Sleep Breath
DOI 10.1007/s11325-011-0595-9

REVIEW

Mandibular advancement devices are an alternative and valid treatment for pediatric obstructive sleep apnea syndrome

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Received: 15 June 2011 / Revised: 7 September 2011 / Accepted: 12 September 2011

Abstract
Background Orthodontic and craniofacial abnormalities have often been reported in pediatric sleep-disordered breathing (SDB). While the reversibility of these craniofacial abnormalities by means of adenotonsillectomy has yet to be established, orthodontic treatment based on oral appliances is considered to be a potential additional treatment for pediatric SDB.
Discussion Oral appliances may help improve upper airway patency during sleep by enlarging the upper airway and/or by decreasing upper airway collapsibility, thereby enhancing upper airway muscle tone. Orthodontic therapy should be encouraged in pediatric OSAS, and an early approach may permanently modify nasal breathing and respiration, thereby preventing obstruction of the upper airway.

Keywords Obstructive sleep apnea · Children · Rapid maxillary expander · Malocclusion · Apnea–hypopnea index · Polysomnography

Introduction

Orthodontic and craniofacial abnormalities have often been reported in pediatric sleep-disordered breathing (SDB): a narrow upper airway accompanied by maxillary constriction and mandibular retrusion is believed to be a common phenotype of pediatric obstructive sleep apnea syndrome (OSAS) [1–7]. Children with SDB who do not have congenital craniofacial anomalies may display mild craniofacial morphometric features [4, 6, 8–10]. These morphometric features may indicate a hyperdivergent skeletal growth pattern, which increases the craniomandibular, intermaxillary, goniac, and mandibular plane angles [11]. Whether this skeletal conformation is genetically determined or influenced by the early onset of habitual snoring has yet to be determined [11]. Some investigators suggest that these craniofacial changes may be reversed by adenotonsillectomy [1], while others believe that children with SDB have a special craniofacial morphology from the outset [2, 11]. This persistent abnormal mandibular development and malocclusion affects the skeletal structures involved in respiratory dynamics [4, 12] and leads to mandibular retroposition, which in turn predisposes patients to the collapse of the upper airway during sleep [13]. Moreover, mandibular retroposition is associated with posterior displacement of the tongue base, which results in a further narrowing of the upper airway and leads to a high-arched (ogival) palate [11, 14].

While the reversibility of these craniofacial abnormalities by means of adenotonsillectomy has yet to be established, orthodontic treatment based on oral appliances is considered to be a potential additional treatment for pediatric SDB [15–17]. Oral appliances may help improve upper airway patency during sleep by enlarging the upper airway and/or by decreasing upper airway collapsibility, thereby enhancing upper airway muscle tone [17].

In 1995, the American Sleep Disorders Association published a position paper, which has recently been updated, regarding the clinical use of oral appliances to treat snoring and obstructive sleep apnea [18, 19]. Since the publication of these practice guidelines, the body of literature regarding oral appliances in adulthood has grown significantly [20, 21]. Epidemiological studies reported that

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Published online: 23 September 2011

2% to 4% of the adult population suffer from OSAS. The current standard treatment for OSAS consists in nocturnal application of continuous positive airway pressure (CPAP) via a nasal mask. Removable oral appliances are alternative treatment options for patients with OSAS and mandibular retrusion. The most effective oral appliances used today are designed to hold the mandible in an anterior position (protrusion) [22]. The mandibular advancement splint reduces upper airway collapsibility during sleep and increases the total airway volume that occurred predominantly because of an increase in the volume of the velopharynx in adults with OSA [23]. This increase in airway caliber was associated with an increase in the lower anterior facial height, reduction in the distance between the hyoid and posterior nasal spine, lateral displacement of the parapharyngeal fat pads away from the airway, and anterior movement of the tongue base muscles [15]. A review of the literature suggests that three variables contribute to the effectiveness of oral appliances: the severity of the sleep apnea, the degree of mandibular protrusion, and the body mass index (BMI) [21]. Although all these data demonstrated that oral appliances improve upper airway and craniofacial abnormalities in adults with OSA, it would appear to be appropriate to recommend oral appliance therapy to adult patients with mild symptomatic OSAS and those patients who are unwilling or unable to tolerate CPAP therapy [24]. Owing to the fact that few studies have assessed the short- and long-term efficacy of orthodontic treatment in pediatric SDB, a Cochrane database systematic review of the scientific literature data up to 2005 [25] concluded that there is not enough evidence to state that oral appliances or functional orthopedic appliances are effective in the treatment of OSAS in children [13, 26]. Recently, the Italian National Guidelines Consensus Conference drew up a guidelines for pediatric adenotonsillectomy and recommended a clinical orthodontic assessment in children with sleep-disordered breathing and malocclusions or craniofacial anomalies, even if they have indications to adenotonsillectomy [27].

Mandibular advancement devices in children with OSAS

Oral appliances and functional orthopedic appliances have been used in children to shift the mandible forwards, to enlarge the upper airway, and to improve respiratory function in patients who have OSAS and craniofacial anomalies. Rapid maxillary expansion (RME) is a dentofacial orthopedic treatment procedure commonly adopted in young patients for the treatment of constricted maxillary arches. Furthermore, rapid maxillary expansion is a clinical procedure that is widely used in orthodontic treatment to treat maxillary transverse deficiencies in young patients (with treatment usually starting after 4 years of age). Such patients usually display unilateral or bilateral posterior crossbite and anterior dental crowding. The distance between the lateral walls of the nasal cavity and the nasal septum is often reduced, leading to increased nasal airflow resistance and, consequently, to nasal respiratory difficulties [28, 29]. RME may relieve nasal breathing problems by increasing the transverse dimensions of the maxilla, which in turn widens the nasal cavity. Treatment-induced widening of the maxilla corrects posterior crossbites, improves maxillary and mandibular dental arch coordination prior to orthopedic or functional treatment of class II and class III malocclusions, and increases the arch perimeter in patients with tooth size/arch size discrepancies [30].

Sleep respiratory and architecture changes and clinical effects of orthodontic treatment in pediatric OSAS

We have previously published a study in which we evaluated the clinical usefulness and tolerability of an oral jaw positioning appliance as a means of treating obstructive sleep apnea syndrome in children (32 patients; mean age, 7.1±2.6 years; 20 males) displaying symptoms of obstructive sleep apnea, malocclusion, and a baseline apnea index of more than 1 event per hour of sleep. A random group of 19 subjects was assigned to a 6-month trial with an oral appliance, while the remainder acted as controls [31]. Out of the 32 subjects enrolled, 4 treated subjects and 5 control subjects were lost to follow-up. After 6 months of orthodontic treatment, a significant reduction in the apnea–hypopnea index and in diurnal symptoms was observed in most of the participants who had received an oral appliance. The results of that study demonstrate that the oral jaw positioning appliance is effective and well tolerated in the short term in children with OSAS and malocclusions [31].

Another study demonstrated the effect of rapid maxillary expansion in children suffering from nasal breathing and obstructive sleep apnea syndrome but who did not have enlarged tonsils or adenoids and were not obese. All the children underwent an otolaryngologic, orthognathic–odontologic and clinical examination, anterior rhinometry and nasal fibroscopy, and anteroposterior and laterolateral telecephalometry upon entry and at follow-up [26]. Thirty-one children (19 boys), mean age of 8.7 years, were enrolled in the study. Rapid maxillary expansion was applied for 6 to 12 months. The baseline mean apnea–hypopnea index was 12.2 events per hour. Four months after the end of the orthodontic treatment, all the children displayed a normal anterior rhinometry and all had an apnea–hypopnea index of less than 1 event per hour. The mean cross-sectional

expansion of the maxilla was 4.32±0.7 mm. That study demonstrated for the first time that rapid maxillary expansion may yield positive long-term effects in children with SDB [26]. Monini et al. [28] measured nasal flow and resistance in 65 children with mixed or deciduous dentition and varying degrees of malocclusion and oral breathing. Following RME treatment, the authors of that study recorded a significant improvement in nasal airflow, which remained stable 1 year after the end of expansion, along with an increase in posterior nasal space. Their findings point to a fundamental role of RME not only for the treatment of maxillary constriction but also for severe nasopharyngeal space constrictions associated with oral breathing, snoring, and OSAS in children.

We also evaluated the effects of rapid maxillary expansion in OSAS in 16 children (mean age 6.6±2.0 years; 9 males) with dental malocclusion and a body mass index below the 85th percentile [13]. We did not include the presence of adenotonsillar hypertrophy among the exclusion criteria. At the baseline and after the trial (i.e., after 1 year of orthodontic treatment), all the patients underwent a physical examination, standard polysomnography, and orthodontic assessment. The subjects enrolled satisfied the following three inclusion criteria: (1) clinical signs of malocclusion (all presented a high, narrow, ogival palate associated with deep bite, retrusive bite, or crossbite); (2) signs and symptoms of OSA, including habitual snoring, apneas, and restless sleep as witnessed by the parents; and (3) an obstructive apnea/hypopnea index higher than 1, as determined by a laboratory polysomnography, and parents who refused an adenotonsillectomy. The orthodontic assessment demonstrated the presence of jaw deviation from normal occlusion in all the children: deep bite, retrusive bite, or crossbite. The children received an endo-oral RME device on the basis of these results. This device is a fixed, two-band RME appliance with an expansion screw fitted to the second deciduous molars of the upper jaw (Leone Sesto Fiorentino-Florence). The screw is turned two turns per day for the first 10 days until the palatal cusp of the upper molar comes into contact with the buccal cusp of the lower molar. After this initial treatment phase, when the maxillary arch is sufficiently over-expanded, the device is assembled using two round stainless steel wires (arms), soldered to bands placed on the second primary molars. The RME is usually removed after 12 months. The height and weight of all the participants were normal for their age. Fourteen of the 16 children who initially received the RME device completed the trial; 1 child was excluded following a weight increase (BMI from 19.59 to 26.7 kg/m^2), while the other was excluded following the development of severe bronchial asthma, which required prolonged medical therapy. The polysomnographic recordings showed that by the end of the treatment phase, the apnea–hypopnea index had dropped significantly if compared with the baseline value (5.8±6.8 vs. 1.5±1.6 events per hour of sleep). Similarly, there was a significant decrease in both the oxygen desaturation index (3.1±3.2 vs. 0.9±1.3 events per hour of sleep) and arousal index (17.2±3.5 vs. 9.2±1.6 events per hour of sleep). None of the other polysomnographic variables considered changed significantly. The Brouillette questionnaire investigating symptoms of OSA was administered to parents before and during the trial to assess the clinical severity of their sleep-disordered breathing [32]. Questionnaire responses before and after treatment showed a significant decrease in the severity of symptoms, such as snoring, oral breathing, sleep apneas, sleepiness, and tiredness during the day. Besides a high narrow palate, all the patients had occlusal anomalies: five subjects had crossbite, while the remaining nine subjects had deep or retrusive bite, or both. Most of the children also had a mild or severe form of adenotonsillar hypertrophy. The changes in the apnea–hypopnea index varied according to the type of malocclusion, dropping to a greater extent in subjects with deep, retrusive bite than in those with crossbite. The mean maxillary expansion achieved was 3.7±0.7 mm in inter-canine diameter and 5.0±2.2 mm in inter-premolar diameter. In that study, we achieved therapeutic success, without resorting to invasive procedures or running any risk of adverse effects, by starting treatment early when the bone is still extremely plastic and its growth rate is maximum [10]. The effects of this treatment persisted even 2 years after the end of the RME application as expressed by the stable decrease of the apnea–hypopnoea index, the increase of mean overnight oxygen saturation, and by the persistent improvement of clinical symptoms (mostly snoring and oral breathing and sleepiness) [33]. Alterations in sleep quality were also found after 2 years from the end of treatment (expressed by an increase of S1, and of S2 percentages, and a decrease of REM and slow-wave sleep percentages). We cannot establish whether these differences are influenced by aging or are an indirect sign of incomplete recovery from OSAS [29].

We also evaluated NREM sleep microstructure in nine children (age 4–8 years) affected by OSAS before and after 1 year of RME treatment by means of the cyclic alternating pattern (CAP), in order to better analyze the effect of treatment on sleep quality. At the baseline, the OSAS group had a higher CAP rate during slow-wave sleep and higher A2 index than normal controls. After one year of RME application, children with OSAS displayed an increased CAP rate associated with an increased A1 index during slow-wave sleep. These results indicate that RME treatment almost normalized sleep architecture and improved sleep respiratory disturbances; however, sleep microstructure and respiratory parameters did not fully recover. The persistence of an increased CAP rate in slow-wave sleep together with

an increased A1 index may reflect a partial failure of the orthodontic treatment. On the other hand, the rebound of A1 subtypes might indirectly be indicative of an attempt to normalize sleep that has been disturbed by the respiratory events [16]. Our analysis of sleep changes after orthodontic treatment warrants further research on sleep changes to verify the normalization of sleep respiratory patterns and the recovery of sleep quality.

Conclusion

Orthodontists are playing an increasingly important role in managing snoring and OSAS by means of oral mandibular advancement appliances and rapid maxillary expansion. However, the data currently available are derived mostly from studies on adults, in whom bone changes occur more slowly than in children and cannot always be achieved without resorting to an invasive surgical procedure [13, 33]. The results of the studies described above suggest that orthodontic therapy should be encouraged in pediatric OSAS and that an early approach may permanently modify nasal breathing and respiration, thereby preventing obstruction of the upper airway. The possibility that early use of rapid maxillary expansion, i.e., from the age of 4 years, may not only improve symptoms associated with snoring, OSAS, and abnormal respiratory effort, but may even change the natural history of pediatric OSAS is an intriguing hypothesis that deserves further investigation [13, 33].

To assess the overall efficacy of adenotonsillectomy (AT) in the treatment of OSAS in children, a multicenter collaborative retrospective review of all nocturnal polysomnograms performed both preoperatively and postoperatively on otherwise healthy children undergoing AT for the diagnosis of OSAS was conducted: Of the 578 children analyzed, only 157 (27.2%) had complete resolution of OSAS [34]. Since a residual disease remains in a large proportion of children after adenotonsillectomy, a multi-therapeutic approach to pediatric OSAS and a defined timing of therapy are required [35]. In cases where sleep-disordered breathing persists, an additional interventional treatment option may be the administration of nasal CPAP, whereas children with mild OSAS fall within a therapeutic gray zone [35]. Indeed, although the latter are exposed to a significant risk of associated morbidity [36], the risk/benefit ratio of surgical adenotonsillectomy has not conclusively been proven, and CPAP is not considered a good option because it may partially be blocked if applied to an airway with enlarged lymphadenoid tissue. A medical therapeutic option in such cases consists in the topical intranasal application of high potency corticosteroids and/or the oral administration of a leukotriene receptor antagonist, which has proven to be effective in mild pediatric OSA [12, 19]. Anti-inflammatory therapy is another effective means of treating residual OSA following an adenotonsillectomy [35]. The orthodontic therapy we propose in this paper may be considered, regardless of the severity of OSA, a valid contribution to treatment [37]. Another important therapeutic aspect that needs to be addressed is the role of oropharyngeal exercises derived from speech therapy (myofunctional therapy). Oropharyngeal exercises may be an effective treatment option for children with OSAS; indeed, such exercises adjust physiological breathing and correct oral breathing, both of which are involved in airway muscle function and upper airway patency and may thus contribute to the genesis of OSAS [38].

As multi-therapies might act synergistically, a greater degree of collaboration between sleep medicine, ear, nose, and throat specialists and orthodontists is warranted to establish the contribution of each therapy to the outcome of pediatric OSAS [37]. Table 1 shows a proposed multi-therapeutic approach to pediatric SDB. This issue needs to

Table 1 Multi-therapeutic steps in children with sleep-disordered breathing (SDB)

Phenotype of SDB	Snoring and mild obstructive sleep apnea (AHI>1<5)	Moderate–severe obstructive sleep apnea: AHI>5
Phenotype without obesity	1. Orthodontic treatment	1. Adenotonsillectomy and orthodontic treatment
		2. If residual OSAS:
	2. Medical therapy	• Nasal CPAP (if AHI>5)
	3. Myofunctional therapy	• Medical therapy
		• Myofunctional therapy
Phenotype with obesity	1. Hypocaloric diet	1. Nasal CPAP
	2. Orthodontic treatment	2. Hypocaloric diet
	3. Nasal CPAP	3. Orthodontic treatment
	Medical therapy	Medical therapy

SDB sleep-disordered breathing, *CPAP* continuous positive airway pressure, *AHI* apnea–hypopnea index

be addressed urgently so that physicians may establish whether a patient should undergo an adenotonsillectomy or may be spared a surgical procedure and receive orthodontic treatment on the basis of a skeletal evaluation. The presence of a narrow hard palate needs to be investigated during the clinical evaluation, as does the size of the tonsils and adenoids. In conclusion, further studies are warranted to define the characteristics of patients who may benefit most from orthodontic treatment and to assess the long-term efficacy of such treatment.

Conflicts of interest All authors are disclosing any conflict of interests, any affiliation, financial agreement, or other involvement of any author with any company whose product figures prominently in the submitted manuscript, and any off-label or investigational use.

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