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REVIEW ARTICLES

Systematic Review of Motor Vehicle Crash Risk in Persons With Sleep Apnea

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Study Objectives: To determine whether drivers with sleep apnea are at increased risk of motor vehicle crash; whether disease severity, daytime sleepiness, or both disease severity and daytime sleepiness affect this risk, and whether treatment of sleep apnea reduces crash risk.
Design: Systematic review of published literature.
Setting: N/A.
Patients/participants: Patients with sleep apnea.
Interventions: N/A.
Measurements and Results: Forty pertinent studies were identified. For studies investigating whether noncommercial drivers with sleep apnea have increased crash rates, the majority (23 of 27 studies and 18 of 19 studies with control groups) found a statistically significant increased risk, with many of the studies finding a 2 to 3 times increased risk. Methodologic quality of the studies did not influence this relationship ($p = .22$). For commercial drivers, only 1 of 3 studies found an increased crash rate, with this association being weak (odds ratio of 1.3). The evidence was mixed regarding whether the risk of crash involvement is proportional to the severity of the sleep apnea, with about half of the studies finding a statistically significant increased risk with increased severity. Correlation with subjective daytime sleepiness and crash risk was also found in only half of the studies reviewed. Treatment of sleep apnea consistently improved driver performance (including crashes) across all studies.
Conclusions: Noncommercial drivers with sleep apnea are at a statistically significant increased risk of involvement in motor vehicle crashes. Studies did not consistently find that daytime sleepiness and the severity of sleep apnea were correlated with crash risk. Successful treatment of sleep apnea improves driver performance. Clinicians should educate their patients with sleep apnea about the importance of treatment adherence for driving safety.
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Motor vehicle crashes are a major cause of morbidity and mortality. Estimates suggest that between 1% and 20% of crashes are due to driver inattention associated with excessive sleepiness.[1-4] Cognitive and perceptual difficulties can also contribute to crashes and injuries.[5,6] The symptoms of some respiratory diseases, especially sleep apnea, can manifest themselves with these difficulties. The sleep of persons with sleep apnea is repeatedly disrupted by arousals that relieve upper airway obstruction. This phenomenon may lead to daytime fatigue and drowsiness resulting in impaired attention and vigilance. This has led numerous investigators to study the association of the presence of sleep apnea with the risk of motor vehicle crash. Other authors have reviewed this body of work,[7-11] including 1 group[12] who performed a limited meta-analysis of 6 studies. To our knowledge, a comprehensive systematic review of studies investigating the relationship of sleep apnea and motor vehicle crashes has not been published.

Further complicating this issue is that clinicians are often mandated by law to determine the medical fitness to drive of their patients.[13-15] A more complete synthesis of the research findings related to the crash risk in persons with sleep apnea may allow future versions of widely used North American guidelines[14,15] to provide more practical and specific recommendations for the driving assessment of these patients. Therefore, the objective of this study is to systematically review the literature in order to answer the following questions:

1. Are drivers with sleep apnea at increased risk of being involved in motor vehicle crashes, and, if so, what is the strength of this association?
2. If there is an increased crash risk in persons with sleep apnea, does the severity of disease, the presence of daytime sleepiness, or a combination of disease severity and daytime sleepiness increase this risk?
3. Does treatment of sleep apnea reduce crash risk?

METHODS

Identification of Studies

Relevant data were gathered by performing systematic litera-

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ture searches using MEDLINE (January 1966 to December 2005), Embase, CINAHL, PsychInfo, Ageline, and Sociofile computerized databases. Pertinent articles were identified by using the following key words (human and English language only): driving, motor vehicle crashes, accidents, sleep apnea, sleep, drowsiness, and risk factors. The bibliographies of each identified, possibly pertinent article were hand searched to identify additional articles. Content experts were also consulted to identify other relevant published work. Only articles reporting primary data relevant to the above questions were included.

Extraction of Data

Pertinent data, as listed in Tables 1, 2, and 3, were extracted from each relevant article. In order to judge the methodologic quality of the included studies, the Newcastle-Ottawa (N-O) Quality Assessment Scale[16] (scale from 0-9 with higher scores indicating higher methodologic quality) was applied to the pertinent case-control and cohort studies. Studies were trichotomized into 3 groups: higher (N-O score of 6-8), medium (N-O score 4-5), and lower (N-O score of 2-3) quality. With no validated scale available to assess the methodologic quality of nonrandomized intervention trials, no quality assessment was performed for studies assessing the effectiveness of different treatment modalities for sleep apnea to reduce motor vehicle crash risk. Two independent reviewers (RE and MM) extracted data from each article, with any differences resolved by collaborative review.

Statistical Analysis

A Fisher exact test was performed to test the effect of methodologic quality of the studies on the results. Review of the pertinent studies revealed substantial heterogeneity in the designs, inclusion criteria, sleep-apnea definitions, and outcome measures. Therefore, no attempt was made to synthesize their results quantitatively.

RESULTS

Identification of Studies

Forty-one relevant studies[17-57] were identified. One article[57] appeared to report on the same drivers with sleep apnea as another article[19] and was excluded. Two publications[28,44] each reported on the results of 2 relevant and separate studies. Data from these 4 studies were extracted and included.

General Characteristics of Studies

The included studies were quite heterogeneous in their study designs and methodologies. Most of the studies recruited participants from specialized sleep laboratories, with a few sampling from general populations. Many different methods of determining the diagnosis of sleep apnea were employed, ranging from the use of different cut-off levels on objective measures such as the apnea-hypopnea index (AHI), to a purely clinical diagnosis (e.g., the presence of a triad of snoring, sleep disturbance, daytime sleepiness). The studies varied in their method of determining driving risk, including the examinations of state crash records, self-reported crashes, and performance on driving simulators. The studies based out of sleep laboratories varied markedly in sample sizes, ranging from 6 to 460 cases. Multiple measures were employed to determine subjective daytime sleepiness, with the most common being the Epworth Sleepiness Scale (ESS).[58]

Risk of Motor Vehicle Crash in Drivers with Sleep Apnea

A total of 30 studies in 28 journal articles[17-44] were identified (Tables 1 and 2), with 27 studying noncommercial drivers from the general population and 3 studying commercial drivers.

Studies Involving Noncommercial Drivers

Nineteen[17-34] studies (in 18 publications) used a case-control design. In 18 of these studies,[17-33] cases were defined as those having sleep apnea and were matched by age and sex with controls. All 4 case-control studies[17-20] that used the outcome of state or insurance driving records found a statistically significant association between sleep apnea and crashes (odds ratios [ORs] varying from 1.3 to 7). Of the 6 studies using self-reported crashes as the outcome measure, all but one[25] found a statistically significant increased risk of crash (ORs varying from 2.7 to 13.3). All 8 studies using driving-simulator performance as the outcome measure found worse performance in drivers with sleep apnea compared with those without the disorder. There was 1 case-control study[34] with a different design than the others. In this study, cases were drivers who presented to the emergency room because of a motor vehicle crash and were compared with age- and sex-matched controls who presented to the emergency room for other reasons. The results showed that persons involved in crashes were 7.2 times (95% confidence interval; 2.4, 21.8) more likely to have sleep apnea (AHI $\geq$ 10), a measure of the number of apneic and hypopneic episodes that occur in an hour). Overall, 18 of 19 case-control studies found a statistically significant correlation between the presence of sleep apnea and increased crash risk.

There were 7 cohort studies[35-41] addressing this issue. In these studies, selected groups of patients (often consecutive patients referred to a sleep laboratory) with and without sleep apnea were compared, with no attempt to match for sex and age. Both cohort studies[35,36] that used the outcome of state driving records found a statistically significant increase in crash rates in those with sleep apnea compared with those without sleep apnea. Three studies used self-reported crash as the outcome measure, with 2 of these[37,39] reporting a positive statistical correlation between sleep apnea and crash (OR 2 to 3), and the other[38] not finding any correlation. The 2 cohort studies[40,41] using driving-simulator performance as their outcome measure found no statistical correlation between sleep apnea and performance. Therefore, 4 of 7 cohort studies found a statistical correlation between the presence of sleep apnea and increased crash risk.

One cross-sectional study[42] used a population-based sample of noncommercial drivers to examine the association between sleep apnea and motor vehicle crashes. This survey[42] found that men who self-reported the diagnosis of sleep apnea had an OR of 3.3 (95% confidence interval; 2.0, 4.9) of also reporting a recent crash.

When all the above studies were categorized by outcome measure used, 6 of 6 studies that used state driving record, 7 of 9 that used self-reported crash, and 8 of 10 using driving-simulator performance found a positive statistical correlation between sleep apnea and crash.

Trichotomizing the studies into 3 groups based on their N-O

Table 1—Characteristics of Studies Examining Risk of Motor Vehicle Crash in Patients With Sleep Apnea

Author	Year	Quality Score[a]	Study Design	Setting	Study population/ Diagnosis of SA	Outcome Measures	Sample size	Men, %	Mean age, y
George[17]	1987	4	Case-control	NR	NR	State driving record (years not reported)	27 cases, 270 controls	100	49 ± 2
Findley[18]	1988	6	Case-control	Sleep lab	AHI ≥ 5	State driving record × 5 years	29 cases, 35 controls	NR	47 ± 12
George[19]	1999	7	Case-control	Sleep lab	AHI >10	State driving record × 5 years	460 cases, 581 controls	88	51 ± 12
Barbe[20]	1998	7	Case-control	Sleep lab	AHI >20	Insurance company records × 3 years	60 cases, 60 controls	98	47 ± 1
Haraldson[21]	1990	4	Case-control	ENT clinic	Clinical triad of SA[b]	Self-reported crash × 5 years	140 cases, 142 controls	100	48 ± 9
Horstmann[22]	2000	4	Case-control	Sleep lab	AHI ≥ 10	Self-reported crash × 3 years	156 cases, 160 controls	90	56 ± 10
Masa[23]	2000	7	Case-control	Random Population survey	Habitually sleepy	Self-reported crash × 5 years	107 cases, 109 controls	87	41 ± 11
Lloberes[24]	2000	5	Case-control	Sleep lab	Referred for SA	Self-reported crash × 5 years	122 cases, 40 controls	95	51 ± 9
Aldrich[25]	1989	4	Case-control	Sleep lab	Clinical diagnosis	Self-reported crash (years not reported)	181 cases, 35 controls	100	50 ± NR
Noda[26]	1998	4	Case-control	Sleep lab	Clinical diagnosis	Self-reported crash (years not reported)	44 cases, 27 controls	NR	61 ± 8
George[27]	1996	8	Case-control	Sleep lab	Clinical triad of SA[b]	Driving simulator performance	21 cases, 21 controls	100	49 ± 13
Findley[28] (a)	1989	5	Case-control	Sleep lab	Clinical diagnosis, ≥ 50 desaturations/h	Driving simulator performance	6 cases, 7 controls	83	46 ± 11
Findley[28] (b)	1989	5	Case-control	Sleep lab	Clinical diagnosis, ≥ 50 desaturations/h	Driving simulator performance	12 cases, 12 controls	75	50 ± 14
Haraldson[29]	1990	5	Case-control	NR	Clinical triad of SA,[b] sleepy while driving	Driving simulator performance	15 cases, 10 controls	100	54 ± NR
Findley[30]	1995	8	Case-control	Sleep lab	AHI ≥ 5, clinical triad of SAb	Driving simulator performance	62 cases, 12 controls	85	51 ± 1
Juniper[31]	2000	5	Case-control	Sleep lab	Desaturations ≥ 10, Epworth ≥ 10	Driving simulator performance	12 cases, 12 controls	100	48 ± NR
Risser[32]	2000	6	Case-control	Sleep lab	AHI ≥ 20	Driving simulator performance	15 cases, 15 controls	87	42 ± 6
Hack[33]	2001	4	Case-control	Sleep lab	Desaturations ≥ 10, ESS ≥ 10	Driving simulator performance	26 cases, 12 controls	NR	50 ± NR
Teran-Santos[34]	1999	7	Case-control	Emergency Room	Cases: involved in crash	AHI severity	102 cases, 152 controls	77	44 ± 10
Findley[35]	1989	6	Cohort	Sleep lab	Consecutive referred to sleep lab	State driving record (years not reported)	46	NR	NR
Young[36]	1997	7	Cohort	Population based	AHI severity ≥ 5 × 5 years	State driving record	913	59	45 ± 8
Shiomi[37]	2002	4	Cohort	Sleep lab	All referred to sleep lab	Self-reported crash × 5 years	554	89	49 ± 14
Goncalves[38]	2004	4	Cohort	Sleep lab	Consecutive referred to sleep lab	Self-reported crash × 2 years	135	100	52 ± 12
Wu[39]	1996	2	Cohort	Sleep lab	All referred to sleep lab	Self-reported crash (years not reported)	253	71	NR
Flemons[40]	1993	5	Cohort	Sleep lab	Consecutive referred to sleep lab	Driving simulator performance	180	NR	NR
Turkington[41]	2001	3	Cohort	Sleep lab	Consecutive referred to sleep lab	Driving simulator performance	150	83	50 ± 11
Powell[42]	2002	2	Cross-sectional	Nonrandom population based	Self-reported SA	Self-reported crash	10,870	39	37 ± 13
Commercial Drivers									
Stoohs[43]	1994	6	Cohort	Truck companies	O_2 desaturation index ≥ 10	Self- and employer-reported crash × 5 years	90	93	37 ± 9
Howard[44] (a)	2004	5	Cross-sectional	Random sample	RDI ≥ 5, ESS ≥ 11	Self-reported crash × 3 years	161	99	48 ± 9
Howard[44] (b)	2004	4	Cross-sectional	Random sample	Questionnaire diagnosis	Self-reported crash × 3 years	2342	99	42 ± 10

SA refers to sleep apnea; ESS, Epworth Sleepiness Scale; AHI, apnea-hypopnea index; NR, not reported; ENT, ear, nose, and throat; RDI, respiratory disturbance index;

[a]Newcastle-Ottawa Quality Assessment Scale.[16]

[b]Snoring, sleep disturbance, and daytime sleepiness.

Table 2—Findings of Crash Risk Studies

Author	Findings	Daytime Sleepiness	Correlation with severity of SA
George[17]	Increased crash risk (OR 2.1)	NR	NR
Findley[18]	Increased crash risk (OR 7)	NR	NR
George[19]	Increased crash risk (OR 1.3)	NR	Increased risk with AHI > 40
Barbe[20]	Increased crash risk (OR 2.3 (95% CI, 1.0,5.3)	ESS not significantly correlated with crash	No significant correlation
Haraldsson[21]	Increased crash risk (OR 6.8 for single-vehicle crashes)	NR	Increased risk with severity of SA
Horstmann[22]	Increased crash rate (OR 8.7)	ESS not significantly correlated with crash	Increased risk with severity of SA
Masa[23]	Increased crash risk (OR 13.3 (95% CI, 4.1-43)	ESS not significantly correlated with crash	No significant correlation with AHI
Lloberes[24]	Increased crash risk (OR 2.7)	Significant correlation with crash	NR
Aldrich[25]	No increase risk of crash	Significant correlation with crash (RR 2.6)	Increased risk with severity of SA
Noda[26]	Increased crash risk (OR 4.6)	ESS significantly correlated with crash	NR
George[27]	Worse performance	NR	No significant correlation with AHI
Findley[28] (a)	Worse performance	NR	NR
Findley[28] (b)	Worse performance	NR	NR
Haraldsson[29]	Worse performance	NR	NR
Findley[30]	Worse performance	NR	Increased risk with severity of SA
Juniper[31]	Worse performance	NR	NR
Risser[32]	Worse performance	NR	NR
Hack[33]	Worse performance	NR	NR
Teran-Santos[34]	Increased crash risk (AHI ≥ 10, OR 7.2 (95% CI; 2.4,21.8)	ESS not significantly correlated with crash	No significant correlation with AHI
Findley[35]	Increased crash rate	NR	Increased risk with severity of SA
Young[36]	Increased crash risk in men (OR ~4) not women	No significant correlation with crash	No significant correlation
Shiomi[37]	Increased crash risk (OR 2-3)	Significant correlation with crash	Increased risk with severity of SA
Goncalves[38]	No increase risk of crash	Epworth not significantly correlated with crash	No significant correlation with AHI
Wu[39]	Increased crash risk (OR 2.6 (95% CI, 1.2-5.5)	NR	NR
Flemons[40]	No correlation with performance	No significant correlation with crash	No significant correlation with AHI
Turkington[41]	No correlation with performance	Epworth significantly correlated with crash	No significant correlation
Powell[42]	Increased crash risk OR 3.3 (95% CI, 2.0-4.9)	ESS significantly correlated with crash	NR
Commercial Drivers			
Stoohs[43]	No increased risk of crash	Significant correlation with crash	No significant correlation
Howard[44] (a)	No increased risk of crash	NR	No significant correlation
Howard[44] (b)	Increased crash risk (OR 1.30 (95% CI, 1.00-1.69)	ESS significantly correlated with crash	No significant correlation

OR refers to odds ratio; ESS, Epworth Sleepiness Scale[56]; NR, not reported; 95% CI, 95% confidence interval; RR, relative risk; AHI, apnea-hypopnea index; SA, sleep apnea.

methodologic quality, 9 of 9 of the higher-quality, 11 of 14 on the medium-quality, and 2 of 3 of the lower-quality studies found a positive correlation between sleep apnea and crash. Fisher exact testing revealed that this was not a statistically significant difference ($p = .22$).

Studies Involving Commercial Drivers

There were 2 papers[43,44] (involving 3 separate studies) investigating crash risk in commercial drivers with sleep apnea. These studies used self-reported crash as their outcome measure. They found a weaker association between sleep apnea and crash risk compared with those studying noncommercial drivers. Two of the commercial driver studies[43,44] reported no statistical association and one[43] found only a weak relationship (OR 1.3 (95% confidence interval; 1.00,1.69).

Risk Factors for Crashes

Daytime Sleepiness

Fifteen of the 30 studies (including the commercial driver studies) reported on the association of subjective daytime sleepiness (often measured by the ESS) and risk of crash in drivers with sleep apnea. In these studies, 8 (4 using the ESS) reported a significant positive statistical correlation, and 7 (5 using the ESS) reported no significant correlation between daytime sleepiness and crashes. Categorization of these studies by quality found that 1 of 5 (0/3 using the Epworth) of the higher-quality, 5 of 8 (2/4 using the ESS) of the medium-quality, and 2 of 2 (both using the ESS) of the lower-quality studies found a positive statistical correlation between sleepiness and crash risk. Fisher exact testing revealed a slight trend toward studies with higher quality being more likely to show no correlation between daytime sleepiness and crashes ($p = .18$).

Table 3—Findings of Treatment Studies

Author	Year	Intervention	Study Design	Setting	Study Population	Outcome Measures	Sample size, no.	Men, %	Mean age, y	Findings with treatment	Daytime sleepiness
George[45]	2001	CPAP	Case-control, before-after	Sleep lab	AHI > 25, CPAP for ≥ 3 years	State driving record	210 cases 210 controls	NR	52 ± 11	Crash rate reduced	NR
Findley[46]	2000	CPAP	Before-after	Sleep lab	Diagnosed SA	State driving record × 2 years	50	86	56 ± 2	Crash rate reduced	NR
Krieger[47]	1997	CPAP	Before-after	Sleep lab	Diagnosed SA	Self-reported crashes × 1 year	893	87	57 ± 11	Crash rate reduced	NR
Cassel[48]	1996	CPAP	Before-after	Sleep lab	Sleep breathing disorder	Self-reported crashes × 5 years	59	100	49 ± 1	Crash rate reduced by 81%	Improved
Hack[33]	2001	CPAP	Before-after	Sleep lab	Desaturations ≥ 10 ESS ≥ 10	Simulator testing	26	NR	50 ± NR	Improved performance	NR
George[49]	1997	CPAP	Case-control, before-after	Sleep lab	AHI ≥ 15	Simulator testing	17 cases 18 controls	100	49 ± 5	Improved performance	Improved
Findley[28]	1989	CPAP	Before-after	Sleep lab	≥ 50 desaturations/h	Simulator testing	6	50	53 ± 11	Improved performance	NR
Hack[50]	2000	CPAP	Randomized	Sleep lab	Desaturations ≥ 10, ESS ≥ 10	Simulator testing	59	100	50	Improved performance	Improved
Yamamoto[51]	2000	CPAP	Before-after	NR	NR	Simulator testing	39	100	NR	Crash rate reduced	Improved
Orth[52]	2005	CPAP	Before-after	Sleep lab	AHI ≥ 5, clinical symptoms	Simulator testing	31	100	55 ± 10	Improved performance	NR
Turkington[53]	2004	CPAP	Non randomized	Sleep lab	RDI > 50/h, ESS ≥ 12	Simulator testing	18 cases 18 controls	94	50 ± 10	Improved performance	Improved
Haraldsson[54]	1995	UPPP	Case-control, before-after	NR	Clinical triad[a] of SA with sleep attacks	Self-reported crashes × 5 yrs	56 cases 123 controls	100	55 ± 9	Crash rate reduced	Improved
Haraldsson[55]	1991	UPPP	Case-control, before-after	ENT clinic	Clinical triad[a] of SA	Simulator testing	15 cases 5 controls	100	54 (median)	Improved performance	NR
Haraldsson[56]	1995	UPPP	Case-control, Before-after	NR	Clinical triad[a] of SA with sleep attacks	Simulator testing	13 cases 5 controls	100	52 ± NR	Improved performance	Improved

CPAP refers to continuous positive airway pressure; UPPP, uvulopalatopharyngoplasty; AHI, apnea-hypopnea index; RDI, respiratory disturbance index; ESS, Epworth Sleepiness Scale; NR, not rated; SA, sleep apnea; ENT, ear, nose, throat.
[a]Snoring, sleep disturbance, and daytime sleepiness.

Severity of the Sleep Apnea and the Crash Risk

Most studies used the scores on the AHI to measure the severity of sleep apnea. In the 18 studies that reported on this relationship, 7 demonstrated a significant positive statistical relationship between the severity of disease and crash risk, and 11 did not. For the studies finding a correlation, the strength of this association was found to be approximately 2 fold.[35,37] Categorization of these studies by quality found that 3 of 10 (1/5 using the AHI) of the higher-quality, 4 of 8 (0/2 using the AHI) of the medium-quality, and 0 of 1 (not using the AHI) of the lower-quality studies found a positive relationship between sleep-apnea severity and crash risk. Fisher exact testing did not reveal any relationship between methodological quality of the studies and a positive relationship between sleep apnea severity and crash risk (p = 1.0).

Other Risk Factors for Crashes

Most studies did not identify risk factors for crashes in drivers with sleep apnea other than subjective sleepiness and severity of disease. For those that did, 1 study[20] reported finding no correlation between crash rate and anxiety and depression symptoms in drivers with sleep apnea. Another study[32] noted an association between electroencephalogram-recorded attention lapses and poorer performance on a driving simulator. The only study that compared male and female drivers with sleep apnea found a statistically significant increased risk of crash in men but not in women.[36]

Treatment of Sleep Apnea and Crash or Performance Outcomes

Continuous Positive Airway Pressure

Eleven studies[28,33,45-53] (Table 3) examined the efficacy of continuous positive airway pressure (CPAP) to prevent crashes. Only 1 was a randomized controlled trial[50] with the rest using non randomized or before/after designs. In all of these studies, regardless of whether the outcome measure was state driving record, self-reported crashes, or simulator performance, the use of CPAP resulted in reduced crash rates or improved driver performance. The study[45] using state driving records as the outcome measure found that the crash rate in drivers using CPAP returned to the rate of those of the general population.

Uvulopalatopharyngoplasty

Three studies by Haraldsson et al,[54-56] investigating the efficacy of uvulopalatopharyngoplasty as treatment for sleep apnea, found that patients' performance on driving simulators, as well as their self-reported crash rates, improved following the procedure (Table 3).

DISCUSSION

This review systematically evaluated the evidence related to the risk of involvement in motor vehicle crashes in persons with sleep apnea. Of the 27 studies examining noncommercial drivers that used various designs, settings, eligibility criteria, and outcome measures, 23 found that persons with sleep apnea are at higher risk of crash, compared with persons who do not have the disorder. The strength of the association between crash and sleep apnea ranged from an OR of 1.3 to 13, with a median of 3.1. No trend was found suggesting that the higher-quality studies were more likely to find a positive correlation ($p = .22$).

When determining risk factors that increase the chance of crash in persons with sleep apnea, there is some evidence (7 of 18 studies finding a positive correlation) that, the more severe the sleep apnea (often measured by the AHI), the greater the risk of crash. This result was not altered when the methodologic quality of the studies was factored in. The studies that reported a positive statistical found that persons with severe sleep apnea are about 2 to 3 times more likely to be involved in a crash, compared with those with mild disease.

Interestingly, the results show that daytime sleepiness, a symptom of sleep apnea that intuitively seems likely to be associated with crashes, is not consistently correlated (8 of 15 studies finding a positive statistical correlation) with involvement in motor vehicle crashes. A recent study[59] also did not find differences in general subjective sleepiness (as measured by the ESS) between persons who have crashed (but did not necessarily have sleep apnea) and those who have not crashed ($p = .93$). Therefore, clinicians should be cautious in using the presence or absence of this symptom as the sole factor in determining the fitness to drive of patients with sleep apnea.

All 14 studies (including 1 randomized controlled trial) that examined whether treatment of patients with sleep apnea, using either CPAP or uvulopalatopharyngoplasty, reported that these interventions lowered crash rates, possibly back to levels found in the general population. Turkington et al[53] have shown that driver performance improves as little as 2 days after starting therapy with CPAP. For patients considering the use of CPAP, clinicians can use this information to stress the importance of treatment adherence to promote safe driving and perhaps maintenance of driving privileges.

The participants in these studies were mostly men and aged between 40 and 55 years. For this age group, the baseline yearly crash rate in the general population is approximately 5 crashes per 100 drivers,[60] suggesting that persons with sleep apnea have a yearly crash rate of approximately 10 to 15 crashes per 100 drivers with sleep apnea. Therefore, the additional annual attributable crash risk due to sleep apnea is approximately 5 to 10 per 100 drivers with this condition.

These crash rates are comparable with those of drivers who have moderate to severe dementia[61] or who are driving with blood alcohol levels of 0.05 to 0.79 mg/dL.[62] Since, at these blood alcohol levels, many North American jurisdictions start to mandate against driving,[63] it is reasonable for policy makers to closely scrutinize the driving capabilities of patients with sleep apnea, especially those who have not been treated successfully.

There are also indications that treatment of sleep apnea is cost-effective, both in the North American[12,64] and European contexts.[65] Data from George et al[45] showed that, for every 500 sleep apnea patients who go untreated for 5 years, there will be an excess of 1 fatal, 75 personal-injury, and 224 property crashes, for a total cost of approximately $10 million US. Successful treatment of these individuals with CPAP would cost approximately $1 million US for the 5 years, thus providing an approximate 4- to 10-fold return on money spent.[12,65]

Two[43,44] of the 3 studies involving commercial drivers did not find a statistically significant correlation between the presence of sleep apnea and crash risk, with the third[43] finding only a weak correlation (OR of 1.3). The reason or reasons for this are unclear and possibly relate to these studies relying predominantly on self-report measures to determine crash rate. This outcome determination is likely prone to significant underreporting bias because reporting crashes could potentially lead to loss of livelihood in this population.

There are a number of reasons why the crash risk in patients with sleep apnea may be underestimated by the studies in this review. None of the studies comprehensively measured driving exposure by the participants. Accurate estimates of the number of miles or hours driven per year were not available. Such data can be important because persons with medical conditions that impact upon driving often reduce or self-restrict their driving exposure.[66] Therefore, if reduced exposure to driving is factored in, persons with sleep apnea may have significantly higher crash rates per mile driven than is suggested by the reviewed studies. Also, many studies used self-reported crashes as their outcome measure. These studies may be susceptible to recall, social desirability, or both recall and social desirability bias because, for fear of losing their driver's license, persons with sleep apnea may be less likely to report previous involvement in crashes, compared to those persons without sleep apnea. Finally, studies[67,68] have shown that state driving records do not fully capture the number of crashes that occur in the population. Correlation between state driving record and self-reported crashes is imperfect, with each method identifying crashes that the other did not.[69]

On the other hand, there are other aspects of the studies included in this analysis that could lead to overestimation of crash risk in patients with sleep apnea. Virtually all of the studies were conducted in sleep disorder clinics and are, thus, prone to referral bias. These specialized clinics are more likely to evaluate persons with more severe forms of sleep apnea, compared with the clinical spectrum of disease that exists in the general population. Therefore, with some evidence of an association between crash risk and the severity of sleep apnea, patients attending these clinics may possibly have higher crash rates than average persons with sleep apnea.

There are a number of limitations to this systematic review. Publication bias may result in studies that have been unable to demonstrate a relationship between drivers with sleep apnea and increased crash risk being less likely to be published. If this is true, then the strength of the relationship between sleep apnea and driving found in this study would be weakened. Also, the majority of studies included in this review recruited mostly male patients. Therefore, caution is needed when applying the results of this study to women. Finally, the studies included in this review were quite heterogeneous regarding their methodologies, beyond their differences in study design and outcomes measures. For example, there was no standardized method of determining the presence and severity of sleep apnea. A similar issue occurred with the measurement of subjective daytime sleepiness, some using the ESS and others not. Also, recently, the reproducibility of the ESS has been questioned.[70] On the other hand, this heterogeneity in methods can be a source of strength because almost all studies examining noncommercial drivers found a positive association between sleep apnea and crashes, despite divergent methodologies.

This review also highlights a number of research gaps in the literature. Future research could further delineate the relationship between sleep apnea severity and daytime sleepiness and crashes. Also, studies to determine whether other potential risk factors (e.g., body mass index, comorbid conditions, use of sedating medications[71]) have an impact on crash risk in drivers with sleep apnea would be helpful.

In summary, the best available evidence suggests that persons with sleep apnea have a 2 to 3 times increased risk of crash, compared with the general population. Studies did not find that daytime sleepiness and the severity of sleep apnea were consistently correlated with crash risk in this population. Successful treatment of sleep apnea mitigates the excess risk of motor vehicle crashes in persons with sleep apnea. Clinicians should be able to use this information in the management of their patients with sleep apnea.

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