Review Article

Sleep disordered breathing in children

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Sleep disordered breathing (SDB) is increasingly being recognised as a cause of morbidity even in young children. With an estimated prevalence of 1 to 4 per cent, SDB results from having a structurally narrow airway combined with reduced neuromuscular tone and increased airway collapsibility. SDB in children differs from adults in a number of ways, including presenting symptoms and treatment. Presentation may differ according to the age of the child. Children have a more varied presentation from snoring and frequent arousals to enuresis to hyperactivity. Those with Down syndrome, midface hypoplasia or neuromuscular disorders are at higher risk for developing SDB. First line definitive treatment in children involves tonsillectomy and adenoidectomy. Rapid maxillary expansion, allergy treatment and continuous positive airway pressure (CPAP) are other options. As untreated SDB results in complications as learning difficulties, memory loss and a long term increase in risk of hypertension, depression and poor growth, it is important to diagnose SDB.

Key words Breathing obstruction - CPAP - children - OSA - sleep disordered breathing - snoring

Introduction

Sleep apnoea in infants was first described in 1975 in relation to sudden infant death syndrome and obstructive sleep apnoea (OSA) was described in 1976 in school children[1]. Since than there has been a significant increase in the recognition of sleep disorders in children. Despite this, there is still a paucity of data on this problem in children and also a lack of training of medical professionals to address the issue. The long term neurocognitive, metabolic and cardiovascular complications and ability to prevent these with early treatment warrant early diagnosis.

Sleep disordered breathing (SDB) encompasses OSA and upper airway resistance syndrome (UARS). OSA is defined as a disorder of breathing during sleep characterized by prolonged partial upper airway obstruction, intermittent complete or partial obstruction (obstructive apnoea or hypopnoea) or both prolonged and intermittent obstruction that disrupt normal ventilation during sleep, normal sleep patterns or both[2,3]. It is agreed that an apnoea-hypopnoea index greater than 1 is abnormal in a child[3,4]. The International Classification of Sleep Disorders 2nd edition (ICSD 2) defines apnoea as a cessation of airflow over two or more respiratory cycles[3]. A specific time in seconds is not applicable to children as normal respirations vary from 12 breaths per minute in an adolescent up to 60 breaths per minute in a newborn. The definition of hypopnoea is more variable across sleep centers, however most agree that a reduction in airflow of at least 30 per cent is required with or without an arousal and/or

oxygen desaturation of 3-4 per cent. UARS has more subtle indications on polysomnography, with increased effort of breathing (measured by increased negative intrathoracic pressure) often leading to an arousal being more prominent than apnoeas/hypopnoeas[5,6].

This article reviews, SDB in children with common symptomatic presentations, and currently accepted treatment options.

Epidemiology

The prevalence of SDB is somewhat difficult to ascertain as definitions vary and the condition has only recently been recognized in children. Snoring has been used as a marker of SDB and the prevalence of snoring in children has been reported as 7.45 per cent in a meta-analysis[7]. This analysis reviewed articles worldwide including USA, Europe, Asia, Middle East and Australia. In the same analysis, parental report of apnoea varied from 0.2 to 4.0 per cent. SDB prevalence has been estimated between 1 and 4 per cent. In terms of ethnicity, African American children have SDB more often than Caucasian children[8-11]. In a study performed at Stanford in USA, Asians had a greater severity of OSA than matched Caucasian counterparts[12]. Gender differences exist in adolescents with males having a higher incidence than females. In pre-pubertal children, there is no significant gender difference[3]. Although SDB can occur at any age, it seems to present most commonly in 2 to 5 yr olds[3,13]. There appears to be some heritability as OSA runs in families. Whether this is due to genetic factors or environmental factors is unclear, but both are likely contributors.

Medical conditions which increase the risk of developing SDB compared to the general population include overweight (including Prader-Willi syndrome), syndromes with midface hypoplasia (*e.g.,* Pierre Robin sequence, Treacher Collins, Crouzon syndrome), large tongue (*e.g.,* Trisomy 21, Beckwith Wiedeman syndrome) and neuromuscular disorders (*e.g.,* cerebral palsy and myotonic dystrophy)[14]. Children with gastroesophageal reflux (GER) are also at increased risk of developing SDB due to airway oedema causing narrowing. Vice versa, SDB can precipitate or worsen GER due to increased negative intrathoracic pressures.

Pathophysiology

In healthy subjects, the transition from wake to sleep involves muscle relaxation and this includes the pharyngeal dilator, intrinsic and extrinsic tongue muscles, which usually stiffen the upper airway in an awake state[15-17]. This relaxation results in collapsibility of the airway and an increased resistance to air flow. These changes may result in an increase in PCO_2 of 3-5mmHg in healthy individuals[15,18].

There are three elements which appear to contribute to the pathophysiology of SDB; anatomical structure, neuromotor tone and inflammation. Patients with SDB have been shown to have a structurally narrow airway when awake which predisposes them to having increased collapsibility and resistance when asleep[19,20]. This leads to reduced or absent airflow resulting in hypopnoeas or apnoeas respectively. The increased resistance to airflow may occur anywhere from the nasopharynx to the hypopharynx and may involve multiple sites. In children, adenotonsillar hypertrophy is a significant factor[21], and it is known that adenotonsillar tissue is at its largest in the first few years of life and then involutes by adolescence and into adulthood.

Anatomical obstruction of the airway at the nasal level is especially important in infants and young children who are obligate nose breathers. Difficulties with nasal breathing, most often due to large adenoids in children, leads to chronic mouth breathing and this can lead to anatomical changes in facial growth. With chronic mouth breathing, the tongue is unable to mould the palate and this results in a narrow, high arched palate and poor maxillary growth, which can also result in narrow nasal passages, narrow dental arches and an anterior crossbite[22]. Children who sleep supine tend to have a smaller maxillary width, possibly because lying supine causes the tongue to maintain a more posterior position[23]. Other changes include the anterior face height increasing and a retrognathic mandible, with shorter maxilla and mandibular length, larger tongue, longer and thicker soft palate and a more inferiorly placed hyoid bone[24-26]. More recently there has been literature regarding lingual tonsils playing a role in obstruction, especially in children who are overweight[27], or have Down syndrome[28,29]. Children with Down syndrome have a number of other factors contributing to development of SDB including macroglossia, glossoptosis, hypopharyngeal collapse, tracheal stenosis, laryngomalacia and recurrent enlarged adenoids[27,28].

Neuromuscular activation also plays a role in the development of SDB. When transitioning from wake to sleep, muscular relaxation occurs and genioglossus tone has been shown to decrease more so in patients with SDB compared to controls. Children with SDB have also been shown to have increased tone

of the same muscle in stage 2 sleep, suggesting a compensation mechanism. Compensation also occurs by increasing respiratory effort, as measured by negative intrathoracic pressure. This may result in an arousal[18]. Children with SDB have blunted ventilatory responses to hypercapnia[30] and higher end-tidal CO_2 when anaesthetized[31], suggesting ventilatory drive is an important factor.

Local and systemic inflammation can contribute to the increased resistance, particularly at the adenotonsillar level[32]. In adults, tissue removed surgically for OSA has had oedema and inflammatory cell infiltration. In children higher levels of cysteinyl leukotrienes have been found in those with SDB[32,33]. At the systemic level, increased CRP levels have been demonstrated in patients with SDB, independent of obesity, which is known to increase CRP levels[34,35]. The mechanism involved is via episodic hypoxia and arousal, which may trigger endothelial dysfunction and systemic inflammation[36,37]. This same process leads to sympathetic activation

which can lead to increased blood pressure[38,39] and also increased insulin resistance[39].

Clinical symptoms

There are three major differences between SDB in children compared to adults. The first is that the presentation in children is much more varied and often difficult to diagnose based on individual symptoms. In children, the individual symptoms often lead a physician to alternate diagnostic pathways, but the constellation of symptoms helps define SDB. The second major difference is that excessive daytime sleepiness is not a significant symptom in children as it is in adults. Only 7 per cent of children with SDB present to a physician with excessive sleepiness during the day[40]. Rather, children tend to become hyperactive. The third difference in children is that symptoms change with age (Table). Some symptoms may be present at any age, such as snoring and night time awakening, while others are seen in certain age groups.

Table. Symptoms of sleep disordered breathing in children by age

Infants (3-12 months)	Toddlers (1-3 yr)	Pre-school (3-5 yr)	School (5-18 yr)
Snoring	Snoring	Snoring	Snoring
Witnessed apnoeas	Witnessed apnoeas	Witnessed apnoeas	Witnessed apnoeas
Frequent arousals	Frequent arousals	Frequent arousals	Frequent arousals
Mouth breathing/dry mouth	Mouth breathing/dry mouth	Mouth breathing/dry mouth	Mouth breathing/dry mouth
Nocturnal sweating	Nocturnal sweating	Nocturnal sweating	Nocturnal sweating
Failure to thrive	Failure to thrive	Failure to thrive	Failure to thrive
Nasal congestion	Nasal congestion	Nasal congestion	Nasal congestion
Hyper extended neck	Hyper extended neck	Hyper extended neck	Hyper extended neck
Recurrent otitis media/Upper Respiratory Infection (URI)	Recurrent otitis media/Upper Respiratory Infection (URI)	Recurrent otitis media/Upper Respiratory Infection (URI)	Recurrent otitis media/Upper Respiratory Infection (URI)
Noisy breathing	Noisy breathing	Drooling	Nightmares
Poor suck	Sleep terrors	Sleep terrors	Sleeptalking
Apparent life threatening event (ALTE)	Confusional arousal	Confusional arousal	Confusional arousal
Poor day/night cycle	Irritability	Sleepwalking	Sleepwalking
Stridor	Daytime sleepiness	Daytime sleepiness/ persistent naps	Daytime sleepiness
Breath holding spells	Restless sleep	Restless sleep	Restless sleep
		Enuresis	Enuresis
		Hyperactivity, inattention	Hyperactivity, inattention
		Difficulty waking up in morning	Difficulty waking up in morning
		Drooling	Drooling
		Morning headache	Morning headache
		Sleep in knee-chest position	Insomnia
			Learning difficulties
			Delayed puberty
			Crossbite, malocclusion (class II or III), overcrowding of teeth
			Mood disturbance *eg*., depression
			DSPS
			Hypertension

DSPS, Delayed sleep phase syndrome
Adapted from Ref. 71

Snoring occurs when there is an imbalance between negative intrathoracic pressure and the oropharyngeal dilator muscles[41]. Habitual snoring is estimated to occur in 10 per cent of children. The American Academy of Pediatrics clinical practice guideline states that any child who snores should have a thorough sleep history and exam done to determine those at increased risk for SDB who may then go on to be investigated[42].

Parents may notice the child stops breathing at night. This presentation is less common than expected as parents may sleep in another room or may also be asleep and not observe apnoeas. Apparent life threatening events (ALTE) may be another presentation of witnessed apnoeas. Periodic breathing may be normal in infants but all apnoeas should be further investigated to determine the cause.

Young children with frequent arousals may be delayed in presentation due to the normal phenomenon of night waking for feeds and behavioural associations that occur with this. Mouth breathing has been associated with structural changes in the face, known as 'adenoid facies'. Dry mouth is associated with mouth breathing at night and is often revealed by asking the patient if they keep water by the bedside. Night sweating is a sign of increased effort of breathing at night and failure to thrive may be the presenting symptom also due to increased work of breathing and relative deficiency of growth hormone[43]. The most common cause of nasal obstruction is enlargement of adenoids but nasal allergies can also be a significant contributing factor and should be asked for on history. Some children may compensate for a narrowed airway by sleeping with their neck hyper-extended to give the best chance of maintaining their airway while asleep. Sleeping in the knee-chest position is done for the same reason and is normal in infants, but abnormal in pre-school children. Children with SDB are thought to be at increased risk for recurrent upper airway infections such as otitis media and tonsillitis[44].

Infants: SDB presents less commonly in this age group. Parents often complain that their child has 'noisy breathing' rather than snoring. A poor suck may be present due to fatigability or hypotonia which can predispose to SDB. As previously mentioned, infants may present with ALTE and have investigations for cardiac arrhythmias, seizures, gastro-oesophageal reflux, *etc*. all of which would be normal. They occasionally present with stridor, due to contributing layngomalacia or vocal cord paralysis[45].

Toddlers: Snoring becomes more common at this age (2 to 5 yr) when the tonsils and adenoids are thought to relatively narrow the airway the most[46]. Children at this age present with sleep terrors or confusional arousals, as well as moving around the bed in restless sleep in order to maintain their airway. Children at this age rarely complain of daytime sleepiness and more often will be 'hyperactive' and irritable as well as have insomnia.

Pre-school: This age group tends to present in a similar fashion to toddlers, but drooling may become more apparent and nocturnal enuresis becomes an issue. Enuresis alone at this age is not a concerning symptom as it occurs in up to 15 per cent of normal children[47], however in conjunction with other features such as snoring or restless sleep it may point to SDB. As children start to go to kindergarten and school and need to wake up at the same time each morning, difficulties waking the child due to sleepiness become more apparent. In this age group, children are also able to communicate symptoms and may start to complain of headaches on awakening in the morning. Sleeping in the knee-chest position at this age is abnormal and indicative of airway collapsibility.

School- age: Children may still present with snoring, night waking, a parasomnia, or nocturnal enuresis as in younger age groups, but the diversity of presentation increases. Long term sequelae start to become apparent in this age group, with learning difficulties secondary to poor concentration and impaired short term memory become apparent. Specific areas of difficulty have been visiospatial problem solving, memory and arithmetic[48] as well as executive function[49]. It has been shown that children who snore in early childhood tend to have lower academic performance than those who do not snore, independent of having treatment with tonsillectomy and adenoidectomy. School aged children also have symptoms of hyperactivity and inattention and may be labelled with attention deficit hyperactivity disorder (ADHD)[50]. Studies have shown an increase in SDB symptoms in those diagnosed with ADHD[51]. As children obtain secondary teeth, bite issues become more apparent and a crossbite or malocclusion may be the presenting problem to dentists, who also need to be aware of SDB. If a patient has orthodontia for overlapping teeth, or requires teeth to be removed due to lack of space, this is a symptom of having a narrow airway.

In older children and adolescents, mood disturbance such as depression becomes more apparent. It has

been shown that children with SDB tend to have more internalizing symptoms such as anxiety, depression, being withdrawn or having somatic complaints[52]. They also report poorer quality of life in physical health, social and emotional functioning, and at school[53]. Although normal adolescents may develop delayed sleep phase syndrome (DSPS) in which they tend to go to bed later, this may be a symptom of SDB, particularly if the child feels sleepy during the day even if allowed to sleep at the preferred later bedtime and wake up at any time (*e.g.,* when on vacation). Although in adults it is well known that untreated SDB can lead to hypertension, there has been conflicting evidence of whether it occurs in children. A meta-analysis of 5 studies found that hypertension was not found in children with SDB, however the study samples were small[54]. Another study by Bixler *et al*[55] with a large cohort found that systolic blood pressure is proportional to the apnoea hypopnoea index in school aged children (kindergarten to 5th grade). There has also been evidence that asthma and wheezing are associated with SDB[56].

Physical signs

The general, appearance of the child should be noted first, including if the child is overweight or appears to have failure to thrive, which can be determined by growth charts. The blood pressure should also be taken, with hypotension, particularly orthostatic, a sign of UARS and hypertension may be indicative of complications of SDB. A neck circumference of greater than 40 cm increases the risk of SDB[57].

Structural narrowing can occur anywhere from the nasopharynx to the hypopharynx. Nasal obstruction may be in the form of enlarged turbinates due to nasal allergies, or a deviated septum, which may be evidenced by asymmetry of the nostrils. Internal nasal valve collapse also causes narrowing of the airway. Most commonly, however, in children, the adenoids are the source of airway narrowing at the nasopharyngeal level. Enlarged adenoids may lead to mouth breathing which, over time, can cause changes in the facial structure, such as poor maxillary development which leads to a crossbite, high arched and narrow hard palate and increased facial height, known as 'adenoid facies'[22]. These structural changes lead to further narrowing of the airway at the oropharyngeal level and increase the severity of SDB. Any syndrome involving midface hypoplasia, such as Pierre-Robin sequence or Crouzon syndrome produces similar results and is at higher risk for developing SDB.

When examining the oral airway, Mallampati staging[57] is useful in determining a small airway. Mallampati score is based on visualization of the airway on opening of the mouth with tongue protruded. A class 1 means hard palate, soft palate, tonsillar pillars and uvula are completely visualized. In class 2, the uvula and tonsillar pillars are partially visualized, class 3 the soft and hard palate are seen and class 4 only the hard palate is visualized[58]. A Mallapati score of 3 or 4 is indicative of a small airway[59]. The tonsils should be examined in terms of size and classified[58]. It is important to note that the size of the tonsils does not always correlate with the presence or severity of SDB, especially if tonsils are not large[60]. The size of the tongue should be noted as a relatively large tongue may indicate mandibular deficiency. Macroglossia in children with Down syndrome or Beckwith Weideman syndrome are risk factors for SDB. Other features suggestive of a narrow airway include a high arched and narrow palate, and a torus palatinus (a ridge in the midline of the hard palate indicating overlap of the bony plates). Teeth markings on the buccal mucosa are suggestive, as is overlapping of the teeth, particularly of the lower jaw. When examining the bite, a crossbite or significant overjet or overbite are signs of maxillary or mandibular deficiency. It is also important to examine the patient's profile as this can determine maxillary deficiency and /or retrognathia or micrognathia.

Diagnosis

The gold standard for diagnosing SDB is in laboratory polysomnography (PSG)[42] which may include electroencephalogram (EEG) leads, electrooculogram (EOG), electromyogram (EMG), nasal pressure/oral thermistor, electrocardiogram (ECG), pulse oximetry, chest and abdominal excursion belts, plethysmography, limb leads, end tidal or transcutaneous CO_2, oesophageal manometry and audio/video taping. The information provided from these parameters can evaluate the sleep architecture, breathing events during sleep (including apnoeas, hypopnoeas, flow limitation, respiratory effort related arousals), desaturation and periodic limb movements, as well as autonomic changes and respiratory effort. An apnoea/hypopnoea index (AHI) of greater than 1 event per hour is considered abnormal in a child. SDB is diagnosed by frequent arousals with increased respiratory effort, hypercapnia, apnoea with desaturation or markedly negative oesophageal pressure swings. (ICD 2). Night to night variation has been shown in adults, however, one night of polysomnography is usually enough to make a diagnosis in children[61].

Given that PSG is expensive and often difficult to obtain, primary care physicians look to other alternatives for diagnosis of SDB. Questionnaires have been developed to try to determine those at higher risk of SDB, however, evaluation of these questionnaires has shown that these do not reliably differentiate those with SDB from those without. This may be because relying on parent report is not reliable as events may be occurring during sleep while the parents are also asleep[62]. Also children with hypopnoeas and flow limitation, compared to apnoeas, may not show signs of obstruction visible to parents.

Audio and video taping at home have been studied as alternatives. Audio taping has been shown to have up to 75 per cent predictive value[42,63] and video taping up to 83 per cent[64]. However, these studies will detect those with significant apnoea but again will not detect those with hypopnoea or flow limitation.

Overnight pulse oximetry is used in some centers, particularly where PSG is not available. This again is a sensitive measure if the test is positive, however SDB cannot be ruled out if the test is negative[65]. If pulse oximetry is used, the averaging time should be short. Standard oximeters have a sampling time over 3 sec and in a young child with short respiratory cycles, desaturations may be missed[45].

Ambulatory studies (portable monitoring) are becoming more popular as technology improves. The American Academy of Sleep Medicine currently recommends the use of home monitoring only if there is a high probability of moderate or severe sleep apnoea. Other indications include those unable to do an in lab study due to critical illness or immobility, or to monitor the response to an oral appliance, surgery or weight loss. Portable monitoring should only be done in conjunction with a physician evaluation to identify those who are at high risk (*e.g.* pulmonary, cardiovascular or neuromuscular disease) or likely to have co-morbid sleep disorders. These patient groups are not suitable to have home monitoring. The recommendations also specify that portable monitoring should not be used as a screening device[66].

Audio/video taping and overnight pulse oximetry may be used as first line investigations where polysomnography is not available, however if the study is negative, SDB cannot be ruled out and polysomnography should be performed.

Treatment

Children differ somewhat to adults in treatment options. Once SDB has been diagnosed, the accepted first line treatment in children is tonsillectomy and adenoidectomy (T & A). Because SDB is a result of structural issues as well as neuromotor tone, even children with relatively small tonsils, or those at risk for SDB for other reasons, such as obesity or Down syndrome may benefit from tonsillectomy and adenoidectomy and should be evaluated by an otolaryngologist. Studies have shown that performing both tonsillectomy and adenoidectomy gives superior results to performing either procedure alone[67]. Children at high risk, such as those with severe OSA and desaturation, craniofacial or neuromuscular disorders or young children (<3 yr) should be observed overnight with pulse oximetry[42]. The success rate of T & A was previously reported as 80 per cent[68] however another study has suggested that cure is achieved in less than 50 per cent with persistent SDB occurring because of other facial structural issues such as retrognathia, enlarged nasal turbinates and a deviated septum[59]. Because of this, it is important that all children have follow up polysomnography after T & A (usually 2-3 months afterwards to allow for resolution of oedema). Complications from T & A are anaesthetic risk and risk of haemorrhage or infection[69]. More common complications include poor oral intake post operatively and pain.

When there is residual SDB after T & A is performed, other factors should be evaluated to decide the next course of action. For children with a high arched palate, rapid maxillary expansion has been shown to improve AHI[70]. This procedure involves application of a distractor to the hard palate anchored to the molars. The distractor applies pressure on the lateral walls of the dental arch to widen the maxilla and also widens the base of the nose and increases the nasal passages, which can be helpful if the child has a deviated septum or narrow nasal passages[71]. It is an orthodontic procedure with expansion occurring within 3 weeks and the device remaining *in situ* for 3 months to allow for remodeling of the cartilage. Mandibular distraction osteogenesis is an option for older children in whom cartilage has fused. This is reserved for those who do not require maxillomandibular advancement but for whom T & A is not sufficient.

Treatment of enlarged turbinates is also important in increasing airway diameter. This may be in the form of radiofrequency ablation[22] or treatment of allergies

with intranasal steroids and/or immunotherapy in the longer term[72]. Some studies have investigated the use of monteleukast given the possible inflammatory factors causing SDB and this has been shown to reduce AHI, including after T & A[73]. More investigation of this medication is warranted.

Continuous positive airway pressure (CPAP) is an option for children, as in adults. It is useful for children who are unable to have T&A or who have residual SDB post operatively. In the US, a lack of availability of masks for infants and small children make this somewhat difficult, however paediatric masks are more readily available in other countries. If a child is to be started on CPAP, desensitization is recommended. This involves positive reinforcement, education of the parents and child and gradual exposure to the CPAP[74]. One study described starting by placing the mask amongst the child's toys and rewarding him for playing with it. This was the followed by placement on the face for increasing periods of time and then adding headgear and finally pressure[75]. Complications of CPAP use can include nasal congestion and dry mouth.

In overweight children, weight control is an important treatment modality. In children who are still growing, weight maintenance may be more appropriate than weight loss as the child will continue to increase height. A recent study in adolescents showed that 72 per cent (13 out of 21) overweight children with SDB were able to reduce their AHI to <2 with weight loss[76].

Oral appliances have been used in adults but have concerns with altering the bite in children prevents its use. Maxillomandibular advancement is an option for adolescents if other treatment options have not been sufficient. This is major surgery which requires an experienced maxillofacial surgeon familiar with the procedure to perform. Finally, tracheostomy is an option for those in whom other treatment modalities are not possible or fail.

Complications

Untreated SDB has been shown to have neurocognitive and cardiovascular complications as well as disturbances of growth and mood.

It is well known that SDB results in daytime sleepiness. However, most children do not present with such complaints and are more likely to be hyperactive or inattentive, often being diagnosed with ADHD[77]. Chervin et al[78] showed that 50 per cent had resolution of ADHD symptoms after treatment with T & A. If

children are not diagnosed, this has a negative impact on school performance and intellectual function[49,79]. In particular, short term memory and concentration ability are affected[48,80].

Cardiovascular complications are well established in adults but only a few studies have evaluated children. Hypertension occurs more frequently in children with SDB compared to those without SDB[81]. It is hypothesized that hypertension in SDB is due to autonomic activation which occurs with sleep fragmentation and intermittent hypoxia[38,82]. Endothelial dysfunction is thought to be related to an inflammatory response[83]. Hypertension and endothelial dysfunction with fatty streaks and fibrous plaques have also been shown to occur in overweight children, which is an added risk factor. Intermittent hypoxia may also lead to increased pulmonary artery pressures which can eventually lead to cor pulmonale. This is seen less often now with earlier treatment of SDB[84].

The increased work of breathing and load on the heart with airway obstruction requires energy. This may take from energy used for growth and children may diminish in weight gain as well as height. Weight gain and increase in growth hormone secretion have been shown to occur after T & A for SDB[24,85]. Links between SDB and depression have also been made in adults, and this may correspond to internalization in children (e.g. withdrawal, somatic complaints)[80].

Conclusion

Sleep disordered breathing in children is more common than previously recognized. It has a variety of presenting symptoms other than snoring and so clinicians must be aware of this constellation. Adenotonsillar hypertrophy is the most common structural cause for SDB in children but it is increasingly being recognized that treatment of this issue alone does not resolve the problem. Other techniques for treatment include rapid maxillary expansion, radiofrequency ablation of the nasal turbinates, CPAP and weight loss in the overweight. If left untreated, SDB in children can lead to long term learning deficits, memory impairment, poor growth and risk for cardiovascular disease as well as mood disorders.

References

1. Guilleminault C, Eldridge FL, Simmons FB, Dement WC. Sleep apnoea in eight children. *Pediatrics* 1976; *58* : 23-30.

2. Standards and indications for cardiopulmonary sleep studies in children. American Thoracic Society. *Am J Respir Crit Care Med* 1996; *153* : 866-78.

3. Medicine AAoS, ed. *The international classification of sleep disorders*, 2nd ed. *Diagnostic and coding manual*. Westchester, Illinois: American Academy of Sleep Medicine; 2005.

4. Witmans MB, Keens TG, Davidson Ward SL, Marcus CL. Obstructive hypopneas in children and adolescents: normal values. *Am J Respir Crit Care Med* 2003; *168* : 1540.

5. Chervin RD, Guilleminault C. Obstructive sleep apnoea and related disorders. *Neurol Clin* 1996; *14* : 583-609.

6. Guilleminault C, Stoohs R, Clerk A, Cetel M, Maistros P. A cause of excessive daytime sleepiness. The upper airway resistance syndrome. *Chest* 1993; *104* : 781-7.

7. Lumeng JC, Chervin RD. Epidemiology of pediatric obstructive sleep apnoea. *Proc Am Thorac Soc* 2008; *5* : 242-52.

8. Johnson EO, Roth T. An epidemiologic study of sleep-disordered breathing symptoms among adolescents. *Sleep* 2006; *29* : 1135-42.

9. Rosen CL, Larkin EK, Kirchner HL, Emancipator JL, Bivins SF, Surovec SA, *et al*. Prevalence and risk factors for sleep-disordered breathing in 8- to 11-year-old children: association with race and prematurity. *J Pediatr* 2003; *142* : 383-9.

10. Redline S, Tishler PV, Schluchter M, Aylor J, Clark K, Graham G. Risk factors for sleep-disordered breathing in children. Associations with obesity, race, and respiratory problems. *Am J Respir Crit Care Med* 1999; *159* : 1527-32.

11. Montgomery-Downs HE, Gozal D. Sleep habits and risk factors for sleep-disordered breathing in infants and young toddlers in Louisville, Kentucky. *Sleep Med* 2006; *7* : 211-9.

12. Ong KC, Clerk AA. Comparison of the severity of sleep-disordered breathing in Asian and Caucasian patients seen at a sleep disorders center. *Respir Med* 1998; *92* : 843-8.

13. Hoban TF, Chervin RD. Pediatric sleep-related breathing disorders and restless legs syndrome: how children are different. *Neurologist* 2005; *11* : 325-37.

14. Mitchell R. Sleep-disordered breathing in children. *Mo Med* 2008; *105* : 267-9.

15. Horner RL. Pathophysiology of obstructive sleep apnoea. *J Cardiopulm Rehabil Prev* 2008; *28* : 289-98.

16. Horner RL. Motor control of the pharyngeal musculature and implications for the pathogenesis of obstructive sleep apnoea. *Sleep* 1996; *19* : 827-53.

17. Gozal D. Obstructive sleep apnoea in children: implications for the developing central nervous system. *Semin Pediatr Neurol* 2008; *15* : 100-6.

18. Katz ES, D'Ambrosio CM. Pathophysiology of pediatric obstructive sleep apnoea. *Proc Am Thorac Soc* 2008; *5* : 253-62.

19. Gozal D, Burnside MM. Increased upper airway collapsibility in children with obstructive sleep apnoea during wakefulness. *Am J Respir Crit Care Med* 2004; *169* : 163-7.

20. Marcus CL, McColley SA, Carroll JL, Loughlin GM, Smith PL, Schwartz AR. Upper airway collapsibility in children with obstructive sleep apnoea syndrome. *J Appl Physiol* 1994; *77* : 918-24.

21. Arens R, McDonough JM, Costarino AT, *et al*. Magnetic resonance imaging of the upper airway structure of children with obstructive sleep apnoea syndrome. *Am J Respir Crit Care Med* 2001; *164* : 698-703.

22. Sullivan S, Li K, Guilleminault C. Nasal obstruction in children with sleep-disordered breathing. *Ann Acad Med Singapore* 2008; *37* : 645-8.

23. Pirila K, Tahvanainen P, Huggare J, Nieminen P, Lopponen H. Sleeping positions and dental arch dimensions in children with suspected obstructive sleep apnoea syndrome. *Eur J Oral Sci* 1995; *103* : 285-91.

24. Peltomaki T. The effect of mode of breathing on craniofacial growth--revisited. *Eur J Orthod* 2007; *29* : 426-9.

25. Johal A, Patel SI, Battagel JM. The relationship between craniofacial anatomy and obstructive sleep apnoea: a case-controlled study. *J Sleep Res* 2007; *16* : 319-26.

26. Zonato AI, Martinho FL, Bittencourt LR, de Oliveira Campones Brasil Or, Gregorio LC, Tufik S. Head and neck physical examination: comparison between nonapneic and obstructive sleep apnoea patients. *Laryngoscope* 2005; *115* : 1030-4.

27. Guimaraes CVA, Kalra M, Donnelly LF, et al. The frequency of lingual tonsil enlargement in obese children. *AJR Am J Roentgenol* 2008; *190* : 973-5.

28. Donnelly LF, Shott SR, LaRose CR, Chini BA, Amin RS. Causes of persistent obstructive sleep apnoea despite previous tonsillectomy and adenoidectomy in children with down syndrome as depicted on static and dynamic cine MRI. *AJR Am J Roentgenol* 2004; *183* : 175-81.

29. Phillips DE, Rogers JH. Down's syndrome with lingual tonsil hypertrophy producing sleep apnoea. *J Laryngol Otol* 1988; *102* : 1054-5.

30. Gozal D, Arens R, Omlin KJ, Ben-Ari JH, Aljadeff G, Harper RM, *et al*. Ventilatory response to consecutive short hypercapnic challenges in children with obstructive sleep apnoea. *J Appl Physiol* 1995; *79* : 1608-14.

31. Waters KA, McBrien F, Stewart P, Hinder M, Wharton S. Effects of OSA, inhalational anesthesia, and fentanyl on the airway and ventilation of children. *J Appl Physiol* 2002; *92* : 1987-94.

32. Goldbart AD, Tal A. Inflammation and sleep disordered breathing in children: a state-of-the-art review. *Pediatr Pulmonol* 2008; *43* : 1151-60.

33. Peters-Golden M, Henderson WR. Leukotrienes. *N Engl J Med* 2007; *357* : 1841-54.

34. Tauman R, Ivanenko A, O'Brien LM, Gozal D. Plasma C-reactive protein levels among children with sleep-disordered breathing. *Pediatrics* 2004; *113* : e564-9.

35. Kheirandish-Gozal L, Capdevila OS, Tauman R, Gozal D. Plasma C-reactive protein in nonobese children with obstructive sleep apnoea before and after adenotonsillectomy. *J Clin Sleep Med* 2006; *2* : 301-4.

36. Apostolidou MT, Alexopoulos EI, Chaidas K, Ntamagka G, Karathanasi A, Apostolidis TI, *et al*. Obesity and persisting sleep apnoea after adenotonsillectomy in Greek children. *Chest* 2008; *134* : 1149-55.

37. Kato M, Roberts-Thomson P, Phillips BG, Haynes WG, Winnicki M, Accurso V, *et al*. Impairment of endothelium-dependent vasodilation of resistance vessels in patients with obstructive sleep apnoea. *Circulation* 2000; *102* : 2607-10.

38. O'Brien LM, Gozal D. Autonomic dysfunction in children with sleep-disordered breathing. *Sleep* 2005; *28* : 747-52.

39. Punjabi NM, Shahar E, Redline S, Gottlieb DJ, Givelber R, Resnick HE. Sleep-disordered breathing, glucose intolerance, and insulin resistance : the Sleep Heart Health Study. *Am J Epidemiol* 2004; *160* : 521-30.

40. Gozal D, Wang M, Pope DW. Objective sleepiness measures in pediatric obstructive sleep apnoea. *Pediatrics* 2001; *108* : 693-7.

41. Ng DK, Chow P-Y, Chan C-H, Kwok K-L, Cheung JM, Kong FY. An update on childhood snoring. *Acta Paediatr* 2006; *95* : 1029-35.

42. Clinical practice guideline : diagnosis and management of childhood obstructive sleep apnoea syndrome. *Pediatrics* 2002; *109* : 704-12.

43. Nieminen P, Lopponen T, Tolonen U, Lanning P, Knip M, Lopponen H. Growth and biochemical markers of growth in children with snoring and obstructive sleep apnoea. *Pediatrics* 2002; *109* : e55.

44. Guilleminault C. Obstructive sleep apnoea syndrome and its treatment in children: areas of agreement and controversy. *Pediatr Pulmonol* 1987; *3* : 429-36.

45. Halbower AC, Ishman SL, McGinley BM. Childhood obstructive sleep-disordered breathing: a clinical update and discussion of technological innovations and challenges. *Chest* 2007; *132* : 2030-41.

46. Jeans WD, Fernando DC, Maw AR, Leighton BC. A longitudinal study of the growth of the nasopharynx and its contents in normal children. *Br J Radiol* 1981; *54* : 117-21.

47. Stone J, Malone PSJ, Atwill D, McGrigor V, Hill CM. Symptoms of sleep-disordered breathing in children with nocturnal enuresis. *J Pediatr Urol* 2008; *4* : 197-202.

48. Giordani B, Hodges EK, Guire KE, Ruzicka DL, Dillon JE, Weatherly RA, *et al*. Neuropsychological and behavioral functioning in children with and without obstructive sleep apnoea referred for tonsillectomy. *J Int Neuropsychol Soc* 2008; *14* : 571-81.

49. Gottlieb DJ, Chase C, Vezina RM, et al. Sleep-disordered breathing symptoms are associated with poorer cognitive function in 5-year-old children. *J Pediatr* 2004; *145* : 458-64.

50. Huang Y-S, Guilleminault C, Li H-Y, Yang C-M, Wu Y-Y, Chen N-H. Attention-deficit/hyperactivity disorder with obstructive sleep apnoea: a treatment outcome study. *Sleep Med* 2007; *8* : 18-30.

51. Corkum P, Tannock R, Moldofsky H. Sleep disturbances in children with attention-deficit/hyperactivity disorder. *J Am Acad Child Adolesc Psychiatry* 1998; *37* : 637-46.

52. Aronen ET, Liukkonen K, Simola P, Virkkula P, Uschakoff A, Korkman M, *et al*. Mood is associated with snoring in preschool-aged children. *J Dev Behav Pediatr* 2009; *30* : 107-14.

.53. Crabtree VM, Varni JW, Gozal D. Health-related quality of life and depressive symptoms in children with suspected sleep-disordered breathing. *Sleep* 2004; *27* : 1131-8.

54. Zintzaras E, Kaditis AG. Sleep-disordered breathing and blood pressure in children: a meta-analysis. *Arch Pediatr Adolesc Med* 2007; *161* : 172-8.

55. Bixler EO, Vgontzas AN, Lin HM, Liao D, Calhoun S, Fedok F, *et al*. Blood pressure associated with sleep-disordered breathing in a population sample of children. *Hypertension* 2008; *52* : 841-6.

56. Sulit LG, Storfer-Isser A, Rosen CL, Kirchner HL, Redline S. Associations of obesity, sleep-disordered breathing, and wheezing in children. *Am J Respir Crit Care Med* 2005; *171* : 659-64.

57. Liistro G, Rombaux P, Belge C, Dury M, Aubert G, Rodenstein DO. High Mallampati score and nasal obstruction are associated risk factors for obstructive sleep apnoea. *Eur Respir J* 2003; *21* : 248-52.

58. Friedman M, Tanyeri H, La Rosa M, Landsberg R, Vaidyanathan K, Pieri S, *et al*. Clinical predictors of obstructive sleep apnoea. *Laryngoscope* 1999; *109* : 1901-7.

59. Guilleminault C, Huang Y-s, Glamann C, Li K, Chan A. Adenotonsillectomy and obstructive sleep apnoea in children: a prospective survey. *Otolaryngol Head Neck Surg* 2007; *136* : 169-75.

60. Fernbach SK, Brouillette RT, Riggs TW, Hunt CE. Radiologic evaluation of adenoids and tonsils in children with obstructive sleep apnoea : plain films and fluoroscopy. *Pediatr Radiol* 1983; *13* : 258-65.

61. Katz ES, Greene MG, Carson KA, Galster P, Loughlin GM, Carroll J*, et al*. Night-to-night variability of polysomnography in children with suspected obstructive sleep apnoea. *J Pediatr* 2002; *140* : 589-94.

62. Goh DY, Galster P, Marcus CL. Sleep architecture and respiratory disturbances in children with obstructive sleep apnoea. *Am J Respir Crit Care Med* 2000; *162* : 682-6.

63. Lamm C, Mandeli J, Kattan M. Evaluation of home audiotapes as an abbreviated test for obstructive sleep apnoea syndrome (OSAS) in children. *Pediatr Pulmonol* 1999; *27* : 267-72.

64. Sivan Y, Kornecki A, Schonfeld T. Screening obstructive sleep apnoea syndrome by home videotape recording in children. *Eur Respir J* 1996; *9* : 2127-31.

65. Brouillette RT, Morielli A, Leimanis A, Waters KA, Luciano R, Ducharme FM. Nocturnal pulse oximetry as an abbreviated testing modality for pediatric obstructive sleep apnoea. *Pediatrics* 2000; *105* : 405-12.

66. Collop NA, Anderson WM, Boehlecke B, Claman D, Goldberg R, Gottlieb DJ, *et al*. Clinical guidelines for the use of unattended portable monitors in the diagnosis of obstructive sleep apnoea in adult patients. Portable Monitoring Task Force of the American Academy of Sleep Medicine. *J Clin Sleep Med* 2007; *3* : 737-47.

67. Guilleminault C, Li KK, Khramtsov A, Pelayo R, Martinez S. Sleep disordered breathing : surgical outcomes in prepubertal children. *Laryngoscope* 2004; *114* : 132-7.

68. Capdevila OS, Kheirandish-Gozal L, Dayyat E, Gozal D. Pediatric obstructive sleep apnoea: complications, management, and long-term outcomes. *Proc Am Thorac Soc* 2008; *5* : 274-82.

69. Tami TA, Parker GS, Taylor RE. Post-tonsillectomy bleeding: an evaluation of risk factors. *Laryngoscope* 1987; *97* : 1307-11.

70. Pirelli P, Saponara M, Guilleminault C. Rapid maxillary expansion in children with obstructive sleep apnoea syndrome. *Sleep* 2004; *27* : 761-6.

71. Guilleminault C, Lee JH, Chan A. Pediatric obstructive sleep apnoea syndrome. *Arch Pediatr Adolesc Med* 2005; *159* : 775-85.

72. Brouillette RT, Manoukian JJ, Ducharme FM, Oudjhane K, Earle LG, Ladan S*, et al*. Efficacy of fluticasone nasal spray for pediatric obstructive sleep apnoea. *J Pediatr* 2001; *138* : 838-44.

73. Kheirandish L, Goldbart AD, Gozal D. Intranasal steroids and oral leukotriene modifier therapy in residual sleep-disordered breathing after tonsillectomy and adenoidectomy in children. *Pediatrics* 2006; *117* : e61-6.

74. Halbower AC, McGinley BM, Smith PL. Treatment alternatives for sleep-disordered breathing in the pediatric population. *Curr Opin Pulm Med* 2008; *14* : 551-8.

75. Kirk VG, O'Donnell AR. Continuous positive airway pressure for children : a discussion on how to maximize compliance. *Sleep Med Rev* 2006; *10* : 119-27.

76. Verhulst SL, Franckx H, Van Gaal L, De Backer W, Desager K. The effect of weight loss on sleep-disordered breathing in obese teenagers. *Obesity* 2009; *17* : 1178-83.

77. Corkum P, Tannock R, Moldofsky H, Hogg-Johnson S, Humphries T. Actigraphy and parental ratings of sleep in children with attention-deficit/hyperactivity disorder (ADHD). *Sleep* 2001; *24* : 303-12.

78. Chervin RD, Ruzicka DL, Giordani BJ, Weatherly RA, Dillon JE, Hodges EK, *et al*. Sleep-disordered breathing, behavior, and cognition in children before and after adenotonsillectomy. *Pediatrics* 2006; *117* : e769-78.

79. Gozal D. Sleep-disordered breathing and school performance in children. *Pediatrics* 1998; *102* : 616-20.

80. Mitchell RB, Kelly J. Outcomes and quality of life following adenotonsillectomy for sleep-disordered breathing in children. *ORL J Otorhinolaryngol Relat Spec* 2007; *69* : 345-8.

81. Marcus CL, Greene MG, Carroll JL. Blood pressure in children with obstructive sleep apnoea. *Am J Respir Crit Care Med* 1998; *157 :* 1098-103.

82. Baharav A, Kotagal S, Rubin BK, Pratt J, Akselrod S. Autonomic cardiovascular control in children with obstructive sleep apnoea. *Clin Auton Res* 1999; *9* : 345-51.

83. Hansson GrK. Inflammation, atherosclerosis, and coronary artery disease. *N Engl J Med* 2005; *352* : 1685-95.

84. Tauman R, Gozal D. Obesity and obstructive sleep apnoea in children. *Paediatr Respir Rev* 2006*; 7* : 247-59.

85. Bar A, Tarasiuk A, Segev Y, Phillip M, Tal A. The effect of adenotonsillectomy on serum insulin-like growth factor-I and growth in children with obstructive sleep apnoea syndrome. *J Pediatr* 1999; *135* : 76-80.

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