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ORIGINAL ARTICLE

Efficacy of rapid maxillary expansion in children with obstructive sleep apnea syndrome: 36 months of follow-up

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Abstract
Purpose In view of the positive outcome of orthodontic treatment using rapid maxillary expansion (RME) on sleep-disordered breathing, we generated data on RME in children with obstructive sleep apnea (OSA) by evaluating objective and subjective data over a 36-month follow-up period, to determine whether RME is effective in the long-term treatment of OSA. We selected all patients with dental malocclusions and OSA syndrome (OSAS) confirmed by polysomnography.
Methods Ten of the 14 children who completed the 12-month therapeutic trial using RME were enrolled in our follow-up study. The study was performed 24 months after the end of the RME orthodontic treatment. We enrolled all children presented with deep, retrusive or crossbite at the orthodontic evaluation. All subjects underwent an overnight polysomnography at the baseline, after 1 year of treatment and 24 months after the end of the orthodontic treatment. The children's mean age was 6.6±2.1 years at entry and 9.7±1.6 years at the end of follow-up.
Results After treatment, the apnea hypopnoea index (AHI) decreased and the clinical symptoms had resolved by the end of the treatment period. Twenty-four months after the end of the treatment, no significant changes in the AHI or in other variables were observed.
Conclusions RME may be a useful approach in children with malocclusion and OSAS, as the effects of such treatment were found to persist 24 months after the end of treatment.

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

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Introduction

Orthodontic and craniofacial abnormalities in children with obstructive sleep apnea syndrome (OSAS) have been widely described though often ignored, despite their impact on public health. Children with OSAS may have a narrow and long face, with large tonsils, a narrow upper airway, maxillary constriction and/or some degree of mandibular retrusion [1–5]. Rapid maxillary expansion (RME) is a dentofacial orthopaedic treatment procedure routinely used in young patients to treat constricted maxillary arches; it is also considered a potential additional treatment in children presenting with OSAS [6–8]. The main goal of RME is to correct existing posterior crossbite and to widen the maxilla and maxillary dental arch, which reduce maxillary constriction and mouth breathing, thereby helping solve nasal airway and naso-respiratory problems [9–11]. It is common to find an increase of craniomandibular and intermaxillar angles (high angle face) in children with OSAS. Upper and lower goniac angles and posterior rotation of the mandible;

mechanical obstruction of the rhinopharynx, crossbites and labial incompetence indicate that upper airway obstruction influences the posture of the tongue, face and teeth, leading to craniofacial modifications [12]. Pirelli et al. [6] demonstrated that RME is a valid treatment for OSAS in children without enlarged tonsils and adenoids. They studied 31 children with malocclusion, characterized by upper jaw contraction, oral breathing, nocturnal snoring and OSAS. None of the children had adenotonsillar hypertrophy. At the 4-month follow-up, the anterior rhinometry was normal and all the children had an apnea-hypopnea index (AHI) <1 event per hour.

The persistence of tonsillar enlargement is known to interfere with orthodontic treatment; however, few data are available on the combined impact of tonsillar enlargement and orthodontic treatment on OSAS. A recent study showed that a partial response to adenotonsillectomy in children with OSAS is associated with several facial abnormalities, involving the maxilla and mandible, which contribute to the persistence of oral breathing and OSA. [13]. The authors of that study stated that both adenotonsillectomy and RME may be necessary to resolve OSA. We have previously evaluated the effectiveness of RME at 12 months as early orthodontic treatment for mild-to-moderate OSAS in young children with dental malocclusion. Fourteen treated subjects completed the study and follow-up; polysomnographic (PSG) recordings showed that maxillary expansion resulted in a significant decrease in the AHI, hypopnea obstructive index and arousal index, even in patients with mild or severe tonsillar hypertrophy [7].

In view of those findings, the aim of this prospective longitudinal study was to evaluate the long-term outcome in the same group of young children (aged 4–10 years) with dental malocclusion successfully treated with RME by assessing sleep respiratory parameters and the clinical sign and symptoms of OSAS [7].

Materials and methods

Subjects

We enrolled children between 4 and 8 years of age who had been referred to our Paediatric Sleep Center (Rome, Italy) and satisfied the following three inclusion criteria: clinical signs of malocclusion (high, narrow palate associated with deep bite, retrusive bite or crossbite); signs and symptoms of OSAS, including habitual snoring, apnea and restless sleep as witnessed by parents; patients whose parents refused an adenotonsillectomy. The diagnosis of OSAS was confirmed by a laboratory PSG recording yielding an obstructive AHI >1, according to the standard criteria recently revised by the American Academy of Sleep Medicine [14]. Children were enrolled between November 2004 and April 2005.

Standard informed consent approved by the Hospital Committee, was obtained from the parents of each child, while assent was obtained from children >6 years old. We excluded patients with a history of previous treatment for OSAS (including tonsillectomy and adenoidectomy), those who were referred for titration of continuous positive airway pressure therapy attributable to sleep-disordered breathing or for obesity, and patients with a history of acute or chronic cardiorespiratory or neuromuscular diseases, dysmorphism, major craniofacial abnormalities or associated chromosomic syndromes.

Study design

A detailed personal and family history was obtained for all participants and a general clinical examination performed. Adenoid hypertrophy was graded according to Greenfeld et al. [15]. Before the RME was applied, all the children underwent an otorhinolaryngologic examination to grade tonsillar hypertrophy according to a standardized scale ranging from 0 to 4 [16]. All the children underwent an orthodontic assessment to detect possible jaw deviation from normal occlusion: deep bite, retrusive bite and crossbite. An endo-oral RME device was applied in all the children. The device was a fixed two-band RME appliance (Leone Sesto Fiorentino, Florence) with an expansion screw fitted to the second deciduous molars of the upper jaw. The screw was turned two turns a day for the first 10 days until the palatal cusp of the upper molar came into contact with the buccal cusp of the lower molar. After this initial treatment, when the maxillary arch was sufficiently over-expanded, the screw was fixed with a steel ligature wire and acrylic.

The bone distraction lasted 12 months because histologic investigations have shown that this is the time required for the ossification process [17]. The RME was thus removed after 12 months. The children underwent a polysomnography at the baseline (before fitting of the RME device, T0), after 1 year of continuous RME use (T1), and 2 years after the end of the orthodontic treatment (T2).

At follow-up (T1 and T2), the children were re-evaluated by an orthodontist, an otolaryngologist and a sleep physician. A detailed personal and family history was obtained from each patient and a general clinical examination performed, including the skin prick test to evaluate allergen sensitization.

Questionnaire data

The participants' parents completed a modified version of the Brouillette questionnaire [18], at T0, T1 and T2, when

the PSG recordings were performed. The questionnaire elicited information on daytime symptoms of OSAS (including sleepiness, irritability, headache, school problems, tiredness and oral breathing) and nighttime symptoms (including habitual snoring, apneas, restless sleep and nightmares). A clinical score was assigned for each daytime and nighttime symptom, with one point per question, yielding a maximum total score of 10.

Sleep analysis

Standard overnight PSG recordings were obtained by means of a Grass Heritage polygraph. The variables recorded included at least an eight-channel electroencephalogram (frontal, central temporal and occipital, referred to the contralateral mastoid), an electrooculogram (electrodes placed 1 cm above the right outer cantus and 1 cm below the left outer cantus and referred to A1), a submental electromyogram and an electrocardiogram (one derivation). Sleep was subdivided into 30-s epochs, and sleep stages were scored according to the standard criteria by Rechtschaffen and Kales [19]. All the following sleep architecture parameters were evaluated: total sleep time (TST=time from sleep onset to the end of the final sleep epoch minus time awake); sleep efficiency (defined as the percentage ratio between TST and time in bed); percentage of stage 1, stage 2, stage 3, stage 4 NREM (non-rapid eye movement) sleep and REM (rapid eye movement) sleep.

Central, obstructive and mixed apnea events were counted according to the criteria established by the American Academy of Sleep Medicine [14]. An obstructive apnea was defined as a >90% drop in the signal amplitude of airflow for >90% of the entire event, compared with the pre-event baseline amplitude, with continued chest wall and abdominal movement for a duration of at least two breaths. A central apnea was defined as the absence of airflow, with the cessation of respiratory effort, lasting more than 20 s or at least two missed breaths (or the duration of two baseline breaths) and is associated with an arousal, an awakening or a >3% desaturation; central apnea occurring after gross body movements or after sighs was not considered as a pathologic finding. A mixed apnea was defined as an apnea that usually began as central and ended in obstruction, according to changes in the chest, abdominal and flow traces. Hypopnea was defined as a >50% drop in airflow signal amplitude compared with the pre-event baseline amplitude for at least 90% of the duration of the event; the event had to last at least two missed breaths and be associated with an arousal, awakening or a >3% desaturation. Chest and abdomen movements were measured by strain gauges. Oronasal airflow was recorded with a thermocouple. Arterial oxygen saturation was monitored with a pulse oximeter. The AHI was defined as the average number of apneas and hypopneas per hour of sleep. All recordings started at the patients' usual bedtime and continued until spontaneous awakening.

Statistical analysis

Data are expressed as means ± SD (standard deviation). Pearson's chi-square test was used to analyze the questionnaire. An analysis of variance (ANOVA, Friedman test) with post hoc Wilcoxon test for paired data sets was used to assess significant differences between measurements at T0, T1 and T2. The SPSS statistical software program (SPSS 10.0, Chicago, USA) was used for calculations; p values less than 0.05 were considered statistically significant.

Results

Study population

Of the 14 children who completed the 12-month therapeutic trial with RME (T1) (for details see Villa et al. [7]), 10 (5 males) were enrolled for the follow-up study. Two children refused to undergo another PSG recording, one child underwent an adenotonsillectomy during the follow-up period (1 year after the end of orthodontic treatment) and another child gained a significant amount of weight (BMI increased from 18 kg/m^2 at T1 to 27 kg/m^2 after 1 year from the end of orthodontic treatment) and refused to undergo PSG recording.

The mean age of the ten children was 6.6±2.1 years at T0, 8.1±2.0 years at T1 and 9.7±1.6 years at T2, The BMI did not increase significantly from T0 to T1 and T2 (16.7±3.6, 18.5±4.6, 18.7±4.4 kg/m^2, respectively)

Baseline clinical sign and symptoms (T0)

The orthodontic evaluation demonstrated that all patients had, besides a high narrow palate, occlusal anomalies: six subjects had crossbite, while four had deep or retrusive bite or both. No child experienced adverse effects when the RME was applied. Five subjects had a positive history for allergy to inhalants with enlarged turbinates and received periodic antiallergic treatment, though none received any chronic medication. The otorhinolaryngoiatric evaluation before treatment detected mild tonsillar hypertrophy (clinical scale +2) in three patients, moderate tonsillar hypertrophy in four patients (clinical scale +3) and severe tonsillar hypertrophy in two cases (clinical score +4).

Sleep parameters and clinical sign and symptoms at T1

At T1, the number of children with tonsillar hypertrophy (clinical scores 3 and 4) decreased significantly, from 6 to 0

out of ten subjects (see Tables 1 and 2). According to the questionnaire, all the parents reported an improvement in symptoms after 12 months of treatment. AHI decreased significantly from T0 to T1 and SaO_2 improved significantly. Total sleep time and stage 2 NREM percentage increased significantly, while stage 1 NREM percentage decreased from T0 to T1.

Sleep parameters and clinical signs and symptoms at T2

At T2, only one subject out of ten showed moderate tonsillar hypertrophy, with a clinical score of 3 (see Tables 1 and 2). All the parents reported an improvement in some symptoms (snoring and oral breathing) 24 months after the end of the RME application. The percentages of REM sleep, of sleep efficiency and of slow-wave sleep decreased from T1 to T2, while AHI and SaO_2 values did not change significantly.

Failure of treatment

Treatment failure was observed in two out of ten cases at the end of the follow-up (T2). In one case (a girl aged 8 years), the AHI did not change after 12 months of RME treatment, but increased after 24 months (from 6.1 to 9.1 events per hour), while SaO2 decreased (from 95.6 to 90.7%). She had a narrow face, deviated nasal septum and tonsil hypertrophy. She subsequently underwent ventilatory nasal continuous positive airway pressure therapy first and adenotonsillectomy later.

In the second case (a boy aged 7.5 year), the respiratory parameters decreased significantly from T0 to T1 (AHI from 4.5 to 0 events per hour; SpO2 from 97% to 98%, respectively), but increased again to their baseline treatment values at T2 (AHI 4.2 events per hour, SaO2 97.3%, respectively). This patient suffered from habitual snoring, daytime fatigue and difficulties at school, together with severe attacks of bronchial asthma and weight gain (BMI increased from 19 kg/m^2 at T1, to 30.5 kg/m^2 at T2).

Discussion

To our knowledge, this is the first study designed to assess the long-term follow-up (24 months) in children with OSAS and malocclusion who have undergone orthodontic treatment. The results of our study show a stable reduction in the clinical and polysomonographic signs and symptoms of OSAS in the majority of the children treated (eight out of ten subjects).

It has been demonstrated that a range of craniofacial abnormalities, such as maxillary constriction, retrognathia and long anterior face height, are induced by nasopharyngeal obstruction during human development. The early detection and treatment of children at risk of developing OSA may prevent the sequelae of the disease. Since maxillary constriction is a feature of chronic nasorespiratory obstruction, RME has the potential to play an important role as preventive treatment in children with OSA, particularly during the prepubertal growth period [9, 20].

These promising findings confirm that RME devices may be useful in the treatment of paediatric OSAS and provide further information on their long-term efficacy [6, 7, 20]. Moreover, our long-term findings suggest that orthodontic treatment in children with dental malocclusion and OSA should be started as early as possible in the

Table 1 Answers to questionnaire and clinical characteristics of subjects (n=10) at baseline (T0), i.e. after 12 months, i.e. at the end of orthodontic treatment (T1) and 24 months after the end of the orthodontic treatment (T2)

	T0 *N*	T1	T2	χ^2 *p* value
Nighttime symptoms				
Habitual snoring	9	4	3	0.016
Apneas	8	1	2	0.002
Restless sleep	6	3	3	NS
Nightmares	1	0	0	NS
Daytime symptoms				
Sleepiness	8	2	2	0.007
Irritability	3	3	0	NS
Headhache	4	2	3	NS
School problems	3	1	1	NS
Tiredness	8	2	3	NS
Oral breathing	7	3	2	0.05
Tonsillar hypertrophy (clinical scores 3 and 4)	6	0	1	0.03
Allergy	5	5	4	NS

Significant values at $p<0.05$ are reported

Table 2 Sleep parameters of subjects (n=10) at baseline (T0), after 12 months, i.e. at the end of orthodontic treatment (T1), and 24 months after the end of the orthodontic treatment (T2)

	T0	T1	T2	ANOVA	Wilcoxon test		
				p value	T0 vs T1	T1 vs T2	T0 vs T2
TST (h)	6.2±11.0	7.7±0.9	6.3±1.2	0.006	0.01	0.01	NS
SE (%)	85.8±10.1	90.9±6	83.6±10.2	0.07	NS	0.06	NS
S1 (%)	5.0±4.1	2.1±1.7	3.3±2.2	0.2	0.07	0.2	0.1
S2 (%)	42.4±10.4	40.0±8.8	51.6±6.8	0.02	0.4	0.01	0.007
SWS (%)	36.4±10.7	34.4±10.4	27.9±8.1	0.02	0.3	0.03	0.01
REM (%)	15.9±6.3	23.4±5.9	17.1±5.7	0.06	0.04	0.06	NS
AHI (n/h)	6.3±4.7	2.4±2.0	2.3±1.7	0.003	0.05	NS	0.05
SaO2 (%)	95.8±1.8	97.0±2.8	97.7±1.0	0.05	0.05	NS	0.008

TST total sleep time, *SE* sleep efficiency, *S1, S2* sleep stages 1 and 2 NREM, *SWS* slow-wave sleep, *REM* rapid eye movement sleep, *AHI* Apnea hypopnea index, *SaO2* overnight arterial oxygen saturation

Significant values at $p<0.05$ are reported

childhood period. The results of the questionnaire revealed a significant decrease in oral breathing and improved nasal respiration, observed both after 1 year of RME treatment and at the long-term follow-up (2 years after the end of therapy). This result confirms that RME may improve nasal respiration and relieve nasal problems in children with OSAS [9].

All the children were studied but three were oral breathers. Oral breathing disappeared after therapy with RME in almost all the children. Widening of the buccal cavity and distension of the maxillary bone proved to reasonably enlarge the space available for the adenoids and tonsils. In our earlier study, we found that jaw-repositioning reduced the degree of subjective tonsillar hypertrophy [20]. These observations suggest that increasing the oropharyngeal space may reduce tonsillar hypertrophy, rendering it stable over time. This hypothesis need to be further demonstrated by means of objective measure, such as scan tomography of oropharyngeal space. A recent study demonstrated that children with maxillary constriction treated with rapid palatal expansion showed an enlargement of retropalatal airway volume detected by cone-beam computed tomography; while oropharyngeal airways remained narrow [21].

These results lend support to the concept that orthodontic therapy should be encouraged in pediatric OSAS as an early approach that may help stably modify nasal breathing and respiration, thereby preventing obstruction of the upper airway. Monini et al. measured nasal flow and resistance in 65 children with mixed or deciduous dentition and varying degrees of malocclusion and oral breathing [11]. Following RME treatment, they observed an improvement in nasal flow and resistance in the supine position in subjects who presented both anterior and posterior obstruction, whereas changes in isolated forms of obstruction and those in the orthostatic position were less marked. The significant improvement we observed in nasal airflow, which remained stable after 2 years of expansion, suggests that RME may be able to play a fundamental role not only in the treatment of maxillary constriction but also of severe constrictions of the nasopharyngeal spaces associated with oral breathing, snoring and OSAS in children.

The results of the sleep architecture revealed some differences between T1 and T2. The decrease of sleep efficiency, and of the percentages of slow wave and REM sleep from T1 to T2 may be a marker of sleep quality alterations. Unfortunately, we did not compare sleep architecture parameters with those of a control group, in order to better understand such discrepancies. We cannot establish whether these differences are influenced by aging, or are an indirect sign of incomplete recovery from OSAS, as we reported in a previous investigation on sleep architecture and arousals in the same group of children treated with RME [22].

Moreover, severe tonsillar hypertrophy and a significant increase in weight at T2 were described in the two cases in which RME treatment failed. Future studies are warranted to clarify the timing and the effect of orthodontic therapy in OSAS children who also underwent an adenotonsillectomy or in those who underwent other forms of therapy (such as ventilatory treatment, weight loss and drug therapy). As multi-therapies might act synergistically, a greater degree of collaboration between sleep medicine, ear–nose–throat specialists and orthodontists is warranted to establish the contribution each therapy may make to the outcome in pediatric OSAS patients [13]. This issue needs to be addressed urgently in order to establish whether a patient requires an adenotonsillectomy or may, on the basis of a skeletal evaluation, be spared a surgical procedure.

Lastly, RME treatment may have positive effect on occlusal discrepancy. Literature data showed that RME treatment induces widening of the maxilla and corrects posterior crossbites, improving maxillary and mandibular dental arch coordination of classes II and III malocclusions [23]. It seems evident that the objective and subjective stable improvement of nasal breathing would play a compensatory role for the relationships between maxillary and mandibular arches with respect to the anterior cranial base [11].

In conclusion, although our sample of subjects was somewhat limited in size, our results point to the usefulness of thoroughly evaluating the size of the airways in snoring children in order to be able to provide the best treatment, since the characteristics of the patients most likely to benefit from RME treatment have yet to be elicited.

One unavoidable limitation of our study is that we did not have a control group, because it is ethically difficult to refrain from treating children with OSAS for 12 months at T1 and for a further 24 months at T2. Our findings warrant further studies based on larger numbers of subjects.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Guilleminault C, Partinen M, Praud JP, Quera-Salva MA, Powell N, Riley R (1989) Morphometric facial changes and obstructive sleep apnea in adolescents. J Pediatr 114:997–999
2. Guilleminault C, Li KK, Khramtsov A, Pelayo R, Martinez S (2004) Sleep disordered breathing: surgical outcomes in prepubertal children. Laryngoscope 114:132–137
3. Tasker C, Crosby JH, Stradling JR (2002) Evidence for persistence of upper airway narrowing during sleep, 12 years after adenotonsillectomy. Arch Dis Child 86:34–37
4. Mitchell RB, Kelly J (2004) Outcome of adenotonsillectomy for severe obstructive sleep apnea in children. Int J Pediatr Otorhinolaryngol 68:1375–1379
5. Souki BQ, Pimenta GB, Souki MQ, Franco LP, Becker HM, Pinto JA (2009) Prevalence of malocclusion among mouth breathing children: do expectations meet reality? Int J Pediatr Otorhinolaryngol 73:767–773
6. Pirelli P, Saponara M, Guilleminault C (2004) Rapid maxillary expansion in children with obstructive sleep apnea syndrome. Sleep 27:761–766
7. Villa MP, Malagola C, Pagani J, Montesano M, Rizzoli A, Guilleminault C, Ronchetti R (2007) Rapid maxillary expansion in children with obstructive sleep apnea syndrome: 12 months follow-up. Sleep Med 8:128–134
8. Cistulli PA, Palmisano RG, Poole MD (1998) Treatment of obstructive sleep apnea syndrome by rapid maxillary expansion. Sleep 21:831–835
9. Kiliç N, Oktay H (2008) Effects of rapid maxillary expansion on nasal breathing and some naso-respiratory and breathing problems in growing children: a literature review. Int J Pediatr Otorhinolaryngol 72:1595–1601
10. De Felippe NL, Bhushan N, Da Silveira AC, Viana G, Smith B (2009) Long-term effects of orthodontic therapy on the maxillary dental arch and nasal cavity. Am J Orthod Dentofacial Orthoped 136:490.e1–490.e8
11. Monini S, Malagola C, Villa MP, Tripodi C, Tarentini S, Malagnino I, Marrone V, Lazzarino AI, Barbara M (2009) Rapid maxillary expansion for the treatment of nasal obstruction in children younger than 12 years. Arch Otolaryngol Head Neck Surg 135:22–27
12. Zucconi M, Caprioglio A, Calori G, Ferini-Strambi L, Oldani A, Castronovo C, Smirne S (1999) Craniofacial modifications in children with habitual snoring and obstructive sleep apnoea: a case–control study. Eur Respir J 13:411–417
13. Guilleminault C, Huang YS, Glamann C, Li K, Chan A (2007) Adenotonsillectomy and obstructive sleep apnea in children: a prospective survey. Otolaryngol Head Neck Surg 136:169–175
14. Ancoli-Israel S, Chesson A, Quan SF, for the American Academy of Sleep Medicine (2007) The AASM manual for the scoring of sleep and associated events: rules, terminology and technical specifications. American Academy of Sleep Medicine, Westchester
15. Greenfeld M, Tauman R, DeRowe A, Sivan Y (2003) Obstructive sleep apnea syndrome due to adenotonsillar hypertrophy in infants. Int J Pediatr Otorhinolaryngol 67:1055–1060
16. Friedman M, Ibrahim H, Joseph NJ (2004) Staging of obstructive sleep apnea/hypopnea syndrome: a guide to appropriate treatment. Laryngoscope 114:454–459
17. Ilizarov GA (1988) The principles of the Ilizarov method. Bull Hosp Joint Dis Orthop Inst 48:1–11
18. Brouillette R, Hanson D, David R, Klemka L, Szatkowski A, Fernbach S, Hunt C (1984) A diagnostic approach to suspected obstructive sleep apnea in children. J Pediatr 105:10–14
19. Rechtschaffen A, Kales A. Springer A manual of standardized terminology, techniques and scoring system for sleep stage of human subjects. Los Angeles: Brain Information Service/Brain Research Institute, University of California; 1968
20. Villa MP, Bernkopf E, Pagani J, Broia V, Montesano M, Ronchetti R (2002) Randomized controlled study of an oral jaw-positioning appliance for the treatment of obstructive sleep apnea in children with malocclusion. Am J Respir Crit Care Med 165:123–127
21. Zhao Y, Nguyen M, Gohl E, Mah JK, Sameshima G, Enciso R (2010) Oropharyngeal airway changes after rapid palatal expansion evaluated with cone-beam computed tomography. Am J Orthod Dentofacial Orthoped 137:S71–S78
22. Miano S, Rizzoli A, Evangelisti M, Bruni O, Ferri R, Pagani J, Villa MP (2009) NREM sleep instability changes following rapid maxillary expansion in children with obstructive apnea sleep syndrome. Sleep Med 10:471–478
23. Chrcanovic BR, Custódio AL (2009) Orthodontic or surgically assisted rapid maxillary expansion. Oral Maxillofac Surg 13:123–137