Sleep disturbance and cardiovascular risk in adolescents

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Abstract

Background: Evidence suggests that inadequate or disturbed sleep is associated with increased cardiovascular risk in adults. There are limited data on sleep quality and associated cardiovascular risk in children.

Methods: We obtained data on adolescents from the 2009/10 cycle of the Healthy Heart Schools' Program, a population-based cross-sectional study in the Niagara region of Ontario. Participants underwent measurements of cardiometabolic risk factors, including body mass index (BMI), lipid profile and blood pressure, and they completed questionnaires measuring sleeping habits and nutritional status. We assessed sleep disturbance using the sleep disturbance score derived from the Pittsburgh Sleep Quality Index. We explored associations between sleeping habits and cardiovascular risk factors.

Results: Among 4104 adolescents (51% male), the mean hours of sleep per night (± standard deviation) were 7.9 ± 1.1 on weeknights and 9.4 ± 1.6 on weekends. In total, 19% of participants reported their sleep quality as fairly bad or very bad on weeknights and 10% reported it as fairly bad or very bad on weekends. In the multivariable regression models, a higher sleep disturbance score was associated with increased odds of being at high cardiovascular risk (highest v. lowest tertile odds ratio [OR] 1.43 [95% confidence interval (CI) 1.16–1.77], $p < 0.001$), increased odds of hypertension (highest v. lowest tertile OR 1.44 [95% CI 1.02–2.05], $p = 0.05$) and increased odds of elevated non-high density lipoprotein cholesterol (highest v. lowest tertile OR 1.28 [95% CI 1.00–1.64], $p = 0.05$). The mean duration of sleep was not associated with these outcomes.

Interpretation: In healthy adolescents, sleep disturbance is associated with cardiovascular risk factor abnormalities. Intervention strategies to optimize sleep hygiene early in life may be important for the prevention of cardiovascular disease.

Competing interests: None declared.

This article has been peer reviewed.

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***CMAJ* 2012. DOI:10.1503/cmaj.111589**

There is emerging evidence in experimental and epidemiologic studies that sleep parameters, specifically sleep duration and quality, are associated with cardiovascular outcomes, including hypertension,[1] as well as diabetes,[2] hypercholesterolemia[3] and obesity.[4] A recent meta-analysis involving 400 000 adults concluded that short sleep duration was associated with a greater risk of developing or dying from coronary heart disease.[5] On average, adolescents sleep less than 8 hours per night,[6] less than the recommended 9 hours,[7] and about 20% of adolescents have significant sleep problems.[6] Despite this knowledge, there is a paucity of epidemiologic research on the cardiovascular consequences of short sleep duration and impaired sleep quality in adolescents.

In this study, we investigated the association between sleep disturbance and duration and measures of cardiovascular disease risk, including cholesterol, hypertension, body mass index (BMI) and dietary factors in adolescents.

Methods

This study was conducted through the Healthy Heart Schools' Program, which was designed to screen and identify adolescents at risk for coronary vascular disease. This program targets adolescents in the Niagara region of Ontario during their mandatory physical education class. The current data were collected during the 2009/10 school year.

Data collection

Participants completed the Pittsburg Sleep Quality Index questionnaire,[8] which is a validated tool for use in adults and has been administered in clinical adolescent populations.[9,10] The questionnaire uses a 19-item scale designed to measure self-reported sleep duration, overall perception of quality of sleep, sleep disturbances, daytime sleepiness, history of snoring and the use of any sleep medication over a 1-month period. The questions were designed to reflect both weeknight and weekend

sleep. We developed an overall sleep disturbance score using the answers to the 15 questions listed in Table 1. The answer "Not during the past month" was given a score of 0, "less than once per week" was scored as 1, "once or twice per week" was scored as 2 and "3 or more times per week" was scored as 3, according to the validated scoring system.[8] The maximum score was 45 points, with higher scores reflecting worse sleep quality. Because no clinically significant score is defined for sleep disturbance, we divided the population into tertiles to avoid any misclassification and to evaluate dose response. The lifestyle assessment section of the questionnaire ascertained the amount of physical activity and screen time (television, video games and computer time) per week. Participants completed an adapted version of the Child and Adolescent Trial for Cardiovascular Health nutrition questionnaire.[11]

The study protocol was reviewed and approved by the research ethics board of the District School Board of Niagara and the Niagara Catholic District School Board. All enrolled participants provided informed assent; parental consent was also obtained.

Measurements

All physical measurements were performed by trained Heart Niagara staff during class time. All participants underwent height (stadiometer) and weight (calibrated scales) measurements in a standardized manner. We then converted these values to age- and sex-based percentiles and to *z* scores.[12] Overweight was defined as BMI between the 85th and 95th percentiles, and obesity was defined as BMI above the 95th percentile.[13] Waist circumference measurement was standardized and concordant with methods used in the National Health and Nutrition Examination Survey, from which normal values for adolescents were used to determine age- and sex-specific percentile categories.[14] Capillary blood samples obtained by finger stick were used to determine nonfasting total and high density lipoprotein (HDL) cholesterol levels (Cholestech LDX System, Inverness Medical Innovations). We classified total cholesterol levels between 4.4 and 5.1 mmol/L as borderline high, and levels 5.2 mmol/L or higher were classified as high.[15]

Blood pressure was evaluated in a standardized manner (sitting) using a Bp TRU blood pressure monitor (Coquitlman) using an appropriate-sized cuff on the participant's right upper arm.[16] Participants with an initial blood pressure measurement above the normal range (≥ 135/85 mm Hg) underwent repeat testing. If the second measurement was also above the normal range, 6 automated readings were taken at 1-minute intervals, and the average was calculated.[16] We converted the systolic and diastolic readings to age-, sex- and height-indexed percentiles.[16] We used the maximum percentiles of the blood pressure readings to classify participants as prehypertensive (> 90th to < 95th percentile) or stage I hypertensive (≥ 99th percentile).[16] We considered patients with the following measurements to be

Table 1: Frequency of sleep disturbances among 3372 adolescents

Variable	No. (%)			
	Not during the past month	Less than once per week	Once or twice per week	Three or more times per week
Woke up during night/early morning	1178 (35.9)	939 (28.6)	678 (20.7)	485 (14.8)
Could not fall asleep within 30 min	1403 (42.8)	782 (23.8)	552 (16.8)	543 (16.6)
Felt too hot	1739 (53.3)	809 (24.8)	483 (14.8)	229 (7.0)
Felt too cold	1842 (56.5)	773 (23.7)	432 (13.0)	225 (6.9)
Got up to use the bathroom	1865 (56.7)	821 (25.0)	409 (12.4)	192 (5.8)
Had bad dreams	2245 (68.8)	617 (18.9)	263 (8.1)	139 (4.3)
Legs twitched or jerked	2234 (75.0)	364 (12.2)	203 (6.8)	176 (5.9)
Had pain	2485 (76.5)	477 (14.7)	187 (5.8)	98 (3.0)
Coughed/snored loudly (self-reported)	2662 (81.8)	339 (10.4)	139 (4.3)	113 (3.5)
Snored loudly (reported by parents)	2550 (84.6)	232 (7.7)	105 (3.5)	126 (4.2)
Could not breathe comfortably	2781 (85.4)	269 (8.3)	137 (4.2)	69 (2.1)
Restlessness while asleep	2395 (89.2)	116 (4.3)	82 (3.1)	93 (3.5)
Disoriented or confused	2658 (89.6)	194 (6.5)	71 (2.4)	42 (1.4)
Disturbed sleep for other reasons	2193 (90.5)	57 (2.4)	70 (2.9)	102 (4.2)
Long pause between breath	2758 (92.7)	128 (4.3)	48 (1.6)	42 (1.4)

at high cardiovascular risk: non-HDL cholesterol > 3.10 mmol/L; blood pressure > 90th percentile; or BMI > 85th percentile.

We defined a history of premature cardiovascular disease in first-degree relatives as a relative with angina, heart attack, bypass surgery or stroke before the age of 65 years for female relatives and before the age of 55 years for male relatives.

Statistical analysis

We report data as means (± standard deviations [SD]), median (interquartile range [IQR]) and frequencies, as appropriate. We decided to use tertiles for the sleep disturbance scores and quartiles for sleep duration to create groups of roughly equal sizes while accommodating the variable distribution.

We assessed the association between sleep disturbance score tertiles, sleep duration quartiles and cardiometabolic risk factors in univariable linear regression models. We used a similar approach to investigate the association between sleep outcomes, lifestyle and sleep disturbance scores. We created additional multivariable ordinal logistic regression models to identify the independent effect of sleep duration and quality on cardiovascular risk factors beyond the other cardiovascular risk factors and lifestyle. We created dual sets of

Table 2: Association between sleep parameters and sleep disturbance scores*

Variable	No. (%) All groups	Tertile 1 (sleep disturbance score 0–3)	Tertile 2 (sleep disturbance score 4–8)	Tertile 3 (sleep disturbance score ≥ 9)	*p* value
Overall sleep quality, weeknights, *n* = 3321					< 0.001
Very good	786 (23.7)	455 (39.6)	241 (20.6)	90 (9.0)	
Fairly good	1882 (56.7)	603 (52.4)	731 (62.5)	548 (54.7)	
Fairly bad	549 (16.5)	79 (6.9)	176 (15.1)	294 (29.3)	
Very bad	104 (3.1)	13 (1.1)	21 (1.8)	70 (7.0)	
Overall sleep quality, weekend nights, *n* = 3273					< 0.001
Very good	1602 (49.0)	700 (61.6)	547 (47.6)	355 (36.0)	
Fairly good	1341 (41.0)	377 (33.2)	501 (43.6)	463 (46.9)	
Fairly bad	260 (7.9)	48 (4.2)	90 (7.8)	122 (12.4)	
Very bad	70 (2.1)	11 (1.0)	12 (1.0)	47 (4.8)	
Use of sleep medication, *n* = 3161					
Not during the past month	2979 (94.2)	1063 (96.9)	1050 (95.5)	866 (89.7)	< 0.001
Less than once a week	81 (2.6)	18 (1.6)	22 (2.0)	41 (4.3)	
Once or twice a week	30 (1.0)	7 (0.6)	9 (0.8)	14 (1.5)	
Three or more times a week	71 (2.3)	9 (0.8)	18 (1.6)	44 (4.6)	
Enough energy, weekday, *n* = 3305					< 0.001
No problem at all	1813 (54.9)	822 (71.8)	636 (55.4)	355 (35.1)	
Slight problem	841 (25.5)	215 (18.8)	323 (28.1)	303 (30.0)	
Noticeable problem	472 (14.3)	79 (6.9)	138 (12.0)	255 (25.2)	
Very big problem	179 (5.4)	29 (2.5)	52 (4.5)	98 (9.7)	
Enough energy, weekend, *n* = 3283					< 0.001
No problem at all	1820 (55.4)	865 (75.9)	611 (53.3)	344 (34.5)	
Slight problem	1197 (36.5)	248 (21.8)	469 (40.9)	480 (48.1)	
Noticeable problem	229 (7.0)	23 (2.0)	59 (5.2)	147 (14.7)	
Very big problem	37 (1.1)	3 (0.3)	7 (0.6)	27 (2.7)	
Daytime sleepiness, *n* = 3206					< 0.001
Not during the past month	2359 (73.6)	980 (88.0)	833 (73.9)	546 (56.6)	
Less than once a week	715 (22.3)	124 (11.1)	267 (23.7)	324 (33.6)	
Once or twice a week	109 (3.4)	9 (0.8)	26 (2.3)	74 (7.7)	
Three or more times a week	23 (0.7)	1 (0.1)	2 (0.2)	20 (2.1)	

*Sleep disturbance scores ranged from 0 to 45, with higher scores indicating greater sleep disturbance.

regression models: initially, sleep disturbance scores and sleep duration were modelled as continuous variables; further regression models used sleep duration and sleep disturbance index as quartiles and tertiles, respectively. We selected factors based on clinical relevance (regardless of *p* value) and previous association with cardiometabolic outcomes in this population.[17] We adjusted for adiposity using waist circumference percentiles, because we have previously shown that waist circumference has a greater association with cardiometabolic risk than BMI *z* score.[18] We did not use stepwise modelling in this study. All regression models used a maximum likelihood algorithm to determine parameter estimates.

Results

In total, 4104 adolescents (51% male) were enrolled in this study out of 4884 (84%) eligible students. Students were not included if they attended physical education class in the summer, were absent or did not provide consent. Complete sleep questionnaires were available for 3372 (82%) students. The characteristics of this population were similar to those included in previously reported population-based studies.[19,20]

The mean hours of sleep per night (± SD) were 7.9 ± 1.1 h on weekdays and 9.4 ± 1.6 h on weekends ($p < 0.001$). The median sleep disturbance score was 5 (IQR 2–10; tertile 1 = 0–3; tertile 2 = 4–8; tertile 3 9). The frequency of specific types of sleep disturbances are presented in Table 1. A higher sleep disturbance score was associated with fewer hours of sleep during weeknights (highest tertile 7.6 ± 1.3 h v. lowest tertile 8.2 ± 1.0 h; $p < 0.001$) and weekend nights (highest tertile 9.2 ± 1.8 h v. lowest tertile 9.5 ± 1.6 h; $p < 0.001$).

In total, 19.6% of students reported that their sleep quality during the week was fairly bad or bad; 10.0% of students rated their weekend sleep quality as fairly bad or bad ($p < 0.001$) (Table 2). Of the participants, 5.9% reported using sleep medications. There was a statistically significant association between sleep disturbance score and overall self-reported sleep quality on weeknights ($r = 0.39$, $p < 0.001$) and weekend nights ($r = 0.27$, $p < 0.001$). The use of sleep medication was associated with a mean (± SD) decrease of 0.32 ± 0.09 h of sleep on week nights ($p < 0.001$), a decrease of 0.45 ± 0.13 h on weekends ($p < 0.001$) and an increase of 4.0 ± 0.4 points in the sleep disturbance score ($p < 0.001$). Daytime sleepiness was associated with lower sleep duration and a higher sleep disturbance scores (Table 2).

In total, 18% of participants consumed more than 1 cup of caffeinated beverages per day, 72% consumed 1 cup per day and 11% did not con-

Table 3: Association between nutrition, physical activity and sleep disturbance scores*

Variable	No. (%)	Sleep disturbance score, mean ± SD	No. (%)	Sleep disturbance score, mean ± SD	No. (%)	Sleep disturbance score, mean ± SD	*p* value
Nutrition	**No serving**		**1 serving/d**		**>1 serving/d**		
Battered or fried chicken, steak or fish	2579 (78.1)	6.6 ± 5.6	642 (19.5)	7.1 ± 5.9	80 (2.4)	8.3 ± 6.9	0.001
French fries or chips	1857 (56.4)	6.4 ± 5.7	1146 (34.8)	7.1 ± 5.7	290 (8.8)	7.7 ± 6.0	< 0.001
Soft drinks	2013 (61.0)	6.5 ± 5.6	916 (27.8)	6.9 ± 5.8	370 (11.2)	7.2 ± 5.6	0.01
Sweet rolls, pies, doughnuts or cookies	1781 (54.1)	6.4 ± 5.5	1155 (35.1)	7.0 ± 5.7	359 (10.9)	7.3 ± 6.2	< 0.001
Snacks	236 (7.2)	6.1 ± 5.9	942 (28.8)	6.5 ± 5.6	2090 (64.0)	6.9 ± 5.7	< 0.001
Caffeinated beverages (combined)	347 (10.5)	4.8 ± 4.8	2357 (71.5)	6.6 ± 5.6	592 (18.0)	8.1 ± 6.3	< 0.001
Coffee, caffeinated tea or espresso	1881 (56.4)	5.9 ± 5.2	1349 (40.5)	7.6 ± 6.1	179 (5.4)	9.2 ± 6.6	< 0.001
Caffeinated soft drinks	761 (22.9)	5.9 ± 5.6	2380 (71.7)	6.9 ± 5.6	179 (5.4)	7.7 ± 6.4	< 0.001
Hot chocolate	2081 (62.5)	6.4 ± 5.6	1232 (37.0)	7.3 ± 15.8	17 (0.5)	10.3 ± 7.2	< 0.001
Physical activity	**0–2 d/wk**		**3–4 d/wk**		**5–7 d/wk**		
Moderate to vigorous physical activity	660 (19.9)	7.4 ± 5.9	782 (23.6)	7.2 ± 5.6	1871 (56.5)	6.3 ± 5.6	< 0 .001
	0–5 h/d		**6–10 h/d**		**> 10 h/d**		
Screen time	1797 (56.1)	6.2 ± 5.4	1187 (37.0)	7.3 ± 5.7	222 (6.9)	7.9 ± 6.3	< 0.001

Note: SD = standard deviation.
*Sleep disturbance scores ranged from 0 to 45, with higher scores indicating greater sleep disturbance.

Table 4: Association between cardiometabolic risk factors and sleep disturbance score*

Variable	*N*	All groups	Mean ± SD or no (%)			*p* value
			Tertile 1 (sleep disturbance score 0–3)	Tertile 2 (sleep disturbance score 4–8)	Tertile 3 (sleep disturbance score ≤ 9)	
No. (%) of participants			1171 (34.7)	1176 (34.9)	1025 (30.4)	
Age at assessment, yr	3372	14.6 ± 0.5	14.6 ± 0.5	14.6 ± 0.5	14.6 ± 0.5	0.2
Male	3372	1650 (48.9)	694 (59.3)	586 (49.8)	370 (36.1)	< 0.001
Hours of sleep						
Weeknights	3235	7.9 ± 1.1	8.2 ± 1.0	8.0 ± 1.1	7.6 ± 1.3	< 0.001
Weekend nights	3176	9.4 ± 1.6	9.5 ± 1.6	9.4 ± 1.6	9.2 ± 1.8	< 0.001
Average	3372	8.4 ± 1.0	8.6 ± 0.9	8.4 ± 1.0	8.0 ± 1.1	< 0.001
Quartile 1: ≤ 7.75 h		966 (28.7)	231 (19.7)	324 (27.6)	411 (40.1)	< 0.001
Quartile 2: > 7.75 to ≤ 8.40 h		784 (23.3)	275 (23.5)	268 (22.8)	241 (23.5)	
Quartile 3: > 8.40 to ≤ 9.00 h		897 (26.6)	361 (30.8)	320 (27.2)	216 (21.1)	
Quartile 4: > 9.00 h		725 (21.5)	304 (26.0)	264 (22.5)	157 (15.3)	
History of premature cardiovascular disease in first-degree relative†	3227	1057 (32.8)	324 (28.7)	367 (32.4)	366 (37.8)	< 0.001
Lipid profile						
Total cholesterol, mmol/L	2955	3.85 ± 0.74	3.81 ± 0.72	3.83 ± 0.73	3.92 ± 0.78	0.003
> 5.2 mmol/L (high)		137 (4.6)	43 (4.2)	45 (4.3)	49 (5.6)	0.03
> 4.4–5.2 mmol/L (borderline)		494 (16.7)	157 (15.3)	164 (15.6)	173 (19.6)	
HDL cholesterol	2953	1.23 ± 0.33	1.21 ± 0.33	1.23 ± 0.33	1.23 ± 0.34	0.3
Non-HDL cholesterol	2955	2.63 ± 0.72	2.60 ± 0.70	2.60 ± 0.72	2.70 ± 0.75	0.003
> 3.75 mmol/L (high)		215 (7.3)	66 (6.4)	74 (7.1)	75 (8.5)	0.003
> 3.10 to 3.75 mmol/L (borderline)		446 (15.1)	147 (14.3)	137 (13.1)	162 (18.4)	
Adiposity						
BMI *z* score‡ (5th, 95th percentile)	3277	0.5 (–0.2, 1.4)	0.4 (–0.3, 1.3)	0.5 (–0.3, 1.3)	0.7 (–0.1, 1.5)	< 0.001
Overweight (> 85–95%)		480 (14.7)	150 (13.2)	172 (15.0)	158 (15.9)	0.005
Obese (> 95%)		612 (18.7)	206 (18.1)	189 (16.5)	217 (21.8)	
Waist circumference percentile	3270					0.02
< 10th		307 (9.4)	119 (10.5)	103 (9.0)	85 (8.6)	
10th–24th		399 (12.2)	145 (12.8)	147 (12.9)	107 (10.8)	
25th–49th		814 (24.9)	285 (25.1)	299 (26.1)	230 (23.2)	
50th–74th		900 (27.5)	311 (27.4)	315 (27.5)	274 (30.5)	
75th–90th		548 (16.7)	176 (15.5)	196 (17.1)	176 (17.8)	
> 90th		302 (9.2)	99 (8.7)	84 (7.3)	119 (12.0)	
Blood pressure						
Systolic blood pressure *z* score‡ (5th, 95th percentile)	3255	–0.6 (–1.3, 0.1)	–0.6 (–1.3, 0.0)	–0.7 (–1.3, 0.0)	–0.6 (–1.2, 0.1)	0.007
Diastolic blood pressure *z* score‡ (5th, 95th percentile)	3252	0.1 (–0.4, 0.6)	0.1 (–0.4, 0.6)	0.0 (–0.5, 0.5)	0.1 (–0.4, 0.6)	0.09
Pre-hypertension (90th–95th)	3252	163 (5.0)	47 (4.2)	48 (4.2)	68 (6.9)	0.05
Stage 1 or 2 (> 95th)		114 (3.5)	37 (3.3)	40 (3.5)	37 (3.7)	
Cardiovascular risk¶	2919	1231 (42.2)	398 (39.3)	415 (40.0)	418 (48.1)	< 0.001

Note: BMI = body mass index, HDL = high-density lipoprotein, SD = standard deviation.
*Sleep disturbance scores ranged from 0 to 45, with higher scores indicating greater sleep disturbance.
†Defined as angina, heart attack, heart or bypass surgery, or stroke before age 65 in women or before age 55 in men.
‡The *z* score represents how many standard deviations a measurement is above or below the mean value for that measurement in a normal age- and gender-matched population.
¶Defined as non-HDL cholesterol > 3.10mmol/L, BMI > 85th percentile or blood pressure > 90th percentile.

	No CVR, No. (%) or mean ± SD	CVR, No. (%) or mean ± SD	Unadjusted odds ratio (95% CI)	Adjusted* odds ratio (95% CI)	*p*
Average sleep duration ≤ 7.75 v. ≥ 9 h	456 (27.0)	357 (29.0)	1.20 (0.97–1.49)	1.03 (0.81–1.30)	0.6
Average sleep duration > 7.75 to ≤ 8.40 v. ≥ 9 h	372 (22.0)	310 (25.2)	1.28 (1.03–1.60)	1.18 (0.93–1.49)	0.2
Average sleep duration > 8.40 to ≤ 9.00 h v. ≥ 9 h	477 (28.3)	315 (25.6)	1.02 (0.82–1.26)	1.06 (0.84–1.34)	0.97
Average sleep duration ≥ 9 h	383 (22.7)	249 (20.2)	Reference	Reference	
Sleep disturbance score ≥ 9 v. 0–3	451 (26.7)	318 (34.0)	1.43 (1.10–1.72)	1.43 (1.16–1.77)	0.001
Sleep disturbance score 4-8 v. 0–3	623 (36.9)	415 (33.7)	1.03 (0.86–1.23)	1.08 (0.89–1.32)	0.2
Sleep disturbance score 0–3	614 (36.4)	398 (32.3)	Reference	Reference	
Premature cardiovascular disease in first-degree relative	525 (32.0)	412 (34.4)	1.07 (0.92–1.25)	1.04 (0.88–1.24)	0.6
Gender (female)	855 (50.7)	636 (52.7)	1.04 (0.91–1.20)	1.02 (0.86–1.22)	0.8
Caffeine intake, cups/d	1.1 ± 0.3	1.1 ± 0.5	1.12 (0.97–1.29)	1.07 (0.91–1.27)	0.4
Snack consumption, serving/d	2.0 ± 0.9	1.8 ± 0.9	0.80 (0.74–0.87)	0.79 (0.72–0.86)	< 0.001
Soft drink consumption, serving/d	0.5 ± 0.8	0.5 ± 0.8	1.01 (0.92–1.11)	0.94 (0.84–1.06)	0.3
Moderate/vigorous physical activity, d/wk	4.5 ± 2.0	4.3 ± 2.0	0.94 (0.91–0.97)	0.95 (0.92–0.99)	0.02
Screen time, h/d	5.4 ± 2.8	5.8 ± 2.9	1.05 (1.03–1.09)	1.05 (1.02–1.09)	0.001

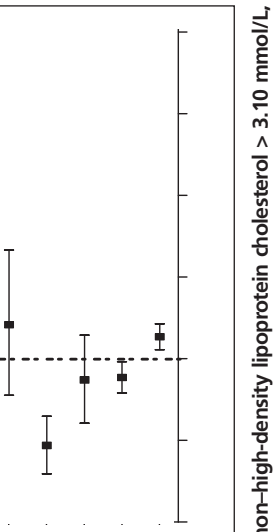

Figure 1: Multivariable logistic regression model for variables associated with the presence of any cardiovascular risk (CVR) factor (non–high-density lipoprotein cholesterol > 3.10 mmol/L, body mass index > 85th percentile or blood pressure > 90th percentile). *Adjusted for all factors listed in the figure. Note: CI = confidence interval, SD = standard deviation.

sume caffeine at all. A higher sleep disturbance score was associated with higher consumption of fried food, soft drinks, sweets, snacks, caffeinated beverages, reduced physical activity and increased screen time (Table 3). Shorter sleep duration was associated with increased consumption of soft drinks ($p < 0.001$) and increased intake of caffeinated beverages ($p < 0.001$) but not with other high fat, high sugar foods. Overweight and obese participants had a higher prevalence of daily consumption of caffeinated beverages than the leaner participants (94% and 88%, respectively; $p = 0.04$). Consumption of caffeinated beverages was significantly associated with increased intake of fried chicken, chips and soda. Shorter sleep duration was also associated with decreased physical activity (shortest quartile, mean ± SD, 4.1 ± 2.1 d/wk v. longest quartile 4.5 ± 2.0 d/wk; $p < 0.001$) and increased screen time (shortest quartile, mean ± SD, 6.1 ± 3.2 h per day v. longest quartile 5.2 ± 2.9 h per day; $p < 0.001$).

A higher sleep disturbance score was associated with higher total cholesterol, higher non-HDL cholesterol, higher BMI *z* scores, higher waist percentile category, higher systolic blood pressure *z* scores and increased odds of hypertension (Table 4). Shorter average sleep duration was associated with higher BMI *z* score (shortest quartile 0.76 v. longest quartile 0.41, $p < 0.001$) and a higher proportion with waist circumference above the 75th percentile (shortest quartile 30.0% v. longest quartile 22.1%, $p = 0.002$). There was no association between average sleep duration and lipid profile or blood pressure *z* scores.

In the multivariable regression models adjusted for lifestyle factors, we found that sex and family history of premature cardiovascular disease in first degree relatives and sleep disturbance were associated with cardiovascular risk (highest v. lowest tertile OR 1.43 [95% CI 1.16–1.77], $p < 0.001$), but average sleep duration was not associated (shortest v. longest quartile OR 1.03 [95% CI 0.81–1.30], $p = 0.6$) (Figure 1). The results were similar when sleep duration and sleep disturbance scores were modelled as continuous variables (Appendix 1, available at www.cmaj.ca/lookup/suppl/doi:10.1503/cmaj.111589/-/DC1).

In the multivariable regression models adjusted for lifestyle factors (nutrition and physical activity), sex, family history of premature cardiovascular disease in first degree relatives and adiposity, the sleep disturbance score was associated with increased odds of hypertension (highest v. lowest tertile OR 1.44 [95% CI 1.02–2.05], $p = 0.05$) (Appendix 2, available at www.cmaj.ca/lookup/suppl/doi:10.1503/cmaj.111589/-/DC1) and increased odds of elevated non-HDL cholesterol (highest v. lowest tertile OR 1.28 [95% CI 1.00–1.64], $p = 0.05$)

(Appendix 3, available at www.cmaj.ca/lookup/suppl/doi:10.1503/cmaj.111589/-/DC1). Average sleep duration was not associated with hypertension (shortest v. longest quartile OR 0.62 [95% CI 0.42–1.09], $p = 0.1$) (Appendix 2) or non-HDL cholesterol (shortest v. longest quartile, OR 0.92 [95% CI 0.70–1.22], $p = 0.2$) (Appendix 3). The models that evaluated hypertension and non-HDL cholesterol yielded similar results for sleep duration and sleep disturbance scores, whether the sleep variables were modelled as ordinal or continuous (Appendices 4 and 5, available at www.cmaj.ca/lookup/suppl/doi:10.1503/cmaj.111589/-/DC1).

Interpretation

We found an association between sleep disturbance and cardiovascular risk in adolescents, as determined by high cholesterol levels, increased BMI and hypertension. These findings are important, given that sleep disturbance is highly prevalent in adolescence[6] and that cardiovascular disease risk factors track from childhood into adulthood.[19]

In a study involving over 14 000 adolescents, short sleep duration documented 5 years earlier was a significant risk factor for high cholesterol in adulthood.[20] However, that study was limited by reliance on self-reporting of apparent high cholesterol levels.[20] Recently, short sleep duration (< 6.5 h) in Chinese adolescents was reported to be associated with measured high total cholesterol,[21] although sleep disturbance was not evaluated in that cohort. In a cross-sectional analysis of 238 adolescents, the odds of prehypertension were increased 3.5-fold for low sleep efficiency and 2.5-fold for short sleep duration (defined as < 6.5 h); however, cholesterol measurements were not obtained.[22] Recent small community-based studies have also observed trends between short sleep duration, metabolic dysfunction and adiposity in children less than 10 years of age.[23,24]

Mechanisms mediating the relation between inadequate or disturbed sleep, high cholesterol and weight gain include changes in the appetite-regulating hormones ghrelin and leptin,[25] preference for fatty foods[26] and circadian alterations in lipid metabolism.[26] In one study, the odds of obesity increased 5-fold for every hour reduction in sleep duration.[27] Similarly, Senegalese girls aged 13–14 years had a reduction in sleep of 6.85 minutes for every 1.0 increase in BMI.[28]

However, additional confounding factors may predispose people to adiposity and cardiovascular risk. For example, caffeine consumption (especially high-caffeine energy drinks), preference for fatty foods and reduced physical activity may simply reflect the current "usual" lifestyle of adolescents, which includes short and disturbed sleep. Nonetheless, the relation is likely bidirectional with disturbed sleep leading to daytime sleepiness, decreased physical activity and increased caffeine consumption.

Strengths and limitations

The strengths of this study were that cholesterol levels were obtained simultaneously with physical measurements and questionnaires assessing sleep and nutrition in over 4000 adolescents. The inclusion of a school-based population strengthens our findings because it minimizes referral bias. Further, our reported incidence of obesity, high cholesterol levels, sleep disturbance and use of sleep medication were similar to other previously reported data.[29–31]

Our study had several limitations. We did not exclude participants with obstructive sleep apnea, which is associated with disrupted sleep, short sleep duration and cardiovascular risk.[32] In adolescence, the most common cause of obstructive sleep apnea is obesity, and sleep apnea is prevalent in about one-fifth of all obese adolescents.[33] Because the incidence of obesity in our population was 18% and less than 8% of our study group reported that they snore, obstructive sleep apnea is considered an unlikely mediator of major sleep disturbances in this cohort.

This study was conducted within the time and material constraints of the school curriculum. As such, blood pressure, height, weight and waist circumference were measured once only, possibly reducing the reliability of these results. Certainly, more accurate measurements of blood pressure should be verified by 24-hour ambulatory monitoring. Although fasting cholesterol measurements are preferable, non-fasting cholesterol values have been linked to an increased risk of cardiovascular disease in previous population-based studies.[34] Moreover, recent data suggest that fasting and non-fasting cholesterol levels are comparable.[35] The sleep questionnaire was not specifically validated for adolescents, and the duration of sleep and sleep disturbance were self-reported on one occasion only without objective assessments. However, it is not usually feasible to obtain objective sleep measurements in large prospective population-based studies. Similarly, eating behaviours were not quantified in a more objective manner. Further, the intake of popular high-caffeine energy drinks was not specifically identified.

Finally, the reported associations do not provide proof of causality, only associations. Some of these associations have limited magnitude; however, previous studies have shown that cardiovascular risk factors and associated lifestyle developed in childhood persist and amplify in adulthood.[36–38] Thus, it

is important to interpret our findings with consideration of the biological plausibility of the observations and experimental data showing that sleep disruption may modify cardiovascular risk.

Conclusion

Poor sleep hygiene among adolescents appears to be associated with increased cardiovascular risk. Future research is needed to dissect the relative influences of sleep curtailment from sleep disruption on different health outcomes. Interventional studies will be necessary to explore the efficacy of optimizing sleep quality, sleep duration and nutrition during adolescence on cardiovascular risk.

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Funding: This work was supported by the CIBC World Markets Children's Miracle Foundation Chair in Child Health Research and a Canadian Institute of Health Research team grant in childhood obesity. The study sponsors had no role in the design of the study, the collection, analysis or interpretation of data, the writing of the report or the decision to submit the article for publication.