Sleep, Death and the Heart

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Meghna P. Mansukhani drafted the manuscript.

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ABSTRACT

Obstructive and central sleep apnea have been associated with increased risk of adverse cardiovascular events and mortality. Sympathetic dysregulation occurring as a result of the respiratory disturbance is thought to play a role in this increased risk. Sleep apnea increases the risk of arrhythmias, myocardial ischemia/infarction, stroke, and heart failure, all of which may increase mortality risk. A higher incidence of nocturnal arrhythmias, cardiac ischemia and sudden death has been noted in subjects with sleep disordered breathing (SDB). In this review, the association between SDB and each of these conditions is discussed, as well as the potential mechanisms underlying these risks and the effects of treatment of SDB. Particular emphasis is placed on the relationship between SDB and nocturnal atrial and ventricular arrhythmias, myocardial ischemia/infarction and sudden death.

KEYWORDS: sleep apnea, sleep disordered breathing, mortality, cardiovascular, arrhythmia
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INTRODUCTION

Obstructive sleep apnea (OSA) is characterized by repeated upper airway occlusion and hypoxemia in sleep. OSA is common in the general adult population and occurs primarily as a result of an anatomically narrow upper airway due to obesity, bony and soft tissue structures, although several other factors, including neural control of the airway, may be important contributors (149). Central sleep apnea (CSA), on the other hand, is most commonly seen in the context of heart failure, where cessation of breathing occurs due to a reduced central drive to breathe (149). In normal sleep, changes in respiration, heart rate (HR) and blood pressure (BP) are sleep stage dependent (118, 145), whereas in obstructive and central sleep apnea, they correlate with severity and duration of apnea (67, 87).

Both types of sleep disordered breathing (SDB), OSA and CSA, have been shown to be associated with sympathetic dysregulation, in sleep, and during wakefulness as well (28, 78, 88, 107, 142, 144). The peripheral chemoreflex is thought to play an important role in this dysregulation (23, 30, 60, 87, 108, 146-148, 155, 175). The response to hypoxemia in OSA appears exaggerated compared to subjects of similar weight without OSA who are exposed to similar levels of hypoxemia (106, 142). The chemoreflex-induced sympathetic response to a combination of apnea, hypoxemia, as well as hypercapnia could explain the increased risk of adverse cardiovascular events and death in patients with OSA (87, 88).

In this review, the association between SDB and sudden death in adults is discussed. The relationship between SDB and nocturnal arrhythmias, nocturnal myocardial ischemia/infarction,
Heart failure, and stroke, all of which could potentially increase mortality risk in this group of
patients, is reviewed. While periodic limb movements of sleep (69) and sleep deprivation (41)
could potentially be associated with increased risk of adverse cardiovascular events and
mortality, these subjects are outside the scope of this review. Medications have not been found to
help significantly in the treatment of OSA (101). There is limited evidence supporting the role of
medication in the treatment of CSA in the context of heart failure when PAP is not tolerated,
especially after optimization of medical therapy (5). The effects of CPAP, oral appliances and
surgical treatment of SDB, where applicable, are discussed.

SYSTEMIC HYPERTENSION

OSA is very closely associated with pulmonary (62) and systemic hypertension (15, 51, 89, 170).
Approximately half of patients with systemic hypertension have co-existing OSA (113). The risk
of both baseline and future hypertension is increased in OSA (15, 51, 89, 170), in a dose-
response fashion. Thus, the higher the severity of untreated OSA the greater the incidence of
hypertension (89, 115). In addition, OSA has been noted to be the most common secondary
etiology in patients with resistant hypertension (113). A recent study showed that REM-
predominant OSA is also significantly associated with current and future risk of hypertension
(97).

It is possible that sympathetic dysregulation induced by OSA may play a role in the development
of hypertension. There are data from a number of animal studies demonstrating increases in BP
in response to airway occlusion (14) and intermittent hypoxia (23, 27, 31, 77, 152). One study of
human subjects with OSA showed that the sympathetic response to hypoxia was related to AHI and daytime/nighttime BP (39). Recent experiments conducted in a rat model of sleep apnea have suggested that the changes in sympathetic control induced by chronic intermittent hypoxia might actually precede the development of hypertension (59).

Furthermore, treatment of OSA with continuous positive airway pressure (CPAP) (56, 105, 144), oral appliances (117), tracheostomy (28) and maxillo-mandibular advancement surgery (58) has been shown to decrease BP. Maximum reduction appears to occur in patients with co-existing diabetes mellitus (104), in those with severe OSA (120) and resistant hypertension (55, 161).

Modest beneficial effects of long-term CPAP treatment on BP have been reported not just in subjects with a current diagnosis of hypertension, but also in subjects who are pre-hypertensive (24, 169). The effects of CPAP use on the risk of incident or new hypertension, on the other hand, are mixed (7, 89). Interestingly, the beneficial effects of CPAP on BP appear to be more pronounced in OSA subjects with excessive daytime sleepiness (116) and are absent in those without sleepiness (7, 8, 128) in some studies.

Non-dipper BP pattern

Non-dipping of BP at night has been noted to be an adverse prognostic factor for cardiovascular morbidity and mortality (163). Undiagnosed sleep disordered breathing could be responsible in part for these surges in BP at night (25, 121). Recurrent episodes of apnea and hypoxemia increase sympathetic activation, increasing cardiac output and peripheral vasoconstriction (145). Once breathing restarts at the termination of an apnea, the increased cardiac output is delivered
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into constricted blood vessels, resulting in striking BP surges at night (111, 126). The severity of respiratory disturbance appears to be related to a non-dipping BP profile in younger subjects, whereas in older subjects, severity of sleep disturbance appears to have more of an influence on non-dipping status (133). Increased inflammation (57) and white matter changes in the brain (76) have been postulated as possible mechanisms conferring an increased risk of adverse events in patients with OSA and a non-dipping BP profile.

CPAP treatment could alleviate the detrimental effects of SDB on nocturnal BP. A study conducted in patients with resistant hypertension demonstrated that a higher proportion of OSA patients treated with CPAP after 12 weeks had a nocturnal dipping BP pattern compared to those not on CPAP (91). Another recent study suggested that evening dosing of antihypertensive medication may result in a decrease in nighttime BP and attenuate non-dipper status in non-sleepy patients with OSA and non-dipping BP, irrespective of CPAP use (68).

ARRHYTHMIAS

Atrial fibrillation

SDB has been found to be more common in patients with atrial fibrillation (AF) than in other high-risk patients with multiple other comorbidities (37), as well as age-matched controls from the community (13). In addition, increasing severity of SDB is associated with increasing odds of having AF (93). In a large study of 3542 subjects without AF undergoing polysomnography, new-onset AF was identified in 133 subjects over a mean follow up period of 4.7 years. Obesity
and magnitude of oxyhemoglobin desaturation during sleep were independent predictors of AF in those less than 65 years of age (34).

In the Women’s Health study including over 30,000 healthy subjects, new-onset AF was associated with increased all-cause and cardiovascular mortality (20). In another recent study of patients with AF and preserved ventricular function, SDB was found to be independently associated with a combined outcome of all-cause mortality and heart failure hospitalization (135). Thus, increased risk of AF may be implicated in the increased risk of mortality in patients with SDB (33).

A number of mechanisms have been proposed to explain the link between SDB and AF, including first, hypoxemia with simultaneous sympathetic and vagal activation. Second, increased transmural pressure gradients occurring in the context of increasing negative intrathoracic pressure from an obstructed airway could result in increased atrial natriuretic peptide (ANP) levels, and cause atrial stretch and remodeling, thereby triggering AF (174). Indeed, Otto et al have reported increased left atrial volumes in subjects with newly diagnosed OSA compared to similarly obese subjects without OSA (112). A reversal of these effects has been demonstrated with CPAP treatment (140). Third, systemic inflammation may play a role in the pathogenesis of AF in OSA; elevated CRP levels have been noted in subjects with OSA (139) as well as in those with increased risk for atrial arrhythmias (19).

The risk of AF has been noted to increase markedly shortly after the respiratory disturbance has occurred in an animal model of sleep apnea (42) as well as on polysomnography in human subjects with SDB (99), suggesting a temporal relationship between SDB and AF. However, there are some studies suggesting that AF may in fact lead to the occurrence of CSA and OSA, by inducing cardiac dysfunction and/or increased fluid retention and airway edema (124, 130).
It should be noted that the distinction between OSA and CSA is not clear in many studies demonstrating the association between SDB and AF. Some researchers have indicated that in subjects with and without congestive heart failure (CHF), AF is more tightly associated with CSA than OSA (26, 94, 141, 171). A recent study in CHF patients that excluded subjects with OSA, showed that CSA was independently associated with increased risk of AF and sinus pauses at night, non-sustained ventricular tachycardia (VT) during the day and night, as well as increased mortality risk (132).

The risk of recurrence of AF after receiving anti-arrhythmic medication (98), or having cardioversion (65) or radiofrequency ablation (12, 43, 102, 109), has been shown to be higher in subjects with untreated versus treated OSA in a number of observational studies. CPAP treatment may also promote more homogenous conduction through the atria in subjects with OSA (11).

Ventricular arrhythmias

SDB has been associated with benign as well as life-threatening ventricular arrhythmias (122). OSA has been noted to be independently associated with increased QRS duration in women but not in men (50). In 45 patients with an implantable cardioverter-defibrillator (ICD) device who underwent an overnight sleep study, significant SDB (AHI≥10/hour) was found in 57.8% of the subjects (172). Appropriate ICD therapy, i.e. anti-tachycardia pacing or shock for VT or ventricular fibrillation (VF), during one year follow up, was seen in 73% of those with OSA versus 47% of those without OSA (p=0.02). A four-fold increase was noted in OSA patients after adjusting for confounders. Interestingly, the risk of ventricular arrhythmias was higher (OR 5.6,
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95% CI 2-15.6, p=0.001) due to an increase in events between midnight and 6am, but there was no effect of OSA on appropriate ICD therapy during the remaining hours of the day (Figure 1). The difference in atrial and ventricular arrhythmias seen in OSA versus CSA was assessed in a large study of 2911 older men (94). The quartile with most severe SDB was compared to the least severe SDB quartile. Overall, increasing severity of SDB was associated with increased risk of AF (OR 2.15, 95% CI 1.19-3.89) as well as complex ventricular ectopy (OR 1.43, 95% CI 1.12-1.82). While an increase in OSA severity was associated with complex ventricular ectopy but not with AF, CSA was found to be more strongly associated with AF, suggesting that different types of sleep apnea-related stresses may be linked to different types of arrhythmias. The effects of treatment of OSA on reducing ventricular arrhythmias are mixed in the medical literature. In one study of 400 patients with SDB undergoing polysomnography, about half were found to have arrhythmias, including non-sustained VT, sinus arrest, second-degree atrio-ventricular block and ventricular premature contractions. After tracheostomy was performed as a treatment for OSA in the 55 patients who had significant arrhythmias, no arrhythmias were noted other than ventricular premature contractions (49). Some studies have shown that CPAP has a favorable effect in reducing ventricular arrhythmias (1,129, 131) while others have not (21); in particular, the impact on the risk of VT is unclear.

Brugada syndrome

Brugada syndrome is an uncommon condition of uncertain prevalence that is associated with sudden death in otherwise healthy individuals, usually occurring in the fourth decade of life. It was first described in 1992 in patients with recurrent VT/VF, with characteristic ST elevation in
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leads V1-V3 and right bundle branch block (16). Some patients have a proven sodium channel
SCN5A gene mutation, but other ion channel mutations have also been described (17).

Sudden unexplained nocturnal death syndrome (SUNDS) has been described in Laos, Japan and
Philippines in healthy young men, as a condition characterized by night terrors, vocalizations,
tachycardia, sweating, sympathetic activation, breathing irregularities, and VF (96, 156).

Brugada syndrome and SUNDS are thought to be closely linked (40, 80, 162).

An increased frequency of VF between midnight and 6am has been demonstrated in patients with
Brugada syndrome (92) and a high prevalence of OSA has also been found in patients with
Brugada syndrome (82). Macedo et al demonstrated that despite a normal BMI of 24.7 kg/m2,
SDB, mainly OSA (AHI 17.2 ± 14/hour), was present in 45% of patients with Brugada syndrome
versus in 27% of matched controls (p≤0.01). In the 9 subjects with Brugada syndrome who were
treated for high risk of fatal arrhythmias, defined as Brugada syndrome type 1 EKG with
syncope or resuscitated sudden cardiac death, two-thirds had SDB. In a recent study, Brugada
syndrome was not found to be associated with autonomic dysfunction unless there was
coexisting SDB (153). Thus, there is a possibility that the presence of OSA in patients with
Brugada syndrome may contribute to the increased mortality in this group of patients through
sympathetic dysregulation, but further studies are needed to confirm these hypotheses.

NOCTURNAL MYOCARDIAL ISCHEMIA/INFARCTION

The association between nocturnal hypoxemia and nocturnal myocardial ischemia and
arrhythmias was initially demonstrated in a study of 19 consecutive patients with acute
myocardial infarction (MI) (32). Subjects were monitored continuously with Holter monitor and
pulse oximetry for at least 2 nights, for 8 hours or longer each night, between 2 and 6 days
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following MI. Episodic and constant hypoxemia were common; the former was found to occur simultaneously with episodic tachycardia, ST segment changes, and other arrhythmias in more than half the patients after the first night. In a series of patients with nocturnal ischemia, Franklin et al described a patient awakened by angina at 04:46 AM preceded by a clear episode of apnea and hypoxemia (29). More recent studies have shown an increased risk of MI in patients with SDB (38, 73). A Danish study of 33,274 individuals with SDB demonstrated heightened risk of MI, particularly in those below 50 years of age (73). Another study showed that OSA was an independent predictor of MI with an OR of 4.9 (95% CI 2.9-8.3, p=0.017) (38).

Sympathetic nerve activity is lower and there is less fluctuation in respiratory and BP measures in normal awake subjects compared to those with OSA. Sympathetic activity, heart rate and blood pressure changes are more marked in sleep, especially in REM sleep, in patients with OSA, and these changes appear to be ameliorated by the use of CPAP (144). These autonomic and hemodynamic changes resulting from hypoxemia and/or apnea in patients with OSA may induce cardiac ischemia. A study conducted in 226 patients undergoing coronary angiography for angina pectoris, who had a sleep study and Holter monitoring performed simultaneously, showed ST-segment depression in 56% of the patients, and nocturnal ST-segment depression in 31% (100). ST segment depression occurring within two minutes following an apnea, hypopnea or desaturation, was seen in 19% of those with nocturnal ST segment depression, particularly in men (p<0.01) and in those with more severe SDB (p<0.001). In most of these subjects (70%), there was a series of three or more breathing events (apnea, hypopnea or desaturation) preceding the ST-segment depression.

Sympathetic activation (88), as well as changes in endothelial (9) and platelet (10) function at night, could increase the risk of adverse nocturnal coronary events and thus may account for the
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reversed day-night variation of acute MI seen in patients with OSA (72). In this study, 92 patients with acute MI in whom the time of onset of chest pain was clearly known, underwent polysomnography. MI occurred in 32% of patients with OSA between midnight and 6am compared to 7% of those without OSA (Figure 2), and was in contrast to the usual diurnal occurrence in the general population. Among those who had an MI between midnight and 6 am, 91% had OSA, a six-fold higher odds (95% CI 1.3-27.3, p=0.01) compared to those in whom MI occurred during the other hours of the day.

CPAP treatment has recently been shown to decrease the risk of repeat revascularization after percutaneous coronary intervention (167). However, the beneficial effects of CPAP on reducing risk of MI have been observed in some (38) but not in other studies (73).

STROKE

OSA has been demonstrated to be an independent risk factor for stroke and death in prospective longitudinal cohorts (6, 73, 90, 103, 123, 159, 168). Additionally, an increased risk of mortality has been noted in OSA patients who have suffered an acute ischemic stroke (85).

Both OSA and CSA can be seen after an acute ischemic stroke, and in many patients, SDB is seen to persist for months following a stroke. Whether this persistent SDB reflects the presence of pre-existing undiagnosed SDB preceding the onset of stroke is unclear at this time (86).

Recently, severe OSA was associated with ischemic stroke, with symptoms noted soon after waking from sleep, the so-called “wake-up stroke” (54). In this subcategory of stroke patients, symptoms are thought to commence during sleep and since the exact time of onset of symptoms is not known, they are generally excluded from revascularization therapy (164).
Possible mechanisms through which OSA may increase the risk of incident stroke include AF (86) or increased thrombogenicity by increasing fibrinogen levels, platelet adhesiveness and blood viscosity (138, 158). One recent study indicated significantly increased morning fibrinogen levels in patients with severe OSA compared to controls (p=0.003) and those with mild OSA (p=0.02), after adjusting for age, BMI, BP, smoking and alcohol consumption (138).

Additionally, increased risk of a right to left shunt across a patent foramen ovale and increased risk of deep venous thromboembolism in patients with OSA as discussed below, are potential contributory factors that could increase overall risk of stroke in these patients.

**Patent foramen ovale**

Patent foramen ovale (PFO) is a congenital defect of the atrial septum that frequently persists into adulthood (53, 166). The vast majority of patients are asymptomatic. However, the most dreaded potential complication of a PFO is cryptogenic stroke through paradoxical embolism (74, 95). PFO may be more common in patients with OSA (48, 66) and patients with OSA may have larger, more clinically significant shunts across a PFO (137).

In a recent study of 10 patients (8 male), aged 55 ± 11 years, undergoing right heart catheterization, simulated OSA via the Mueller maneuver resulted in an increased right-left pressure gradient across the atrial septum, higher than that recorded during the valsalva maneuver (70). This was thought to be secondary to greater blood return to the right atrium from extrathoracic veins. These preliminary results provide a possible hemodynamic basis for increased right to left shunting across a PFO in patients with OSA.
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Both OSA and PFO have been shown to be associated with reduced fibrinolytic activity during sleep; thus it is possible that a combination of both of these conditions results in a greater prothrombotic state in sleep that can predispose to stroke, as compared to either condition alone (125).

One case report described disappearance of right to left shunting across a PFO in a patient with OSA treated with CPAP for one week (119). Further studies are needed to ascertain the effects of treatment of SDB in the context of PFO.

The effects of PFO closure on symptoms and oxygen desaturation in patients with OSA is mixed in the literature, with one study showing no change (137) and others showing beneficial effects on these measures (2, 164).

Deep venous thrombosis

Deep venous thrombosis (DVT) can lead to pulmonary embolism in 50% of untreated individuals, usually within days or weeks (22, 45). Also, paradoxical embolism from DVT can result in stroke in the setting of a PFO as noted above, and both of these complications, namely pulmonary embolism and stroke, can be fatal.

OSA is a state of hypercoagulability and several reports have indicated a higher prevalence of DVT in patients with OSA (3, 4, 18, 114). A recent large prospective study evaluated 5680 subjects with newly diagnosed sleep apnea and 4505 controls, over an average follow up period of 3.6 years (18). A total of 30 subjects (0.53%) with sleep apnea developed a DVT versus 10 (0.22%) from the control group (p=0.002) (Figure 3). This effect was independent of confounders, demonstrating that sleep apnea may be an independent risk factor for DVT. The
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risk of DVT was noted to be even higher in those needing CPAP treatment (HR 9.58, 95% CI 3.18-28.82, p<0.001). Another recent study (114) showed an up to four-fold increase in the risk of DVT and PE in patients with OSA and one study (4) suggested that the association between SDB and DVT/PE was significant in female but not in male subjects. Patients with OSA also appear to need a higher dose of warfarin for anticoagulation than those without OSA (64). The effects of CPAP treatment on the risk and outcomes of DVT are unknown at this time.

HEART FAILURE

Patients with heart failure can have both OSA and CSA, with the latter often manifesting as a crescendo-decrescendo breathing pattern called Cheyne-Stokes Respiration (CSR) (63, 141). CSA and CSR are thought to arise as a result of increased responsiveness to arterial carbon dioxide levels noted in patients with heart failure (61). High sympathetic drive is evident in subjects with systolic and diastolic heart failure, and in those with CSA, levels of sympathetic activity increase even further (135, 143, 154, 160). This increased sympathetic activity may explain the higher mortality risk noted in patients with CHF and CSA (79). However, some data suggest that in patients with CHF, increased sympathetic activity may be related to heart failure severity and not to CSA severity (83). In a study of 55 patients with CHF, mean pulmonary artery pressure, but not measures of sleep apnea severity, independently correlated with total and cardiac norepinephrine spillover. Autonomic dysfunction, evidenced by decreased heart rate variability, has also been reported in patients with CSA (75). CPAP treatment has been shown to decrease cardiac sympathetic activity and alleviate autonomic dysfunction in patients with CHF (44, 52).
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In a study designed to elucidate the mechanisms underlying sudden cardiac death in 216 patients with stable advanced heart failure, 21 (9%) patients experienced cardiac arrest over a 4-year follow up period. The most common electrocardiographic rhythms preceding sudden cardiac death included severe bradycardia in 9 patients, VT/VF in 8 patients, electromechanical dissociation in 2 patients and AV block in 2 patients (81). All of these arrhythmias, including bradyarrhythmias, are commonly noted in patients with severe SDB.

Severe CSA has been associated with increased risk of AF in systolic heart failure patients (46). CSA has also been associated with ventricular arrhythmias in CHF, and VT/VF is the most common cause of sudden nocturnal death in patients with CHF (47). Thus, there may be a link between nocturnal arrhythmias and sudden nocturnal death in patients with CHF.

One study in CHF patients demonstrated that SDB induced electrical instability in the form of increased nighttime T-wave alternans, a risk marker of lethal arrhythmias and sudden death at night (151). Further studies are required to demonstrate conclusively increased mortality in CHF patients as a result of sleep disordered breathing, both CSA and OSA.

CPAP treatment has been shown to increase ejection fraction in almost all patients with OSA and in 50% of those with CSA (71). A meta-analysis showed that the ejection fraction improved by about 5% after CPAP treatment in patients with OSA and heart failure (150). Observational studies have indicated improved survival rates in patients with CHF who are effectively treated with PAP (6, 71). It should be noted, however, that preliminary results from the not yet published SERVE-HF randomized controlled trial have indicated increased cardiovascular mortality risk in patients with moderate-severe CSA and chronic symptomatic heart failure (New York Heart Association classes II-IV) with an estimated ejection fraction of ≤45% using an adaptive
servoventilator (ASV) form of PAP treatment. The reasons for these findings are unclear and further analyses will need to be undertaken to clarify this issue (135).

EXERCISE TOLERANCE

A decrease in functional capacity on exercise testing has been noted in patients with OSA (84, 127) and one study showed that decrease in functional capacity in patients with OSA was associated with increased mortality risk (110). A recent study showed that exercise training reduced sympathetic nerve activity in patients with CHF. Exercise training was seen to improve SDB and increase duration of deep sleep in those with OSA but not in those with CSA (157). Further studies are needed to clarify the association between reduced exercise capacity and increased mortality in patients with SDB.

SUDDEN DEATH

An increased risk of nocturnal sudden death has been demonstrated in patients with OSA (35, 36). In a study spanning 16 years and involving 112 adult subjects with sudden cardiac death (SCD) who had undergone prior polysomnography, rates of SCD during four different intervals of the day were compared between those with and without OSA (35). In contrast to the general population, where the risk of SCD peaks during the day with a nadir between midnight and 6am, in this study, SCD occurred between midnight and 6am in 46% of subjects with OSA versus 21% of those without OSA (p=0.01) (Figure 4). In addition, the apnea-hypopnea index (AHI) correlated directly with the relative risk of SCD between midnight and 6am. Similar results were seen when data were analyzed by usual sleep-wake cycles, i.e. rates of SCD were higher during
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...sleep (10pm to 6am) in those with OSA (54% of total sudden deaths) versus those without OSA (24%).

While OSA increased the probability of SCD occurring at night, it may also increase the overall risk of SCD per se. The incidence of SCD in OSA was assessed in 10,701 adults who underwent first polysomnography between 1987 and 2003 and were followed for up to 15 years (36). A total of 142 subjects had resuscitated/fatal SCD during a mean follow up period of 5.3 years, which was an annual rate of 0.27%. An AHI>20/hour (HR 1.6) (Figure 5a), mean nighttime oxygen saturation<93% (HR 2.93) and minimum nighttime oxygen saturation <78% (HR 2.60; all p<0.0001) were strong predictive factors for SCD. In multivariate analysis, minimum nighttime oxygen saturation independently predicted SCD (per 10% decrease of oxygen saturation, HR 1.14, p=0.029) (Figure 5b).

The mechanisms underlying increased risk of SCD in SDB are unclear. An autopsy study of 25 subjects with OSA and sudden death revealed cardiomyopathy in 11 cases, sudden unexpected death without morphologic findings in 6 cases, and other cardiovascular diseases not related to OSA in the remainder (173).

CONCLUSIONS

Sleep disordered breathing, both OSA and CSA, has been associated with increased risk of death. Apnea, hypoxemia and hypercapnia act synergistically to elicit sympathetic activation, which is thought to be a major mechanism underlying elevated risk of adverse cardiovascular consequences and mortality. Vagal responses to apnea are also of importance, especially in bradyarrhythmias and in triggering atrial fibrillation. OSA has been shown to increase the risk of...
sudden cardiac death at night. An increase in potentially lethal nocturnal arrhythmias, including atrial fibrillation and ventricular tachycardia/fibrillation, may confer higher nighttime mortality risk in patients with OSA. In addition, OSA is being recognized as a risk factor for nocturnal myocardial ischemia and myocardial infarction, and may raise the risk of ischemic stroke occurring in sleep as well. While the risk of stroke could be mediated through atrial fibrillation in patients with OSA, patent foramen ovale and deep venous thrombosis, both of which are seen in association with OSA, may be additional mechanisms conferring increased stroke and mortality risk in this population. Finally, OSA and CSA are closely linked to heart failure, another potential mechanism that may contribute to an elevated mortality risk in patients with SDB. Other factors such as impaired exercise capacity, increased periodic limb movements of sleep, and sleep deprivation, seen more frequently in patients with SDB than in the general population, may also play a role in increasing mortality. Large scale prospective randomized trials are required to definitively demonstrate a causal association between SDB and each of the above cardiovascular conditions and death, and to clarify the effects of treatment of SDB. Identification of the exact mechanisms underlying these relationships may provide potential new avenues for individualized screening, prevention and treatment of the adverse cardiovascular consequences.
ACKNOWLEDGEMENTS

GRANTS

This work was supported by the National Heart, Lung, and Blood Institute of the National Institutes of Health under Award Number R01HL065176. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

DISCLOSURES

Meghna P. Mansukhani has no disclosures.

Shihan Wang has no disclosures.

Virend K. Somers has served as a consultant for ResMed, Resplicardia, Price Waterhouse Coopers, Ronda Grey, GlaxoSmithKline, Philips Respironics, U-Health and Sorin. Dr. Somers has also received research support derived from a gift from the Respironics Foundation to the Mayo Foundation.
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FIGURE CAPTIONS

Figure 1
Ventricular arrhythmias in patients without and with sleep-disordered breathing by time of day.
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Figure 2
Day and night pattern of myocardial infarction (MI) in subjects with OSA (64) and without OSA (28).
Reproduced with permission from (72)

Figure 3
Freedom from deep vein thrombosis (DVT) in subjects with and without sleep apnea.
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Figure 4.
Day and night pattern of sudden cardiac death (SCD) in subjects with (78) and subjects without (34) Obstructive Sleep Apnea (OSA) and in the general population.
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**Figure 5A**

Survival free of fatal/resuscitated sudden cardiac death (SCD), based on apnea hypopnea index (AHI).

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**Figure 5B**

Survival free of fatal/resuscitated sudden cardiac death (SCD), based on lowest nocturnal oxygen saturation threshold.

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Freedom from deep-vein thrombosis (%)

Follow-up period (years)

Without sleep apnea

With sleep apnea

Log rank $P = 0.001$

Patients at risk

<table>
<thead>
<tr>
<th>Follow-up period (years)</th>
<th>Without sleep apnea</th>
<th>With sleep apnea</th>
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