



## The role of oral appliance therapy in the treatment of obstructive sleep apnea

Kathleen A. Ferguson, MD, FRCPC, FCCP

*Division of Respiriology, London Health Sciences Centre, University of Western Ontario, 375 South Street, London, Ontario, N6A 4G5, Canada*

Oral appliances are an established treatment option for simple snoring and obstructive sleep apnea (OSA). Early evidence led to the recommendation that they be used for the treatment of mild OSA or simple snoring [1,2]. Recently published, randomized controlled clinical trials have shown them to be an effective treatment option in many patients, and some studies have suggested a reasonable level of effectiveness in more severe OSA. Oral appliances are appealing because they are simple to use, reversible, and portable and generally have a low complication rate. This article reviews available types of oral appliances, their mechanism of action, and the evidence for using oral appliance therapy. The role of the physician and dentist is discussed. The article also reviews the side effects and complications of appliance therapy and the evidence about predictors of outcome of treatment.

### Appliance types and mechanisms of action

There are two main appliance groups in common clinical use: tongue repositioning devices and mandibular repositioning appliances (MRAs) (Figs. 1–3). An infrequently used design is a palatal lifting device, which contacts the soft palate directly. Because of the limited effectiveness of this device in the treatment of snoring [3] and obstructive sleep apnea (OSA) [4], it is not discussed in this article.

### *Effects of mandibular and tongue advancement on upper airway patency*

The effects of oral appliances on upper airway size are variable and depend on the method of imaging the airway, when the studies are performed (ie, wakefulness versus sleep), the subject's body position (ie, supine versus upright), the type of appliance, and the amount of mandibular protrusion. Oral appliances may improve upper airway patency by enlarging the upper airway or by decreasing upper airway collapsibility (eg, improving upper airway muscle tone). Simple active anterior movement of the tongue or mandible can increase cross-sectional airway size in subjects with and without OSA [5]. Passive mandibular advancement during general anesthesia stabilized the upper airway by increasing airway size in the retro-palatal and retro-glossal area and reducing closing pressure [6]. The effect of passive pharyngeal advancement during anesthesia in the retro-palatal area is greater in nonobese subjects [7].

Several studies have evaluated the effects of MRAs on upper airway size using upright lateral cephalometry (during wakefulness) (Fig. 4). These results are sometimes conflicting. In two studies, an MRA increased the posterior airway space in most subjects [8,9]. In another study in which the amount of protrusion was individualized in each patient, there was no change in the size of the posterior airway space with the appliance on a cephalogram [10]. Other studies that used upright lateral cephalometry have shown that MRAs lower the tongue position, reduce the mandibular-plane-to-hyoid distance, advance the mandible, and widen the upper oropharynx (retropalatal and ret-

*E-mail address:* [kafergus@uwo.ca](mailto:kafergus@uwo.ca)



Fig. 1. The Klearway adjustable oral appliance. (Courtesy of Great Lakes Orthodontics, Ltd., Tonawanda, NY.)

roglossal) in some subjects [9,11–13]. Similar reductions in mandibular-plane-to-hyoid distance [14], increases in oropharyngeal airway size [14,15], and velopharyngeal airway size [16] have been seen using supine cephalograms.

Other imaging modalities (eg, CT, MRI) also have demonstrated increases in pharyngeal airway size [9,17] and volume [18]. Direct imaging of the awake supine airway with videoendoscopy confirms that an



Fig. 2. An adjustable Herbst appliance. (Courtesy of Great Lakes Orthodontics, Ltd., Tonawanda, NY.)



Fig. 3. A Monobloc appliance. (Courtesy of Dr. Konrad Bloch, University of Zurich.)

MRA increases the cross-sectional area of the airway, particularly in the velopharynx [19].

The presence of an intraoral device affects upper airway muscle tone. Tongue retaining devices (TRDs) affect genioglossus muscle activity in patients with OSA (awake or asleep), but effects of a TRD on other upper airway muscles have not been evaluated [20,21]. A TRD worn during sleep reduced the AHI and decreased genioglossus electromyogram (EMG) activity [21]. The modified TRD (no bulb) also reduced the apnea-hypopnea index (AHI) and increased the peak genioglossus activity measured just before airway reopening. The presence of the device without tongue advancement did have an impact on genioglossus activity and on apnea severity. The mechanism for this effect is not certain. A study using an MRA found that upper airway muscle tone increased with an MRA except in the postapnea period in the genioglossus, where tone was lower [22]. This study suggested that activation of the upper airway muscles may contribute to upper airway patency during sleep. In a more recent placebo-controlled trial, the simple presence of an intraoral appliance had no impact on the AHI or oxygen saturation [23]. The study suggested that mandibular advancement is required for the appliance to improve OSA because the presence of an intraoral device without advancement showed no clinical effect.

## Effectiveness of oral appliance therapy

### *Mandibular repositioning appliances*

Several studies have evaluated the efficacy of mandibular advancers. A detailed review of oral

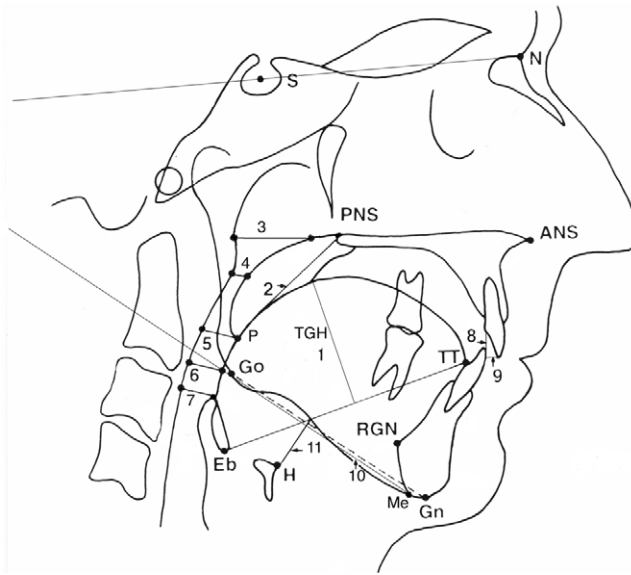


Fig. 4. Diagrammatic representation of the anatomic points and planes used to identify craniofacial and soft tissue parameters and areas on lateral cephalometric radiographs. S, center of the sella turcica; N, nasion; PNS, posterior nasal spine tip; ANS, anterior nasal spine tip; Gn, gnathion; RGN, retrognathion; Me, menton; Go, gonion; H, anterior superior tip of hyoid bone; TT, tongue tip; Eb, base of epiglottis; P, inferior tip of palate; SN-MP angle, angle between the cranial base (line between S and N) and the mandibular plane. Linear measurements: 1. TGH, tongue height; 2. PNSP, soft palate length; 3. boundary between velopharynx and nasopharynx; 4. RPAS, retropalatal airway space; 5. RNAS, retro nasal airway space; 6. PAS, posterior airway space; 7. inferior margin oropharyngeal airway space (upper boundary hypopharynx); 8. OB, overbite; 9. OJ, overjet; 10. MP, mandibular plane, line between Me and Go; 11. MPH, mandibular plane to hyoid. Areas: Tongue area, area outlined by the dorsal configuration of the tongue surface and lines which connect TT, RGN, H and Eb; Soft Palate Area, area confined by the outline of the soft palate which starts and ends at PNS through P.

appliance therapy was published in 1995 [1]. The literature at that time consisted of case reports and retrospective and prospective case series (before and after design), and most, but not all, were peer reviewed. The authors pooled the results for the TRD and MRA of different designs. Seventy percent of the 304 subjects had a reduction in AHI by 50%, 51% had a posttreatment AHI of less than 10 per hour, but as many as 40% had a posttreatment AHI of more than 20 per hour. Snoring was reported to be improved in most patients. Since 1995, several prospective studies have been published, including randomized and controlled trials. In the more recent prospective case series of oral appliance therapy, 54% to 81% of patients had a reduction in AHI by 50% [24–27], and 51% to 64% of patients had a posttreatment AHI of less than 10 per hour [24–26,28,29].

Ten prospective controlled clinical studies have been published: five cross-over studies that compared oral appliances to continuous positive airway pressure (CPAP) (four randomized [30–33] and one non-randomized [34]), three randomized studies that compared two different appliance designs [35–37], and

two randomized, placebo-controlled trials [23,38]. Three of the cross-over studies that compared oral appliances to CPAP have been described in detail elsewhere [39].

Clark et al published a cross-over study of the Herbst appliance compared with CPAP therapy in 23 men with OSA [34]. The choice of initial therapy was not randomized, and most patients used CPAP before they used the MRA. Although not reported directly, from the figure provided it seems that 4 patients (19%) had an AHI of less than 10 per hour with the MRA set at roughly two thirds of maximal protrusion. The mean decrease in AHI was 39%. Sleep quality was improved more by CPAP than by the MRA, and CPAP was more effective at reducing the AHI. Symptoms of excessive daytime sleepiness were equally improved by the two treatments. The first cross-over study by Ferguson et al assessed a fixed position, boil and bite MRA [30], and the second study assessed a partly adjustable custom appliance [31]. Patients were randomly assigned to 4 months of treatment first with the MRA or with CPAP and then they crossed over to the other treat-

ment for 4 months. Treatment success for the fixed position MRA was 48% (reduction in AHI to  $\leq 10$  per hour with relief of symptoms). The appliance was well tolerated and had fewer side effects than CPAP, but some patients (24%) were unable or unwilling to use the fixed position MRA because of poor overnight retention or discomfort. The MRA was effective in reducing snoring in most patients and reducing excessive daytime sleepiness. The partly adjustable custom MRA was successful in treating 55% of patients (AHI  $\leq 10$  per hour and relief of symptoms). In these three published prospective cross-over studies of MRA therapy versus CPAP in the treatment of mild to moderate OSA, CPAP was more effective in reducing snoring, improving oxygenation, and decreasing the AHI. In two of the three studies they were equally effective in relieving excessive daytime sleepiness. The MRA had a lower side effect rate (in one study) and was the form of therapy preferred by patients in all three studies.

Randerath et al conducted a randomized cross-over study of an intraoral sleep apnea device (ISAD) versus CPAP in patients with mild to moderate OSA (AHI between 5 and 30 per hour) [32]. The appliance was arbitrarily set at two thirds of maximum mandibular protrusion and was not further adjusted during the study. CPAP was titrated to an effective pressure in the laboratory. After 6 weeks of therapy, CPAP was more effective at improving snoring, AHI, and oxygenation. The ISAD was not particularly effective at reducing the AHI (baseline AHI  $17.5 \pm 7.7$  to  $13.8 \pm 7.7$  at 6 weeks;  $P = NS$ ), although patients reported greater ease of use and higher compliance with the ISAD. Overall only 30% of patients (6/20) had an AHI of less than 10 per hour with the ISAD. The relatively low level of efficacy of the ISAD may be related to the lack of titration of the appliance during the 6-week period of therapy.

Engleman et al published a randomized cross-over study of CPAP and an oral appliance in patients with a range of severity of OSA (AHI 11–43 per hour) and at least two symptoms of OSA [33]. The patients were selected for the presence of reported sleepiness. In addition to the usual outcomes, the study included a maintenance of wakefulness test, the functional outcomes of sleep questionnaire, the Short Form 36 health survey (SF-36), and an assessment of cognitive performance. The appliance was set at roughly 80% of maximum mandibular protrusion. CPAP was more effective than the oral device for improving AHI and subjective ratings of daytime function, even in the patients with milder OSA (AHI between 5 and 15). There were no differences between the treatments in the effect on objective measures of sleepiness or

cognition or patient preference. Preference for CPAP therapy over the oral appliance was related to a higher body mass index and greater daytime impairment. The authors concluded that CPAP would be the preferred first-line therapy in patients with OSA who have significant functional impairment and sleepiness over an oral appliance, even in patients with mild OSA (defined by a lower AHI).

Three studies have compared different oral appliances or designs. Hans et al evaluated a fixed position appliance (SnoreGuard) and a modified device in 24 patients with mild OSA [35]. The device that protruded the mandible (Device A) was more effective in reducing the AHI than the device that minimally opened the vertical dimension but did not protrude the mandible (Device B). Three out of 10 patients with Device A (30%) had an AHI of less than 10 per hour with the appliance. Four of the 7 subjects who switched to Device A after failing on Device B had an improvement in AHI. Some patients had an increase in AHI using Device A or Device B. Bloch et al conducted a randomized, 21 February 2003 controlled, cross-over study of the Herbst (Fig. 2) and Monobloc (Fig. 3) appliances, both of which set approximately 75% of maximum protrusion [36]. The AHI was less than 10 in 75% of patients with the Monobloc appliance and in 67% of patients with the Herbst appliance. Both devices reduced sleepiness and snoring, but patients felt that the Monobloc device was more effective in reducing symptoms and preferred it for long-term therapy.

A recent randomized, cross-over study evaluated the effect of vertical dimension opening on the efficacy of an oral appliance [37]. The splint was constructed with 4 mm of interincisal opening (MAS-1) or 14 mm of opening (MAS-2). Twenty-three patients wore each appliance for 2 weeks in a random order. Both appliances had similar efficacy in reducing the AHI (complete and partial response 74% with MAS-1 and 61% with MAS-2). Both appliances improved snoring and sleepiness, but there was a trend to more jaw discomfort with MAS-2. Overall, the patients preferred the MAS-1 for long-term therapy. In this short-term study, increasing the vertical opening did not have an impact on appliance efficacy, but there is concern that with long-term use this could have an impact on side effects and complications.

Mehta et al published the first prospective, randomized, placebo-controlled cross-over trial of an MRA for the treatment of OSA [23]. Twenty-eight patients had an acclimatization period during which the mandible was incrementally advanced until symptoms resolved or maximum tolerated protrusion was obtained. Patients were then randomly assigned to

treatment with the placebo followed by the active device or treatment with the active device followed by the placebo (lower plate of the appliance only). A partial response was defined as symptomatic improvement with an AHI reduced by 50% or more, but more than 5 per hour and a complete response was defined as a resolution of symptoms along with an AHI of less than 5 per hour. The active appliance resulted in a partial or complete response in 15 patients or 62.5% (complete response in 9%–37.5%). Seventy-one percent of patients had an AHI of less than 10 per hour with the active appliance. The placebo device had no impact on the AHI or oxygen saturation. The active appliance improved snoring, sleep structure, oxygenation, and daytime symptoms. There were few important side effects and no complications.

A recent study has evaluated the effect of oral appliance therapy on symptoms of OSA in a randomized, cross-over design that compared a mandibular advancement splint to a placebo device [38]. In contrast to most other trials, the study included a multiple sleep latency test to assess the impact of oral appliance therapy on an objective measure of sleepiness. Most of the patients (62 of 73; 85%) had moderate to severe OSA (AHI  $\geq$  15 per hour). 38 patients (52%) reported subjective sleepiness (defined as an Epworth Sleepiness Scale score  $>$  10). On average the appliance was set at 80% of maximum mandibular protrusion. The active splint improved symptoms such as snoring and reduced the AHI by 52% overall, with 63% of patients having a complete or partial response. The active splint reduced the Epworth Sleepiness Scale score and increased the mean sleep latency significantly when compared with the placebo device.

In summary, MRAs are an effective treatment option for many patients with OSA, including some patients with more severe OSA (higher AHI). They improve snoring and daytime symptoms and reduce the AHI and improve oxygenation during sleep. They are not as effective as CPAP in reducing the AHI or snoring. In some studies they were not as effective in reducing symptoms of sleepiness as CPAP but in other studies they were. Overall, CPAP is a more effective treatment than an MRA and should be considered first-line therapy in patients with more severe symptoms and perhaps in patients with more severe OSA, particularly if there is significant impairment of oxygenation.

#### *Tongue repositioners*

Tongue repositioning devices include the TRD, which is the best studied of these devices. The TRD is a custom-made soft acrylic appliance that covers the

upper and lower teeth and has an anterior plastic bulb. It uses negative suction pressure to hold the tongue in a forward position inside the bulb. In 1982, Cartwright and Samelson reported their initial experience with the TRD in 20 patients [40]. Fourteen of the 20 patients had undergone polysomnography before and with the TRD. There was a reduction in AHI of approximately 50%, although patients only wore the TRD half the night. Cartwright reported a second uncontrolled study of the TRD in 16 patients [41]. Treatment success in this study was defined as a reduction in apnea index to the normal range (0–6 per hour) or a 50% reduction in apnea index. 69% were successfully treated by the TRD by these criteria. In another case series that evaluated the TRD in 15 patients, the success rate was reported as 73% for the reduction of the AHI to less than 10 per hour [42].

#### **Side effects and complications**

In a review published in 1995, the authors found nine studies that reported side effects and complications [1]. Excessive salivation and temporary discomfort after awakening were commonly reported. In one long-term study, 3 out of 20 patients stopped the device because of temporomandibular joint pain, but the pain ceased when they stopped treatment [43]. In another study, 3 out of 14 patients reported a sense of altered occlusion, but it was not systematically studied [44]. In most short-term studies of oral appliance therapy published since the 1995 review article, side effects were common but generally minor and no serious complications were generally observed. Several long-term studies have been published that systematically have evaluated side effects and complications from oral appliance therapy.

Pantin et al assessed 132 of 191 (69%) patients consecutively treated with a mandibular advancement splint over a 5-year period and performed a dental examination on 106 of them [45]. Ten patients had discontinued using the appliance because of minor dental side effects. They documented occlusal changes in 14% cases, and in two cases the changes were great enough to recommend that the patient stop treatment. Marklund et al investigated orthodontic side effects of a soft and a hard acrylic MRA in 75 patients who reported using the device more than 50% of nights for approximately 2.5 years [46]. Overbite and overjet decreased, and 3 patients reported a permanent change in occlusion. Hard acrylic appliances and larger amounts of protrusion were associated with more occlusal changes.

Fritsch et al evaluated 22 patients who had used either a Monobloc or a Herbst oral appliance for the treatment of OSA [47]. Common side effects included mucosal dryness (86%), tooth discomfort (59%), excessive salivation (55%), jaw pain (41%), and occlusal changes (32%), but they were described as minor side effects. Long-term appliance use was associated with small orthodontic changes: decreased overjet and overbite, retroclined maxillary incisors, and slight anterior movement of the first mandibular molars. Patients reported that symptoms caused by these changes generally resolved after a few minutes in the morning. A detailed study of skeletal and dental changes with mandibular advancers in 100 patients found similar results [48]. At 6 months of follow-up, a vertical change in condylar position was noted, the total anterior and posterior facial height was increased, and overbite and overjet were decreased. After 24 months of treatment, similar changes were noted but the decrease in overbite and overjet was more marked related to proclination of the mandibular incisors. By 30 months of reported regular MRA use, the proclination of the mandibular incisors was more pronounced. The author did not comment on whether these changes led to any clinical problems for the patients who used the oral device. Overall, there is a degree of occlusal change in patients with long-term MRA use, and these changes must be monitored and dealt with when they arise. Patients must be informed of the potential for occlusal change when they embark on oral appliance therapy.

#### *Worsening of sleep apnea*

Occasionally, an oral appliance can worsen apnea severity [8,27,31,35,41]. In one of the more recent trials, 4 of 28 subjects (14%) had an increase in AHI with the appliance. The reason for this increase could not be determined from a review of the patient data [27].

#### **Treatment compliance**

Some studies in the 1995 review reported the long-term compliance of patients using an oral appliance. Reported regular appliance use was in the range of 75% to 100% for most of the studies, with one study having a low compliance rate of only 50%. More recent studies have had 76% to 90% of patients reporting regular use [14,26]. In two of the cross-over studies that compared oral appliances to CPAP, compliance was measured by patient reports [30,31]. There was no difference in reported nightly use of approximately 60% for all treatment arms. Until

objective compliance monitors are available, the actual long-term compliance rates will be uncertain given the unreliability of patient self-report for treatment usage.

#### **Titration of oral appliance therapy**

Relative medical contraindications to first-line therapy with an oral appliance include severe OSA, severe excessive daytime sleepiness, and marked arterial oxygen desaturations during sleep (eg, obesity-hypoventilation). It may take time to optimize the anterior position of the appliance and optimize treatment success. Two studies have assessed overnight titration of an oral appliance to determine the effective therapeutic position [49,50]. This is a promising approach that may allow better identification of patients in whom an oral device might be effective. CPAP therapy can be titrated to the optimal pressure in a single night and overall is more effective than oral appliance therapy at reducing the AHI and correcting abnormalities of oxygenation [30,31,34]. If an appliance could be titrated more rapidly, then patients with more severe OSA could be treated without delay.

#### **Predictors of treatment outcome**

##### *Clinical predictors*

Many studies have evaluated variables that may be associated with treatment outcome (Box 1). Most studies have been underpowered to find a significant relationship between treatment outcome and these variables. A younger age [32,51], lower body mass index [41,51], lower neck size [23], positional OSA [41,52,53], and lower AHI [8,23,34,51,54] and further amounts of mandibular protrusion [55] have been related to improved treatment response. Some studies, however, have demonstrated reasonably good success rates in patients with more severe OSA [4,23,25,27,50,56].

##### *Craniofacial and dental predictors*

Published studies have used various imaging techniques to assess the upper airway and the factors associated with treatment response. Several features from cephalometry, including a smaller or narrow oropharynx [11,51], smaller overjet [51], normal mandible length [57], shorter mandibular plane to hyoid distance [10], shorter soft palate length [10], smaller upper to lower facial height ratios [58],

**Box 1. Predictors of oral appliance efficacy***Clinical predictors*

Younger age  
 Lower body mass index  
 Lower neck circumference  
 Positional OSA (worse supine)  
 Lower AHI (not a consistent predictor)  
 Increased protrusion of appliance

*Dental and craniofacial variables*

Smaller and/or narrow oropharynx  
 Smaller overjet  
 Normal mandible length  
 Shorter mandibular plane to hypoid distance  
 Shorter soft palate length  
 Smaller upper to lower facial height ratios  
 Normal or reduced lower facial height  
 Small soft palate and tongue  
 Increased retropalatal airway space  
 Larger angle cranial base to mandibular plane

normal or reduced lower facial height [57], small soft palate and tongue [57], increased retropalatal airway space [23], and larger angle between the anterior cranial base and mandibular plane [23] are associated with improved outcome. Some authors have suggested that a more micrognathic or retrognathic mandible is associated with improved treatment response [59]. Finally, hypopharyngeal closure that causes OSA may be associated with improved treatment outcome, but many patients with velopharyngeal closure still get a good result [27].

**Indications for oral appliance therapy**

The American Academy of Sleep Medicine has published guidelines about the use of oral appliance therapy in the treatment of OSA [2]. These guidelines stated that oral appliances are indicated as first-line therapy in patients with simple snoring and mild OSA and as second-line therapy for patients with moderate to severe OSA when other therapies have failed. At the time the guidelines were published the available studies of oral appliance therapy were only uncontrolled, largely retrospective case series. Since then,

many prospective studies have been published, including controlled clinical trials with comparisons to CPAP, other appliances, and placebo [23,30,31, 34–36]. With evidence of effectiveness from randomized controlled trials it is reasonable to expand the indications for first-line therapy with an oral appliance to the treatment of patients with moderate OSA.

The guidelines defined the roles of the physician and dentist in the provision of oral appliance therapy [2]. Physicians, preferably trained in sleep disorders, perform the initial assessment and determine whether the patient is “medically” suitable for oral appliance therapy. A dentist skilled in this type of treatment determines the patients’ “dental” suitability for oral appliance treatment from a full assessment of oral and dental health.

Treatment must be individualized to each patient, with the dentist choosing the most appropriate oral appliance. Tongue repositioning devices, such as the TRD, are used particularly in patients with large tongues or inadequate healthy teeth to use an MRA. In general, MRAs require an adequate number of healthy teeth for good retention. Severe temporomandibular joint problems, inadequate protrusive ability, and advanced periodontal disease are relative contraindications to the use of an MRA. In a study of 100 patients consecutively assessed by oral and maxillofacial surgeons, 34% of patients had primary contraindications to therapy and 16% had dental problems or concerns about temporomandibular joint function that would require careful dental follow-up [60]. Although many patients may be medically suitable for oral appliance therapy, they require a careful assessment by a qualified dental practitioner to determine if dental contraindications are present.

Long-term dental follow-up includes optimizing the appliance, monitoring retention, and assessing effectiveness. Periodic adjustments and repairs may be required. Monitoring dental health, side effects, and complications of therapy is also important. Medical follow-up is necessary to evaluate treatment response and assess for recurrence of OSA. It is recommended that follow-up sleep studies be performed to verify the improvement in apnea, oxygenation, and sleep fragmentation by the oral appliance [2]. This recommendation is supported by the evidence that some patients have an increase in AHI with oral appliance treatment [8,27,31,35,41].

**Future directions**

Future randomized controlled trials are needed to compare the effectiveness of different types of appli-

ances and different design features (eg, the amount of vertical opening). The effect of oral appliances on excessive daytime sleepiness and performance must be determined with objective and validated tools. The precise indications, complication rates, and reasons for treatment failure must be determined for each oral appliance if it is going to be used in clinical practice. Ongoing refinements of appliance design eventually may lead to improved treatment outcomes. Only when the mechanisms of action of oral appliance therapy are fully understood can more effective appliances be developed. On the horizon for the field of oral appliance therapy is the introduction of a compliance monitor that will allow an objective determination of appliance usage. Several investigators also are developing systems that would allow overnight titration of oral appliances in the sleep laboratory. This might ultimately shorten the time from initiation of oral appliance therapy to optimization of the appliance.

### Summary

The development of oral appliance treatment for OSA represents an important step in the management of this disease. Randomized, controlled clinical trials have shown them to be an effective treatment option for snoring and OSA in some patients, particularly patients with less severe OSA or simple snoring and patients who have failed other treatment modalities. Although oral appliances are not as effective as CPAP therapy, they work in most patients to relieve symptoms and apnea and are well tolerated by patients. Most patients report improvements in sleep quality and excessive daytime sleepiness. Short-term side effects are generally minor and are related to excessive salivation, jaw and tooth discomfort, and occasional joint discomfort. These symptoms may lead to discontinuation of appliance therapy but usually improve in most patients over time. Serious complications are not common, but occlusal changes are more common than previously believed.

### References

- [1] Schmidt-Nowara W, Lowe A, Wiegand L, Cartwright R, Perez-Guerra F, Menn S. Oral appliances for the treatment of snoring and obstructive sleep apnea: a review. *Sleep* 1995;18:501–10.
- [2] American Sleep Disorders Association. Practice parameters for the treatment of snoring and obstructive sleep apnea with oral appliances. *Sleep* 1995;18:511–3.
- [3] Marklund M, Franklin KA. Dental appliances in the treatment of snoring: a comparison between an activator, a soft-palate lifter, and a mouth-shield. *Swed Dent J* 1996;20:183–8.
- [4] Barthlen GM, Brown LK, Wiland MR, Sadeh JS, Patwari J, Zimmerman M. Comparison of three oral appliances for treatment of severe obstructive sleep apnea syndrome. *Sleep Medicine* 2000;1:299–305.
- [5] Ferguson KA, Love LL, Ryan CF. Effect of mandibular and tongue protrusion on upper airway size. *Am J Respir Crit Care Med* 1997;155:1748–54.
- [6] Isono S, Tanaka A, Sho Y, Konno A, Nishino T. Advancement of the mandible improves velopharyngeal airway patency. *J Appl Physiol* 1995;79:2132–8.
- [7] Isono S, Tanaka A, Tagaito Y, Sho Y, Nishino T. Pharyngeal patency in response to advancement of the mandible in obese anesthetized persons. *Anesthesiology* 1997;87:1055–62.
- [8] Schmidt-Nowara WW, Meade TE, Hays MB. Treatment of snoring and obstructive sleep apnea with a dental orthosis. *Chest* 1991;99:1378–85.
- [9] Ishida M, Inoue Y, Suto Y, Okamoto K, Ryoke K, Higami S, et al. Mechanism of action and therapeutic indication of prosthetic mandibular advancement in obstructive sleep apnea syndrome. *Psychiatry Clin Neurosci* 1998;52:227–9.
- [10] Eveloff SE, Rosenberg CL, Carlisle CC, Millman RP. Efficacy of a Herbst mandibular advancement device in obstructive sleep apnea. *Am J Respir Crit Care Med* 1994;149:905–9.
- [11] Mayer G, Meier-Ewert K. Cephalometric predictors for orthopaedic mandibular advancement in obstructive sleep apnoea. *Eur J Orthod* 1995;17:35–43.
- [12] Battagel JM, L'Estrange PR, Nolan P, Harkness B. The role of lateral cephalometric radiography and fluoroscopy in assessing mandibular advancement in sleep-related disorders. *Eur J Orthod* 1998;20:121–32.
- [13] Liu Y, Lowe AA. Factors related to the efficacy of an adjustable oral appliance for the treatment of obstructive sleep apnea. *Chin J Dent Res* 2000;3:15–23.
- [14] Johal A, Battagel JM. An investigation into the changes in airway dimension and the efficacy of mandibular advancement appliances in subjects with obstructive sleep apnoea. *Br J Orthod* 1999;26:205–10.
- [15] Battagel JM, Johal A, L'Estrange PR, Croft CB, Kotecha B. Changes in airway and hyoid position in response to mandibular protrusion in subjects with obstructive sleep apnoea (OSA). *Eur J Orthod* 1999;21:363–76.
- [16] Tsuiki S, Hiyama S, Ono T, Imamura N, Ishiwata Y, Kuroda T, et al. Effects of a titratable oral appliance on supine airway size in awake non-apneic individuals. *Sleep* 2001;24:554–60.
- [17] Gale DJ, Sawyer RH, Woodcock A, Stone P, Thompson R, O'Brien K. Do oral appliances enlarge the airway in patients with obstructive sleep apnoea? A prospective computerized tomographic study. *Eur J Orthod* 2000;22:159–68.
- [18] Cobo J, Canut JA, Carlos F, Vijande M, Llamas JM. Changes in the upper airway of patients who wear a



- modified functional appliance to treat obstructive sleep apnea. *Int J Adult Orthodon Orthognath Surg* 1995;10:53–7.
- [19] Ryan CF, Love LL, Peat D, Fleetham JA, Lowe AA. Mandibular advancement oral appliance therapy for obstructive sleep apnoea: effect on awake calibre of the velopharynx. *Thorax* 1999;54:972–7.
- [20] Ono T, Lowe AA, Ferguson KA, Pae EK, Fleetham JA. The effect of the tongue retaining device on awake genioglossus muscle activity in patients with obstructive sleep apnea. *Am J Orthod Dentofacial Orthop* 1996;110:28–35.
- [21] Ono T, Lowe AA, Ferguson KA, Fleetham JA. A tongue retaining device and sleep-state genioglossus muscle activity in patients with obstructive sleep apnea. *Angle Orthod* 1996;66:273–80.
- [22] Yoshida K. Effect of a prosthetic appliance for treatment of sleep apnea syndrome on masticatory and tongue muscle activity. *J Prosthet Dent* 1998;79:537–44.
- [23] Mehta A, Qian J, Petocz P, Darendeliler MA, Cistulli PA. A randomized, controlled study of a mandibular advancement splint for obstructive sleep apnea. *Am J Respir Crit Care Med* 2001;163:1457–61.
- [24] Millman RP, Rosenberg CL, Carlisle CC, Kramer NR, Kahn DM, Bonitai AE. The efficacy of oral appliances in the treatment of persistent sleep apnea after uvulopalatopharyngoplasty. *Chest* 1998;113:992–6.
- [25] Pancer J, Al-Faifi S, Al-Faifi M, Hoffstein V. Evaluation of variable mandibular advancement appliance for treatment of snoring and sleep apnea [see comments]. *Chest* 1999;116:1511–8.
- [26] Yoshida K. Effects of a mandibular advancement device for the treatment of sleep apnea syndrome and snoring on respiratory function and sleep quality. *Cranio* 2000;18:98–105.
- [27] Henke KG, Frantz DE, Kuna ST. An oral elastic mandibular advancement device for obstructive sleep apnea. *Am J Respir Crit Care Med* 2000;161:420–5.
- [28] Menn SJ, Loube DI, Morgan TD, Mitler MM, Berger JS, Erman MK. The mandibular repositioning device: role in the treatment of obstructive sleep apnea. *Sleep* 1996;19:794–800.
- [29] Marklund M, Sahlin C, Stenlund H, Persson M, Franklin KA. Mandibular advancement device in patients with obstructive sleep apnea: long-term effects on apnea and sleep. *Chest* 2001;120:162–9.
- [30] Ferguson KA, Ono T, Lowe AA, Keenan SP, Fleetham JA. A randomized crossover study of an oral appliance vs nasal-continuous positive airway pressure in the treatment of mild-moderate obstructive sleep apnea. *Chest* 1996;109:1269–75.
- [31] Ferguson KA, Ono T, Lowe AA, Al-Majed S, Love LL, Fleetham JA. A short term controlled trial of an adjustable oral appliance for the treatment of mild to moderate obstructive sleep apnoea. *Thorax* 1997;52:362–8.
- [32] Randerath WJ, Heise M, Hinz R, Ruehle KH. An individually adjustable oral appliance vs continuous positive airway pressure in mild-to-moderate obstructive sleep apnea syndrome. *Chest* 2002;122:569–75.
- [33] Engleman HM, McDonald JP, Graham D, Lello GE, Kingshott RN, Coleman EL, et al. Randomized crossover trial of two treatments for sleep apnea/hypopnea syndrome: continuous positive airway pressure and mandibular repositioning splint. *Am J Respir Crit Care Med* 2002;166:855–9.
- [34] Clark GT, Blumenfeld I, Yoffe N, Peled E, Lavie P. A crossover study comparing the efficacy of continuous positive airway pressure with anterior mandibular positioning devices on patients with obstructive sleep apnea. *Chest* 1996;109:1477–83.
- [35] Hans MG, Nelson S, Luks VG, Lorkovich P, Baek SJ. Comparison of two dental devices for treatment of obstructive sleep apnea syndrome (OSAS). *Am J Orthod Dentofacial Orthop* 1997;111:562–70.
- [36] Bloch KE, Iseli A, Zhang JN, Xie X, Kaplan V, Stoeckli PW, et al. A randomized, controlled crossover trial of two oral appliances for sleep apnea treatment. *Am J Respir Crit Care Med* 2000;162:246–51.
- [37] Pitsis AJ, Darendeliler MA, Gotsopoulos H, Petocz P, Cistulli PA. Effect of vertical dimension on efficacy of oral appliance therapy in obstructive sleep apnea. *Am J Respir Crit Care Med* 2002;166:860–4.
- [38] Gotsopoulos H, Chen C, Qian J, Cistulli PA. Oral appliance therapy improves symptoms in obstructive sleep apnea: a randomized, controlled trial. *Am J Respir Crit Care Med* 2002;166:743–8.
- [39] Ferguson KA. Oral appliance therapy for the treatment of obstructive sleep apnea. *Semin Respir Crit Care Med* 1998;19:157–64.
- [40] Cartwright RD, Samelson CF. The effects of a nonsurgical treatment for obstructive sleep apnea. *JAMA* 1982;248:705–9.
- [41] Cartwright RD. Predicting response to the tongue retaining device for sleep apnea syndrome. *Arch Otolaryngol* 1985;111:385–8.
- [42] Cartwright R, Ristanovic R, Diaz F, Caldarelli D, Alder G. A comparative study of treatments for positional sleep apnea. *Sleep* 1991;14:546–52.
- [43] Clark GT, Arand D, Chung E, Tong D. Effect of anterior mandibular positioning on obstructive sleep apnea. *Am Rev Respir Dis* 1993;147:624–9.
- [44] Nakazawa Y, Sakamoto T, Yasutake R, Yamaga K, Kotorii T, Miyahara Y, et al. Treatment of sleep apnea with prosthetic mandibular advancement (PMA). *Sleep* 1992;15:499–504.
- [45] Pantin CC, Hillman DR, Tennant M. Dental side effects of an oral device to treat snoring and obstructive sleep apnea. *Sleep* 1999;22:237–40.
- [46] Marklund M, Franklin KA, Persson M. Orthodontic side-effects of mandibular advancement devices during treatment of snoring and sleep apnoea. *Eur J Orthod* 2001;23:135–44.
- [47] Fritsch KM, Iseli A, Russi EW, Bloch KE. Side effects of mandibular advancement devices for sleep apnea treatment. *Am J Respir Crit Care Med* 2001;164:813–8.
- [48] Robertson CJ. Dental and skeletal changes associated with long-term mandibular advancement. *Sleep* 2001;24:531–7.

- [49] Raphaelson MA, Alpher EJ, Bakker KW, Perlstrom JR. Oral appliance therapy for obstructive sleep apnea syndrome: progressive mandibular advancement during polysomnography. *Cranio* 1998;16:44–50.
- [50] Pételle B, Vincent G, Gagnadoux F, Rakotonanahary D, Meyer B, Fleury B. One-night mandibular advancement titration for obstructive sleep apnea syndrome: a pilot study. *Am J Respir Crit Care Med* 2002;165:1150–3.
- [51] Liu Y, Lowe AA, Fleetham JA, Park YC. Cephalometric and physiologic predictors of the efficacy of an adjustable oral appliance for treating obstructive sleep apnea. *Am J Orthod Dentofacial Orthop* 2001;120:639–47.
- [52] Marklund M, Persson M, Franklin KA. Treatment success with a mandibular advancement device is related to supine-dependent sleep apnea. *Chest* 1998;114:1630–5.
- [53] Yoshida K. Influence of sleep posture on response to oral appliance therapy for sleep apnea syndrome. *Sleep* 2001;24:538–44.
- [54] O'Sullivan RA, Hillman DR, Mateljan R, Pantin C, Finucane KE. Mandibular advancement splint: an appliance to treat snoring and obstructive sleep apnea. *Am J Respir Crit Care Med* 1995;151:194–8.
- [55] de Almeida FR, Bittencourt LR, de Almeida CI, Tsuiki S, Lowe AA, Tufik S. Effects of mandibular posture on obstructive sleep apnea severity and the temporomandibular joint in patients fitted with an oral appliance. *Sleep* 2002;25:507–13.
- [56] Lowe AA, Sjöholm TT, Ryan CF, Fleetham JA, Ferguson KA, Remmers JE. Treatment, airway and compliance effects of a titratable oral appliance. *Sleep* 2000;23:S172–8.
- [57] L'Estrange PR, Battagel JM, Harkness B, Spratley MH, Nolan PJ, Jorgensen GI. A method of studying adaptive changes of the oropharynx to variation in mandibular position in patients with obstructive sleep apnoea. *J Oral Rehabil* 1996;23:699–711.
- [58] Liu Y, Zeng X, Fu M, Huang X, Lowe AA. Effects of a mandibular repositioner on obstructive sleep apnea. *Am J Orthod Dentofacial Orthop* 2000;118:248–56.
- [59] Yoshida K. Prosthetic therapy for sleep apnea syndrome. *J Prosthet Dent* 1994;72:296–302.
- [60] Petit FX, Pépin JL, Bettega G, Sadek H, Raphaël B, Lévy P. Mandibular advancement devices: rate of contraindications in 100 consecutive obstructive sleep apnea patients. *Am J Respir Crit Care Med* 2002;166:274–8.