Systematic Review

Indoor/outdoor not-voluptuary-habit pollution and sleep-disordered breathing in children: a systematic review

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Background: Exposure to environmental pollutants is advocated to be a major risk factor, with increased morbidity and mortality in humans due to acute and chronic airway inflammation. The aim of the present review is to show the literature research regarding the link between the sleep-disordered breathing and exposure to indoor/outdoor pollution in children. We hypothesized that environmental air pollution can play a role in childhood sleep-disordered breathing.

Methods: We conducted an electronic search in Medline (with PubMed interface), Scopus and the ISI Web of Science using the keywords “sleep” or “sleep apnea” or “sleep disordered breathing” and “pollution” and “children” in “Title/Abstract/Keywords”, with language restriction (non-English paper) and no date limitation to present. The tobacco smoke pollution is well established linking and is not considered for the present subject. We examined the strength of the evidence according to the Oxford Centre for Evidence-Based Medicine [2011] and the Centre for Evidence-Based Medicine [2009].

Results: A total of 105 articles were identified, but 97 of these had to be excluded after an accurate reading of the title, abstract or full text. In the end, eight studies were selected for our analysis for a total of a total of 5,826 children. The results suggest an involvement (grade C) of environmental (not from voluptuary habits) pollution in the worsening of sleep-disordered breathing in children.

Conclusions: To date, some studies reported significant differences between areas with higher and lower pollutants and the interventions on indoor pollution reduced sleep-disordered breathing in children. Therefore, although the relevance of the argument is high, the number of studies and the interest in the subject seems at this time quite limited.

Keywords: Children; environmental pollution; sleep disordered breathing (SDB)

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Introduction

Sleep-disordered breathing (SDB) is a general term for several chronic conditions in which partial or complete cessation of breathing occurs many times throughout the night. Symptoms may include snoring, pauses in breathing and disturbed sleep. Obstructive sleep apnea syndrome (OSAS), which is by far the most common form of SDB, is characterized by episodes of complete or partial upper airway obstruction during sleep (1).

Children with OSAS are increasingly recognized as an important group of patients (2). In childhood, OSAS is most frequently due to tonsil and adenoid hypertrophy. However, obesity and anatomic alterations of the upper airways play a role (3). In childhood, the prevalence of OSAS is in the

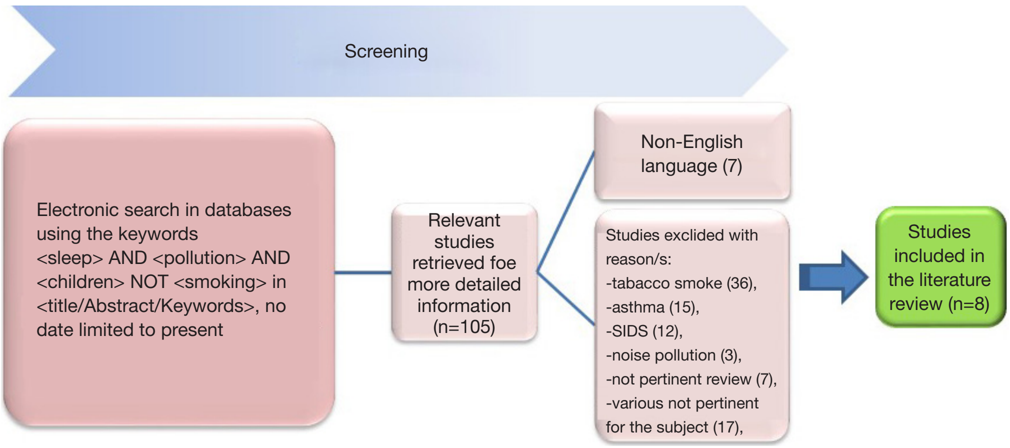

Figure 1 Flow chart of the literature search.

range of 1% to 5%, making this a relatively common disease (3,4). Screening and early treatment are recommended for children at high-risk (5,6).

The complications of OSAS are sleep fragmentation, neurocognitive, behavioural (7), cardiovascular (8) and artery hypertension (9,10). Increased levels of inflammation have been found in children with OSAS (11), linking cardiovascular pathologies with secondary oxidative stress and intermittent hypoxia (12).

Low-levels of tobacco smoke exposure have been associated with increased inflammatory biomarkers in children with asthma (13). The secondhand smoke has been associated with SDB (evidence level 3b) (14). SDB is prevalent in asthmatic children and its prevalence increased with increasing asthma severity (15). Air pollutants, such as NO_2 and particles from diesel exhausts, have adjunct effects on the pathogenesis of asthma and chronic bronchitis, which increased significantly with an increasing traffic pollution load (16). Early traffic-related air pollution exposure (particulate matter—$PM_{2.5}$ and black carbon) was related to asthma and allergic diseases in children (17). Allergies have also been associated with airway inflammation and sleep disturbances in children (18).

Urban outdoor air pollution refers to the air pollution experienced by populations living in and around urban areas. Indoor air pollution refers to the pollutants found in indoors. The main cause of indoor air pollution is inefficient fuel combustion from rudimentary technologies. In adults, increases in SDB indices or percentage of sleep time at less than 90% O_2 saturation and decreases in sleep efficiency were all associated with increases in short-term variations in PM_{10} from urban areas (19).

Aims of the review

We hypothesized that environmental air pollution can play a role in childhood SDB. The aim of this review was to find if existing researches warrant the conclusion of an association between indoor and outdoor environmental pollution (not from voluptuary habit) and SDB in children.

Methods

We conducted an electronic search in Medline (with PubMed interface), Scopus and the ISI Web of Science using the keywords "sleep" or "sleep apnea" or "sleep disordered breathing" and "pollution" and "children" in "Title/Abstract/Keywords", with language restriction (non-English paper) and no date limitation to present. All the articles that responded to the search criteria were systematically reviewed by two authors (Marco Zaffanello and Laura Tenero). Asthma and tobacco smoke's topics were subsequently excluded because they were not pertinent to the review. The references of the selected articles were also hand-searched to identify other pertinent reports. We examined the strength of the evidence according to the Oxford Centre for Evidence-Based Medicine [2011] and the Centre for Evidence-Based Medicine [2009].

Results

A total of 105 published articles were identified, but 97 of these had to be excluded after an accurate reading of the title, abstract or full text (*Figure 1*). More specifically, studies were excluded due to: tobacco smoke (n=36), asthma (n=15), SIDS (n=12), noise pollution (n=3), various non-pertinent reviews (n=7), and articles not pertinent to the subject (n=17). Moreover, 7 papers were not in English, the preferred language. In the end, 8 studies were selected for our analysis (*Table 1*) (20-27).

There were a total of 5,826 enrolled children. Diagnosis of SDB was made subjectively (questionnaires) in six studies (20-23,25,26) and objectively (instrumentation) in two studies, including otherwise healthy (27) or with sickle cell anaemia (24) children, respectively. Five studies quantified the environmental pollution, according to PMs and/or NO_2 (20,23,25-27), or considered the possible differences between rural versus urban areas (24) or before/after indoor intervention (21,22).

Interestingly, two studies showed the beneficial effects of using less-polluting smoke stoves over SDB symptoms in children who were using before traditional smoke stoves (21,22). However, the exposure to nitrogen dioxide (NO_2) in a domestic environment during winter was significantly associated with snoring in children. In particular, high exposure (NO_2 >60 microg/m^3) category showed higher OR of snoring (4.5; 95% CI: 1.4–14.3) than media exposure (30–60 microg/m^3) category (2.5; 95% CI: 0.7–8.7) (25). Furthermore, significantly higher habitual snoring frequencies was found among children residing in neighbourhoods with great pollution exposure (South 24.5% and Central 12.1%) versus lower pollution exposure (North 7.0% and East 7.7%) (26). Moreover, the geographical variation of SDB in children showed higher severity in the South part of the Varese Italian province, particularly in the Western zone close to the airport, matching the PM_{10} and NO_2 distribution (27). All studies were of 3b evidence levels.

A summary of the results observed is as follows: between highly versus less polluted environments, there were significant differences in snoring (25,26), initiating and maintaining sleep (20-22), sleep hyperhidrosis (20), difficulty breathing and apnea (21,23,27), and, for sickle cell anaemia children, mean and minimal nocturnal saturation (24). These results suggest an involvement (grade C) of environmental (not from voluptuary habits) pollution in the worsening of SDB in children.

Discussion

Exposure to environmental pollutants is advocated to be a major risk factor, with increased morbidity and mortality in humans due to acute and chronic airway inflammation (28). $PM_{2.5}$ environmental pollution, in particular black carbon (a traffic-related $PM_{2.5}$ constituent), from proximity to major roadways has been associated with lower lung function in the Boston, USA, area (29). Moreover, from a study conducted at a day-care center in northeastern Seoul, Korea, indoor air pollutants resulting from nearby heavy traffic and a metro station increased the risk of allergy in children (aged 4.4±1.2 years). In addition, toluene from the indoor environment was found to be an aggravating factor. Indeed, symptoms significantly increased by 12.7% (95% CI: −0.01 to 27.1) as indoor levels of toluene increased by 1 ppb (P=0.05) (30). Moreover, long-term exposure to PM_{10} and NO_2 has been associated with cause-specific mortality in the Dutch population (31).

Exposure to smoke impairs ciliary function in pediatric airways. Furthermore, environmental tobacco smoke exposure in children increases the incidence of upper respiratory infections, chronic sinusitis, and chronic otitis media (32). In addition, some studies found a significant association between secondhand smoke and childhood SDB (14,33,34).

Exposure to biomass smoke in rural areas may account for the higher prevalence of snoring and observed apnea by parents and grandparents of students from 20 randomly selected primary schools in urban and rural areas of Turkey. In particular, snoring and the observed apnea were more prevalent among parents and grandparents of students from rural areas [52.6% *vs*. 46.6%, odds ratio (OR) 1.2; P<0.001] than among those from urban areas (16.2% *vs*. 10.1%, OR 1.7; P<0.001) (35). Moreover, annual exposure to air pollution was associated with SDB and to a change in blood pressure among 3,762 Taiwan patients. The association between annual air pollution exposure and diastolic blood pressure accounted for high AHI ($PM_{2.5}$: OR 0.49; P=0.03) and increased BMI ($PM_{2.5}$: OR 0.52; P=0.04) (36). Unfortunately, the above research has not been conducted on a childhood population.

Exposure to indoor and outdoor pollutants may increase the incidence, severity and persistence of SDB in youth. Pathogenic mechanisms can be related to an interaction between genes and various pollutants, which leads to allergies and chronic inflammation of the upper airways (*Figure 2*). Although there are few studies in the topics, the results encourage further investigations. In particular, four related studies concern indoor pollution sources (21-23,25) and four studies concern outdoor pollution sources (20,24,26,27) of which one was designed for children with sickle cell anaemia (24). Two studies showed

Table 1 Summary of the studies regarding indoor and outdoor not-voluptuary-habit pollution and sleep disordered breathing (SDB) in children

Reference	Cases	Nation	Methods of measurement	Evaluation of environmental pollution	Results	Design (evidence levels)
(20)	276 children (42.9% response rate), 121 males (44%), age 9.3±2.0 years	Egypt	Sleep Disturbance Scale for Children questionnaire	Outdoor pollution from industrial sources; PM_{10} exposure in highly versus less polluted	✓ SDB: 9.4% (P=0.692) ✓ Initiating and maintaining sleep: 19.9% (P=0.012) ✓ Excessive somnolence: 24.3% (P=0.184) ✓ Sleep hyperhidrosis: 8.3% (P=0.045)	Cross-sectional study (level 4)
(21)	59 children (62.7% males; mean age 7.76±4.2 years)	Peru	Validated questionnaire	Indoor pollution: before and 12 months after at home installation of Inkawasi wood stove versus traditional stoves	✓ Snoring (52.5% *vs.* 18.2%, P<0.0001) ✓ Nasal congestion (33.9% *vs.* 1.8%, P<0.0001) ✓ Behavioural hyperactivity (28.8% *vs.* 3.8%, P<0.002) ✓ Night-time awakenings (42.4% *vs.* 1.7%, P<0.0001) ✓ Sore throat (38.2% *vs.* 5.5%, P<0.0001) ✓ Breathing through the mouth during the day (33.9% *vs.* 1.8%, P<0.001) ✓ Daytime sleepiness (21.1% *vs.* 1.8%, P<0.003) ✓ Falling asleep at school (14.6% *vs.* 0%, P<0.03)	Prospective survey (level 3-I)
(22)	82 children (40% boys; 8.3±3.2 years) from 56 families	Peru	Sleep-related symptom questionnaires	Indoor pollution; before and 2 years after at home installation the Inkawasi stove versus traditional stoves	✓ Improvement in easiness to fall asleep (29.6% *vs.* 55.6%, P<0.01)	Prospective survey (level 3-I)
(23)	77 children (11.8±1.4 years)	Peru (high altitude)	Validated questionnaire	Indoor pollution: particulate matter 2.5 ($PM_{2.5}$) and carbon monoxide (CO)	✓ Nocturnal awakenings: 48.1% ✓ Repetitive movements and restless sleep: 46.8% ✓ Habitual snoring: 33.8% ✓ Positive caregiver perception of difficulty breathing during sleep (P<0.0001) and presence of apneic episodes (P=0.005, respectively)	Cross-sectional study (level 4)
(24)	Sickle cell anemia (SCA) children: 95 rural, 54 urban and 19 controls	Kenya versus Tanzania	Overnight oximetry	Outdoor pollution: rural (Kenya) versus urban (Tanzania) areas	✓ Mean: SCA Kenyan 99.0% (96.7–99.8%) *vs.* SCA Tanzanian 97.9% (95.4–99.3%) *vs.* Tanzanian controls TC 98.4% (97.5–99.1%); P=0.01 ✓ Minimum nocturnal SpO_2: 92% (86–95%) *vs.* 87% (78.5–91%) *vs.* 90 (83.5–93%), P=0.0001	Cohort study (level 3-II)
(25)	A sub-group of 88/996 children (aged 4–6 years)	Perth metropolitan area (Australia)	School-based respiratory survey	Domestic pollutant assessments (NO_2)	✓ Adjusted ORs of snoring by children with medium (30–60 microg/m^3) and high exposures (> 60 microg/m^3) to NO_2 were 2.5 (95% CI: 0.7–8.7) and 4.5 (95% CI: 1.4–14.3)	Cohort study (level 3-II)
(26)	4,322 (aged 6–12 years) children attending public schools	Tehran, Iran	Questionnaires	Officially published air quality measures by the governmental Air Pollution Control Company	✓ Higher habitual sno-ring frequencies among children residing in neighbourhoods with greatest pollution (24.5% and 12.1% in South and Central neighbourhoods versus 7.0% and 7.7% in North and East neighbourhoods, respectively)	Cohort study (level 3-II)
(27)	754 children	Varese province, Italy	Embla's Embletta Gold sleep system	National officially published air quality measures (PM_{10} and NO_2)	✓ SDB was more severe in the South Varese province, close to the airport	Cohort study (level 3-II)

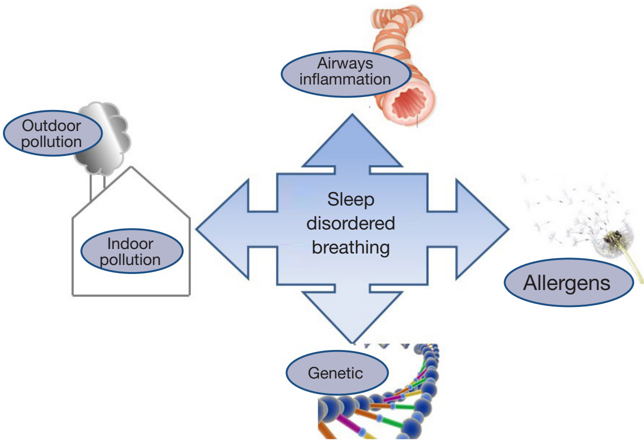

Figure 2 Pathogenetic mechanisms of sleep disordered breathing from environmental pollution.

reductions in SDB following successful air-quality home-based interventions (21,22). Three studies come from the same research team (21-23); but the places of the studies were not the same, so they evaluated different cohorts. However, one communication reported higher severity of SDB in children living close to the airport (27) and two studies showed higher habitual snoring among children living in place with greater environmental pollution (25,26).

A possible limitation comes from one study: sickle cell anemia children are non-healthy and hypoxemic by definition (24). Moreover, other possible limitation of these studies is that they mainly used questionnaires to screen for SDB in children exposed to environmental pollution, this is less reliable as a real measurement of SDB level (37). Therefore, some research has supported the validity of questionnaires and the convergence of polysomnography and questionnaires for assessing SDB (38,39). It is not easy to conduct studies on air pollution and its impact on health in general and especially, on a complicated, multifactorial disease like SDB.

There are a few medical studies on children living in the most industrialized countries, although the global impact of city traffic and industries on the health of the human population is often an issue. Moreover, exposures assessed among the studies are very heterogeneous, making a systematic review more challenging. That heterogeneity of exposure measurements should be acknowledged.

Conclusions

There is currently some interesting information in the literature concerning SDB in children exposed to indoor/outdoor pollution. In particular, some studies reported significant differences between areas with higher and lower pollutants and the interventions on indoor pollution reduced sleep-disordered breathing in children. Therefore, although the relevance of the argument is high, the number of studies and the interest in the subject seems at this time quite limited.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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