingly diverse alternative sources of caffeine (eg, caffeinated alcoholic beverages, candy, foodstuffs). Finally, it should also be noted that both over-the-counter (ie, diphenhydramine) and prescription (ie, zolpidem) medications taken by adolescents to induce sleep may result in residual daytime sleepiness and that commonly used medications (eg, decongestants) and prescription drugs (eg, activating antidepressants [eg, fluoxetine], stimulant medication for attention-deficit/hyperactivity disorder) may also result in disrupted sleep and consequent daytime sleepiness in adolescents.

CONSEQUENCES OF INSUFFICIENT SLEEP

It is important to recognize that the causes and consequences of chronic sleep loss in adolescents are often closely intertwined in complex ways, further exacerbating the situation. For example, alcohol consumption can lead to insufficient and poor-quality sleep and subsequent daytime sleepiness.[10,32,87] In turn, chronic sleep loss has been linked to an increased risk of alcohol and drug use.[14,28,34] Similarly, compensatory oversleep behavior on weekends provides some temporary relief from sleepiness generated by insufficient sleep on weekdays, but it also leads to disrupted sleep–wake cycles, exacerbation of the normal adolescent circadian phase delay, and perpetuation of compromised weekday alertness. Moreover, consequences such as poor judgment, lack of motivation, and inattention and affective dysregulation resulting from sleep loss, as well as the effect of insufficient sleep on decision-making skills,[88] further compound the potential negative effects in adolescents. In particular, higher level cognitive "executive functions," for which adolescence is a critical period of evolution, are selectively affected by sleep loss.[89]

Sleep Loss and Depression, Mood Disturbances, and Suicidal Ideation

It has long been recognized that mood disorders (especially major depressive disorder) in clinical samples of adults exhibit a bidirectional relationship with sleep disturbances, and the presence of sleep problems has been shown to both increase the relative risk of developing depression[90] and to be a predictor of relapse.[91,92] Similar findings have emerged in the child and adolescent population, particularly with regard to an association between insomnia (difficulty initiating and/or maintaining sleep) and clinically diagnosed depression.[93] Recent studies have shown that addressing insomnia will greatly improve treatment of depression. Although studies examining sleep architecture in depressed adolescents[94] have not consistently replicated differences in polysomnographic findings in depressed adults (ie, increased REM sleep, decreased REM onset latency), there may be other sleep electroencephalographic markers, such as sleep spindle activity and cyclic alternating patterns,[95] that have more relevance for the adolescent population.

Sleep debt in college students has been shown to be associated with a higher risk of reporting depressive symptoms.[96] Similarly, in high school students, shorter school-night total sleep time has been associated with both daytime sleepiness and depressive symptoms,[97] whereas increased risk-taking behaviors were associated with irregular sleep patterns and self-reported sleep problems rather than sleep loss. These outcomes are similar to the findings of a large longitudinal adolescent health study in which symptoms of possible insomnia (ie, trouble sleeping, morning tiredness) predicted risk behaviors (eg, drinking and driving, smoking, delinquency) after controlling for depression symptoms.[97,98]

There is evidence that other sleep-related parameters may also have a significant effect on mood; for example, adolescent self-reported sleep variables (including trouble sleeping, tiredness, nightmares, and being a long sleeper) have been found to be significantly associated with psychological symptoms, including anxiety/depression, and withdrawal.[99] Circadian factors may also play a role in mood regulation; increased self-reported "eveningness," a marker of circadian phase delay, has also been associated with depression and lower behavior activation/positive affect.[100]

A number of recent studies have focused on the possible relationship between sleep and suicidal ideation.[101,102] Sleeping less than 8 hours at night seems to be associated with an almost threefold increased risk of suicide attempts after controlling for a number of confounding variables.[101] Not only do adolescents with insufficient sleep have an increased risk of suicidal ideation, but the risk may be similarly increased in adolescents whose parents also have insufficient sleep, raising some interesting questions about multigenerational environmental and/or genetic factors.[103] A

similar relationship has been found in middle and high school students; adolescents with parental-set bedtimes of midnight or later are significantly more likely to suffer from depression and to have suicidal ideation compared with adolescents with parental-set bedtimes of 10:00 PM or earlier. Earlier parental-set bedtimes, therefore, could potentially be protective against adolescent depression and suicidal ideation. Finally, both decreased (≤5 hours) or increased (≥10 hours) total sleep times may put adolescents at a significantly higher risk of suicidality compared with a total sleep time of 8 hours.[104] However, increased risk of the most severe forms of suicidality (attempt requiring treatment) seems to be associated with significantly shorter sleep duration (total sleep time ≤4 hours).

In summary, sleep has an important influence on mood and the development of depressive symptoms in adolescents. Although insufficient sleep and daytime sleepiness seem to have the most robust relationship with mood dysregulation, poor-quality sleep and irregular sleep patterns are also associated with depressed mood. Importantly, from a clinical standpoint, improvements in sleep may lead to improvements in mental health functioning (and vice versa). The association between sleep loss and increased suicidality in adolescents is particularly troubling and is clearly important for pediatricians to recognize.

Insufficient Sleep and Obesity Risk

A considerable body of evidence now links short sleep duration in both adults and children with an increased risk of obesity, an association that obviously has long-range health implications. With regard to mechanisms, experimental studies of sleep restriction in healthy adult volunteers have shown that there are alterations in metabolic profiles (eg, insulin, ghrelin, leptin, cortisol) associated with sleep loss, which result in insulin resistance, increased sympathetic nervous system activity, and increased hunger and decreased satiety.[105] As a result, sleep-restricted subjects consume more calories, exercise less, and consume a higher percentage of calories from fat.[106–109]

In 1 earlier study, it was estimated that for each hour sleep lost, the odds of being obese increased in adolescents by 80%.[110] Furthermore, there is evidence of a "dose–response" inverse relationship between sleep and weight,[111] with odds ratios of overweight increasing with decreasing sleep duration (<5 hours, 5–6 hours, 6–7 hours, and 7–8 hours compared with students sleeping >8 hours). The increased risk of obesity associated with insufficient sleep seems to be equivalent to or higher than the risk associated with other factors strongly correlated with weight, such as parental obesity and television viewing.[112]

Early sleep patterns may influence BMI in adolescents and young adults as well. Longitudinal data suggest that children who sleep less, have later bedtimes, or get up earlier subsequently have higher BMIs and are more likely to be overweight, even after controlling for baseline BMI.[113] This association may be established early in life; for example, an increased BMI and high prevalence of obesity in young adults was found in individuals whose mothers had reported sleeping problems ("irregular" or "troubled" sleeping) at ages 2 to 4 years (although sleep duration was not specified) compared with those who had not had sleeping problems.[114]

Although the underlying potential mechanisms for the relationship between sleep and weight in adolescents have yet to be elucidated, metabolic alterations associated with sleep loss similar to those observed in adults are likely to play an important role. In particular, perturbations in the levels of neurohormones known to be associated with hunger and satiety (eg, adiponectin, ghrelin) as well as increased insulin resistance (as measured by the homeostatic model assessment [HOMA]) have been demonstrated in adolescents sleeping <5 hours per day.[115] These "short sleepers" were also found to have a higher percentage of carbohydrate intake according to a dietary questionnaire.[116] Similarly, older adolescents sleeping less than 8 hours have been shown to consume a higher proportion of calories from fats, and shorter sleep duration is also associated with increased odds of consuming a higher percentage of daily caloric intake from snacks.[117] Importantly, these metabolic perturbations also increase the risk of development of type 2 diabetes in these obese adolescents.[118,119] Finally, it should be noted that the relationship between short sleep duration and obesity may be further complicated by the presence of obstructive sleep apnea. Not only is obesity emerging as an increasingly important risk factor for sleep-disordered breathing in children,[120] but obstructive sleep apnea may further exacerbate the inflammatory and metabolic consequences of both obesity and chronic sleep loss.[7,121–123] Some evidence also suggests there may be gender differences in the strength of the association between obesity and sleep duration, with adolescent boys seeming to be at higher risk compared with girls in both cross-sectional and longitudinal studies using large data sets.[124] However, not all studies have identified gender differences; in 1 study of junior high school students, short sleep duration was significantly associated with overweight in girls only.[125]

Finally, it should be noted that not all studies have found an inverse

relationship between sleep duration and obesity in adolescents.[126] It has been postulated that some of these discrepancies may be attributable to measurement issues; in a nationally representative sample of adolescents that included 2 different measures of sleep duration (24-hour time diaries and self-reported "usual" sleep hours), self-reported sleep duration and time-diary sleep were only weakly correlated with each other, and only self-reported sleep hours were inversely associated with overweight.[127]

In summary, despite a number of methodologic limitations, the body of evidence from studies assessing the relationship between short sleep and increased overweight/obesity risk in adolescents is both compelling and potentially far-reaching in its public health implications. More research is urgently needed to identify specific metabolic, inflammatory, and hormonal mechanisms as well as the interactions among sleepiness and activity levels, mood, cognition, and behavioral responses in this complex equation. Moving forward, both community-based obesity prevention programs, such as "Let's Move" (http://www.letsmove.gov), and clinical treatment programs for overweight and obese teenagers should include consideration of sleep as an important variable in the relative success or failure of these interventions.

Drowsy Driving in Adolescents

It is now well recognized that daytime sleepiness and fatigue are associated with an increased rate of motor vehicle crashes.[128–131] The fact that sleepiness could be a major factor in individuals without known sleep disorders was not universally accepted until the landmark paper[132] by Pack et al in 1995. This group reviewed crash reports from the state of North Carolina between 1990 and 1992 in which the driver was judged to have fallen asleep behind the wheel. In the 85% of crashes in which intoxication was not thought to be a contributing factor, the majority (55%) occurred in individuals 25 years or younger. Crashes in this younger age range generally occur at night, unlike crashes with older adults, which typically occur during the mid-afternoon,[133,134] and tend to occur predominantly when the drowsy driver is alone.[135–137] In addition, young male drivers are more likely to be involved in sleep-related crashes than are young female drivers.[132,134,136]

Sleepiness while driving is a common complaint among adolescents[136] and college students.[137] In a study of high school students with driver's licenses, one-fifth reported poor-quality sleep, almost two-thirds complained of daytime sleepiness, 40% reported having sleepiness while driving, and 11% reported having had an automobile crash in which sleepiness was the main cause. Being sleepy behind the wheel and poor-quality sleep at night also seem to increase the risk of having an automobile crash in college students.

Countermeasures may potentially help prevent traffic accidents in this age range. Avoidance of driving when sleep deprived and not drinking alcohol before getting behind the wheel are obvious solutions. Other countermeasures that have some empiric support in adults and may be effective in adolescents include planned napping.[138,139]

CONCLUSIONS

Adolescent sleep loss poses a serious risk to the physical and emotional health, academic success, and safety of our nation's youth. The prevalence and effects of insufficient sleep may be further magnified in high-risk adolescents. Pediatricians have the opportunity to make significant inroads into addressing the health risk that sleep loss presents through screening and health education efforts. Many of the factors that have been shown to contribute significantly to the current "epidemic" of insufficient sleep in teenagers, such as electronic media use, caffeine consumption, and early school start times, are potentially modifiable and, as such, are important intervention points in anticipatory guidance in the clinical setting. On the local and national levels, pediatricians need to advocate for educational, administrative, and health policies that promote healthy sleep and reduce the risk factors for sleep loss in adolescents.

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