Dental Sleep Appliance Therapy for the Treatment of Obstructive Sleep Apnea

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Abbreviations

A/P	Anterior/posterior
AADSM	American Academy of Dental Sleep Medicine
AASM	American Academy of Sleep Medicine
AHI	Apnea-hypopnea index
BMI	Body mass index
BULL	Buccal upper lingual lower
CPAP	Continuous positive pressure
CT	Computerized tomography
DISE	Drug-induced sleep endoscopy
DSA	Dental sleep appliance
DSAT	Dental sleep appliance therapy
MAD	Mandibular advancement device
MAS	Mandibular advancement splint
MPS	Mandibular positioning simulators
MRA	Mandibular repositioning appliance
MRI	Magnetic resonance imaging

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NPG	Nasopharyngoscopy
NSAIDS	Nonsteroidal anti-inflammatory drugs
OA	Oral appliance
OB	Overbite
OJ	Overjet
OSA	Obstructive sleep apnea
PSG	Polysomnography
RDI	Respiratory disturbance index
REM	Rapid eye movement
SS	Snore screener
TMJ	Temporomandibular joint
TRD	Tongue retaining device
TSA	Temporary sleep appliance

10.1 Introduction

Obstructive sleep apnea (OSA) is a chronic disorder that affects the majority of the adult population, and effective long-term treatment is necessary to prevent associated health risks. There is strong evidence demonstrating that a custom-fabricated dental sleep appliance (DSA) is as effective as continuous positive airway pressure (CPAP) for patients with mild to moderate OSA, but the efficacy of CPAP has entrenched it as the gold standard of treatment, until now. Higher adherence seen with DSAs makes it comparable to CPAP in treatment effectiveness. Randomized trials show similar improvements in health outcomes between these two treatments. The long-term efficacy of DSAs is more uncertain due to side effects associated with this therapy and age-related progression of OSA itself. Research is needed for better DSA designs related to improving long-term efficacy and reducing side effects. Therapeutic outcomes could also be improved by identifying physiological and polysomnographic predictors of DSA success, which in turn would limit patient frustration. In order to achieve the best results for OSA patients, a dentist must work in close collaboration with the sleep physician to define treatment success and encompass both sleep and general health parameters on an individual basis to improve the diagnosis and management of patients with OSA. This chapter will discuss the clinical relevance of dental sleep appliance therapy (DSAT). It will cover the history of DSA, mechanism of action, predictors for successful treatment, DSA types and designs, record taking, and management of side effects.

10.2 History and Evolution of Dental Sleep Appliance Therapy

The history of functional appliances began in 1879 by Norman W. Kingsley who introduced the first “bite jumping” (advancement) device. A vulcanite (hard rubber) device was designed as a removable bite plane with molar clasps.

Kingsley explained that the goal of the bite jumping device was not to protrude the lower teeth but to change the bite in cases of mandibular retrognathism. Kingsley's bite jumping device is believed by many to be the first functional appliance [1, 2].

Another repositioning appliance was discovered by Dr. Emil Herbst, an orthodontist, in the beginning of the twentieth century. He presented his appliance in 1909 at the Fifth International Dental Congress in Berlin. The Herbst appliance was a fixed appliance (anchored to teeth) for the treatment of skeletal Class II malocclusions. It has bilateral telescopic mechanisms using tubes and plungers connecting the maxillary molar to the mandibular first bicuspids (Fig. 10.1a). This forcefully advanced and kept that position during all mandibular functions such as speech, chewing, biting, and swallowing. Although Herbst developed the appliance in the early 1900s, Hans Pancherz reintroduced it in 1979, ultimately leading to the present day. Pancherz recognized its potential for mandibular growth stimulation, publishing several papers in support of his theory in the field of orthodontics [1, 3].

The Bionator was discovered by Wilhelm Baiter from Bonn. The Bionator appliance is a monoblock repositioning appliance with acrylic on the occlusal surface, indexing the mandible in a protrusive position in the 1960s. In 1977, Dr. William Clark developed the twin block appliance. This is a two dual-arch removable appliance fitting with acrylic pads on the occlusal surface. The twin block appliance has acrylic on the bicuspids on the lower arch and acrylic on the molars of the upper arch. These blocks cause the patient to bite in an advanced jaw position [4, 5]. Edward H. Angle also designed a repositioning device which had pairs of interlocking rings. These rings were soldered to molar bands creating occlusal interferences, forcing patients to posture the mandible in an advanced position, similar to today's MARA [1, 2]. The MARA appliance is the precursor to the dorsal-fin-type appliance coming from the orthodontic field (Fig. 10.1b).

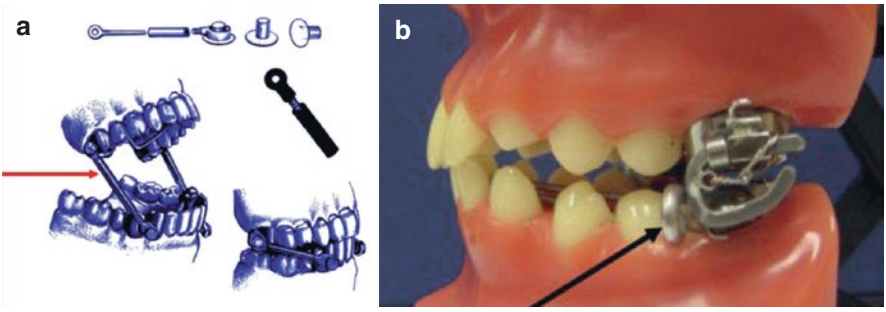

Fig. 10.1 (**a**) Dr. Emile Herbst's original appliance. Red arrow pointing to the fixed bar connected to the maxillary molars and mandibular cuspids. (**b**) MARA appliance, precursor of the dorsal fin appliance. Black arrow points to the metal bar that advances the mandible. (Figure adapted from [1])

10.3 Definition of Dental Sleep Appliance

A dental sleep appliance (DSA), also known as an oral appliance, mandibular repositioning device, or mandibular advancement device, is an apparatus that is worn in the mouth during sleep to maintain a patent oropharyngeal airway to manage OSA and/or snoring. By increasing the vertical dimension and advancing the mandible we are three-dimensional creating more space in the oral cavity for the tongue and moving it anteriorly as it is connected to the mandible via the genial tubercle (insertion of muscle). Therefore by moving the mandible and tongue anteriorly, it places tension in the palatoglossus muscle causing the oropharyngeal muscles to expand laterally, hence creating a patent oropharyngeal airway. It can be one or two separate pieces. Most DSAs are dual arch with some kind of a connector, such as a bar, rods, strap, or wings. DSAs have adjustable mechanisms to advance the mandible in increments, thereby allowing titration and thus dilation of the oropharyngeal airway.

10.3.1 Mechanism of Action of DSA

Various structural and functional factors contribute to the increased collapsibility of the oropharyngeal airway in OSA. Common findings in patients with more severe OSA include airway lumens with smaller cross-sectional areas, increasing numbers of regions showing collapse, increasing degrees of collapse, and finally a general trend to overall longer airways. Superimposed on these factors are several other nonanatomic contributors. These include the neuromuscular control of the pharyngeal muscles (which does not seem to change significantly with increasing OSA severity), and the brain/brainstem arousal system, as well as the biochemical feedback loops (CO_2, O_2H^+), which impact the brainstem ventilatory complex. These latter two clearly change with OSA severity as shown by increases in both the threshold for respiratory events to prompt arousals and an increase in the loop gain of the ventilatory control system [6, 7].

Multiple studies demonstrate that custom-fabricated DSAs are as effective as CPAP for patients with mild to moderate OSA with the most recent being a meta-analysis of noninvasive or minimally invasive treatment options, ranking it second only to CPAP. Oral appliances reposition the lower jaw forward in order to increase the upper airway volume and reduce pharyngeal collapsibility. Magnetic resonance imaging (MRI) studies and nasopharyngoscopy (NPG) both confirm that with a DSA in place, the upper airway enlarges most in the lateral dimension and particularly at the velopharyngeal level (Fig. 10.2), and there is clear and strong displacement of the tongue anteriorly. DSAs, which impact only the anatomic features of OSA, have little or no effect on the loop gain of the brainstem ventilatory control system and also have no effects on either the arousal threshold or pharyngeal dilator muscular activity [8, 9].

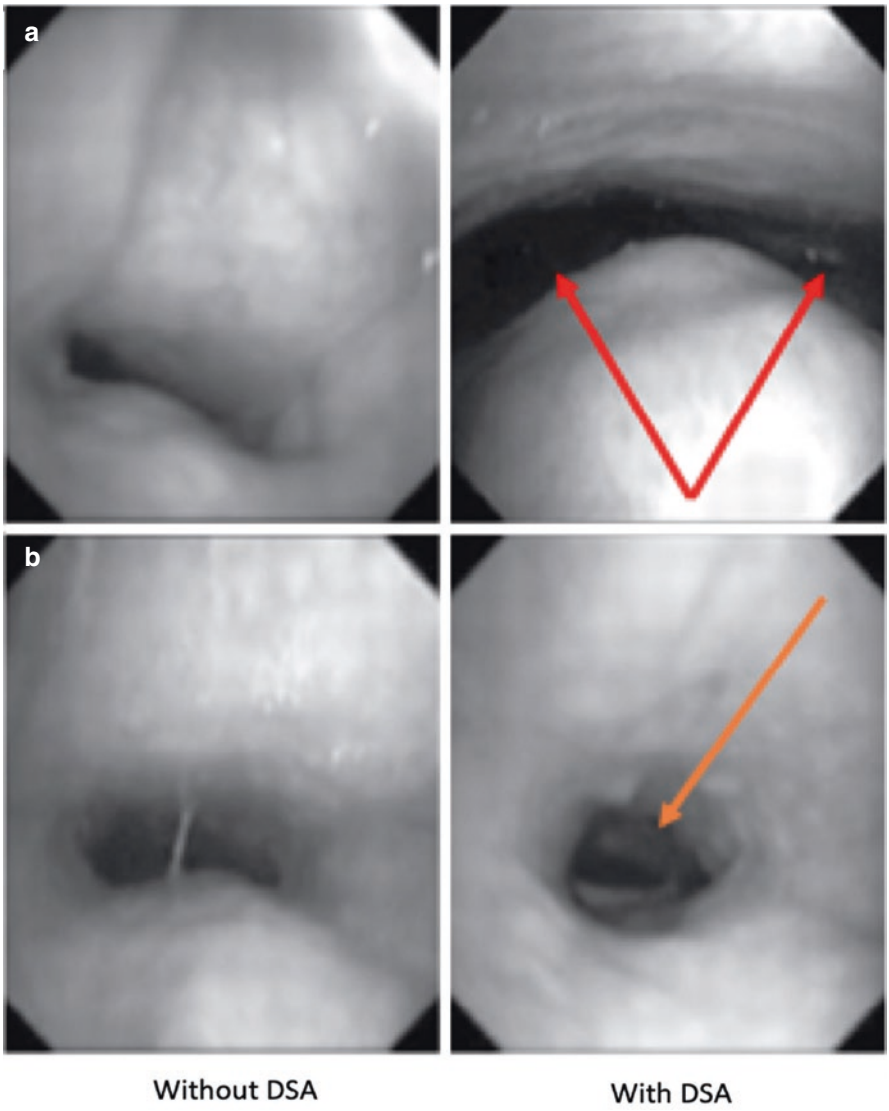

Fig. 10.2 Representative nasopharyngoscopic images of the velopharynx from (**a**) a responder. Notice the red arrows pointing to the great increase in the oropharyngeal airway passage laterally. (**b**) A nonresponder during tidal breathing. Notice the orange arrow pointing to the oropharyngeal airway passage, in the nonresponder. The shape of the airway changes but does on increase in size significantly. (Figure adapted from [10])

10.3.2 Predictors of Success

Clinicians have historically used a patients' unique clinical features [BMI (body mass index], Mallampati score, anthropomorphic factors) and results from physiological studies such as polysomnography (PSG), and in addition cephalometry, as well as computerized tomography (CT) and MRI airway imaging, to help discern the likelihood of responding to DSA therapy [9, 11]. Specific physical factors of a given patient that have been reported to have some positive predictive value include younger age, female sex, lower BMI, smaller neck circumference, lower apnea-hypopnea index (AHI), retracted maxilla and mandible, shorter soft palate, smaller oropharynx, and smaller overjet [12, 13]. A negative physical predictor is an increase in the patient's weight during the course of treatment [11]. The cephalometric factors of patients including shorter soft palate, longer maxilla, shorter distance between mandibular plane and hyoid bone, bigger ANB angle (A point-nasion-B point), and smaller SNB angle (sella-nasion-B point) have also all been identified at one time as predictors of DSA treatment success [11, 13]. It is important to note that the above reports had varying cutoffs for the index or feature being assessed and varying definitions of what represented treatment success [11]. When applying accepted definitions of OSA severity and defined DSA treatment success parameters, to date no airway imaging technology including cephalometry, traditional CT, and cone beam CT as well as MRI has been shown to reliably predict success with a DSA [14].

PSG factors that do support a successful DSA intervention include less severe OSA (lower AHI) and the presence of supine-dependent OSA [9, 13]. Lower required CPAP pressure has been suggested as another simple predictor [11]. A recent study reported that the combination of CPAP maximum pressure >12 cmH_2O and a baseline AHI $\geq$ 30 had a very high predictive value in identifying DSA non-responders, but as the authors clearly stated, this needs prospective validation [15].

Recent studies suggest that methods such as NPG, drug-induced sleep endoscopy (DISE), and multi-sensor studies which measure the change in upper airway collapsibility/patency may have good predictive value for OSA treatment success. During a quantitative analysis of the pharynx using awake NPG, both an improved cross-sectional area expansion ratio and a reduced velopharyngeal collapse during Muller's maneuver have shown to predict positive responses to DSA therapy [11]. Using DISE, both Huntley and Vonk have reported that greater increases in airway dimension observed with manual mandibular advancement maneuvers also predicted a positive response [16, 17]. In-laboratory DSA titration PSG studies using MATRx identify patients who will respond to DSA therapy and also confirm the mandibular position (in 87%) needed to overcome the patient's obstructive respiratory events [18]. Multi-sensor airflow analyses performed by recording data from pressure and/or flow sensors between the mouth and epiglottis are likely to predict success with a DSA when the airway collapse is localized to the oropharynx rather than the velopharynx [19].

In a systematic review, Okuno reported on the above investigatory methods noting that nearly all the studies were derivative in nature rather than validation studies,

making broad application in clinical practice difficult. She summarized that NPG studies have the best combination of predictive accuracy and quality. Multi-sensor flow studies follow in utility, but like NPG these remain invasive prediction methods [11].

Identifying a single validated index test of airway physiology with high predictive accuracy that is more simple, less invasive, and broadly applicable would be very useful in clinical practice and allow for greater disease management efficiency.

Recently, Sutherland attempted to use only qualitative rather than quantitative measures from awake NPG to predict DSA treatment outcome, but this study did not meet with success [20]. A DISE prediction model for dental sleep appliance success recently showed that a 75% improvement in airway dimension could be achieved using a combination of jaw thrust and proper head position [17]. Another study by Remmers et al. documented how MATRx studies may be moved into a patient's home and still successfully identify the most efficacious mandibular position and predict future treatment success in 86% of their cases [21]. Regarding multi-sensor airflow analyses, work is underway to determine if the same detailed collapse prediction information can be extracted from flow loops recorded from standard nasal cannula during routine polysomnography [22].

The concept of "loop gain" is used to quantify the internal amplification of a system governed by feedback loops to develop an unstable behavior such as respiration [23]. The gain can be influenced by the control of variables related to hypercapnia, hypoxic ventilatory responses (controller gain), or the ability to eliminate CO_2 and the size of stored oxygen (plant gain) [24]. Circulation time has effects on the interaction between ventilation and controller gain. Upper airway factors such as resistance have effects on the interaction between controller gain and ventilation [25]. The presence of sleep reduces controller gain relative to wakefulness, and upper airway tone during rapid eye movement sleep (REM) (Fig. 10.3). Higher

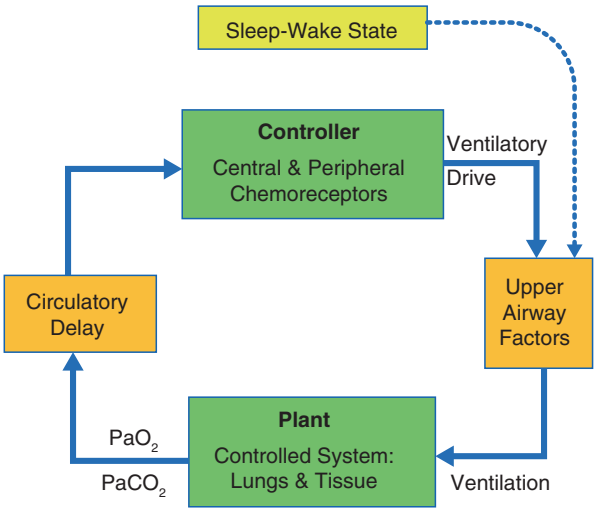

Fig. 10.3 Diagram of breathing during sleep, showing the relationship between ventilation and the feedback system of the two gains. (Figure adapted from [25])

loop gain causes the respiratory control system to become more unstable. A high loop gain promotes recurrent apneas as a response to an initial disturbances, such as a sigh, because it is over compensated, while a low loop gain dampens subsequent oscillations in breathing [25]. High loop gain has been shown to predict an unfavorable response to oral appliances therapy [6]. High loop gain OSA patients need nonanatomical interventions such as supplemental oxygen, acetazolamide, and partial rebreathing [26]. Simple methods to estimate the loop gain of a given patient from home sleep apnea testing (HST) or from awake breath-holding measurements could reduce the time from diagnosis to institution of effective treatment [26, 27].

10.3.3 Dental Sleep Appliance Design and Effects

Dental sleep appliances (DSAs) are designed to improve upper airway configuration and prevent collapse through alteration of jaw and tongue position. DSAs have various terminologies, such as oral appliances (OA), mandibular advancement devices (MAD), mandibular advancement splints (MAS), or mandibular repositioning appliances (MRA).

There are numerous differences in the design features of DSA. Appliances also come in a one-piece (monobloc) versus two-piece design (separate upper and lower plates). Two-piece appliances also vary in permissible lateral jaw movement and in the coupling mechanisms which attach the two arches together. Other variations include the range of advancement, vertical opening, fabrication material, and amount of occlusal coverage [28].

There is no "one-size-fits-all" DSA in improving PSG indices. All DSAs start off with a certain amount of vertical opening which is based on the thickness of material. This vertical opening causes a vertical jaw displacement. A crossover trial compared two levels of vertical opening (4 mm and 14 mm, equivalent advancement) found no detrimental impact on AHI, although patient preference was in favor of the smaller degree of mouth opening [29]. Bite opening should be minimized to improve patient tolerance and increase the beneficial effect on upper airway dimensions. In one study the effects of vertical occlusion on the cross-sectional area of the upper airway at the level of the tongue base during sleep endoscopy were scored and categorized. The study showed that 32 patients (80%) showed an adverse effect of vertical opening, one patient (2.5%) had a positive effect, and seven patients (17.5%) demonstrated an indifferent effect [30]. Milano et al. (2018) suggest that vertical elastics that minimize mouth opening enhance the outcome of DSA treatment in patients with positional OSA [31].

One of the many challenges is to predict side effects with long-term oral appliance therapy. Past studies suggested that DSAs have short-term and long-term side effects such as excess salivation or mouth dryness and temporomandibular joint and dental discomfort [32]. Other negative side effects such as skeletal and dental changes are a problem because they are irreversible [33]. The dental side effects of DSA treatment are a product of protruding the mandible to

achieve a therapeutic effect and duration of treatment (Pliska et al. 2014) [34]. During long-term treatment with DSAs, changes in overjet and overbite, retroclination of the upper incisors, and a proclination of the lower incisors have also been described [35]. This is attributed to a labially directed force to the mandibular incisors and a palatally directed force to the maxillary incisors while the appliance is in place and the mandible attempts to return to a less constrained position [36, 37].

Venema et al. (2018) evaluated dental side effects of anterior traction DSA, bilateral thrust DSA, and CPAP therapy. They observed that CPAP and both DSAs resulted in significant dental changes with long-term use. However, the changes in overjet and anterior–posterior movement in the bilateral thrust and CPAP group were less pronounced than the changes observed in the anterior traction group. CPAP therapy does not protrude the mandible. However, changes in the number of occlusal contact points in the CPAP group may also occur as a result of a tight-fitting and therefore large pressure of the nasal mask on the frontal part of the maxilla, which may result in a retro-inclination of the maxillary incisors [38, 39].

Although occlusal changes may be progressive in some patients during DSA therapy, in over 50%, the effects may represent an improvement to their baseline occlusion [28]. At some point, patients may become disturbed by esthetic changes or with changes in their chewing. Interestingly, many patients are unaware of such changes to their bite, and even noting these changes, the majority of patients concur that positive effects of OSA treatment far outweigh any adverse effects related to dental changes, indicating they are less disturbing than expected [28]. From a sleep apnea standpoint, these bite changes will influence the mechanism of the device, since a forward shift of the lower teeth compared with the upper ones will result in a successively reduced degree of mandibular advancement. This may limit the long-term efficacy of the treatment [9].

10.4 Types of Oral Appliances

10.4.1 Over the Counter

Non-adjustable, over-the-counter “boil and bite” appliances are the cheapest option available. They are constructed of a thermoplastic material that becomes moldable when warmed by immersion in hot water. The user takes a mold of their teeth by biting into the softened material that then sets on cooling. The TOMODO study found that thermoplastic DSAs could reduce AHI. However, they were less effective because they were poorly tolerated and fell out easily, making adherence lower [40]. We also know from other studies that tooth movement is very common even with custom-made DSAs and proper follow-up by a sleep dentist [41]. We can thus assume that there is a great risk that unsupervised use of over-the-counter dental devices can result in occlusal discrepancies that will cost a lot more to resolve than the cost of an oral appliance made by a trained dentist.

10.4.2 Temporary Sleep Appliances

Temporary sleep appliances (TSAS) are fitted by trained dentists which are thermoplastic and adjustable such as MyTAP, EMA now, alpha, apnea guard, blue pro, and others. With all over the counter or TSAs, there is a higher chance of tooth movement and sensitivity due to the material shrinkage while cooling. Vanderveken et al. used a randomized controlled crossover trial which provided primary evidence that a custom-made DSA is more efficacious than a prefabricated made from thermoplastic material in the treatment of snoring and mild sleep apnea. In addition, on the basis of their results, a pre-screening trial with a prefabricated DSA that is directly fitted intraorally cannot be recommended as a convenient low-cost screening strategy to predict success with custom-made DSAs [42].

10.4.3 Tongue Retainer Device

Tongue-retaining device (TRD) was first described in 1982 [43]. These devices use suction to protrude the tongue and improve upper airway structure and function. The earlier designs were similar to a mouthguard, covering the upper and lower teeth to assist retention, with a flexible bulb into which the tongue was protruded. The current design has no dental coverage, reduced bulk, and has the bulb being retained in place only by suction. As they are not reliant on the teeth for retention, TRDs have been proposed as an option for patients with a reduced number or absence of teeth (hypodontia, edentulism) or compromised dental health (periodontal disease). Although the efficacy of TRD in snoring, sleep apnea, and daytime sleepiness has been shown in small populations, its tolerance has appeared to be lower than that of DSA in some studies [44–46].

In one short-term randomized controlled study, it was demonstrated that DSA and TRD had similar effects on AHI but that DSA was associated with greater symptomatic improvement, compliance, and patient preference. This may be the reason why TRD is so seldom prescribed by clinicians.

10.4.4 Dental Sleep Appliances

There is a huge variety of commercially (FDA approved) available DSAs, with different design features [47]. These devices are fabricated by the dentist in coordination with a dental laboratory based on dental models and a bite registration. A custom appliance can either be a one-piece or an adjustable two-piece. A DSA is usually adjusted using a screw located in the midline, anteriorly or in the palate, or laterally with arms of different lengths or screws on both sides of the appliance. Some designs permit the opening of the mandible and/or some lateral movement,

while others fixate the jaws more rigidly. The use of rigid intermaxillary elastics makes these two arches approach each other. The stability of these designs in the longer term is unknown. More research is needed about the influence of various DSA designs on the efficacy of the treatment in order to further improve the quality of this treatment modality.

Several titratable DSAs with different basic advancement mechanisms have been described, are tested in the literature, and are summarized in Fig. 10.4. In a systematic review looking at the efficacy of appliance design in the management of OSA, the authors concluded that all DSAs proved successful in improving AHI/respiratory disturbance index (RDI), and a comparison with inactive appliances suggests that mandibular advancement is crucial in terms of establishing efficacy. The evidence as to whether DSA designs have an impact on PSG indices is conflicting, and more research is needed to investigate how different design features may affect the AHI or RDI in certain patients. There is no "one-size-fits-all" DSA, the choice of which DSA is "best" in improving PSG indices depends on a variety of factors ranging from severity of OSA, materials used and method of fabrication, and design features to individually determined sagittal/vertical protrusion [47]. See Figs. 10.5, 10.6, 10.7, 10.8, 10.9, 10.10, 10.11, 10.12 and 10.13 for various versions of DSAs.

Most of the DSAs can be modified based on what the dentist is trying to accomplish for the specific needs of the patient, such as asking the laboratory to create a space for the patient to breath from the mouth or to add an anterior pad to minimize headaches because the patient is a primary clencher or to add clasps to place rubber bands for the patient to keep the mouth shut while sleeping.

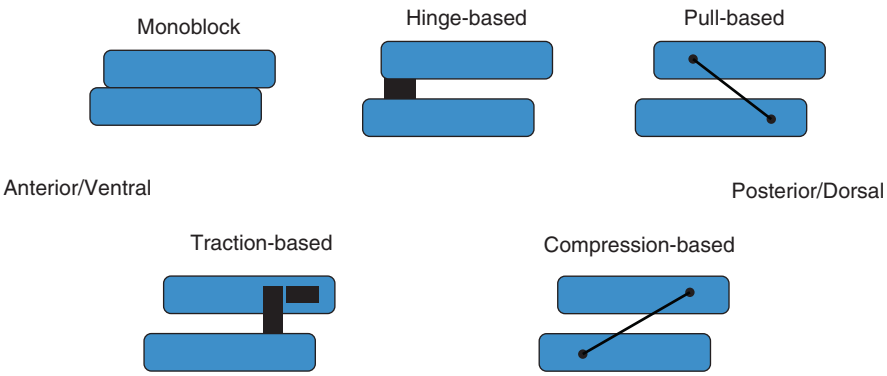

Fig. 10.4 Various common mechanisms for protruding the mandible. Monoblock is the two pieces fused together. Hinge based has a mechanism to hold the mandible forward with an anterior attachment. Pull based has straps connecting the maxillary cuspids to the mandibular molars. Traction based has a "fin" or projection that is anteriorly positioned to an advancement mechanism. Compression based has a rod that attaches between the two arches protruding the mandibular aspect anteriorly [47]. (Figure created by Dr. Mayoor Patel)

Fig. 10.5 Herbst appliance: The Herbst appliance is a dual arch compression-based appliance with connecting bars. (**a**) Classic Herbst has the adjusting component in the bar, where a key is placed and rotated on a screw causing the advancement. (**b**) The Herbst Advance by SomnoMed has a visual calibration indicator. (**c**) ProSomnos (HP). (**a** supplied by True Function Laboratories, **b** supplied by SomnoMed laboratory, **c** supplied by ProSomnos Laboratory)

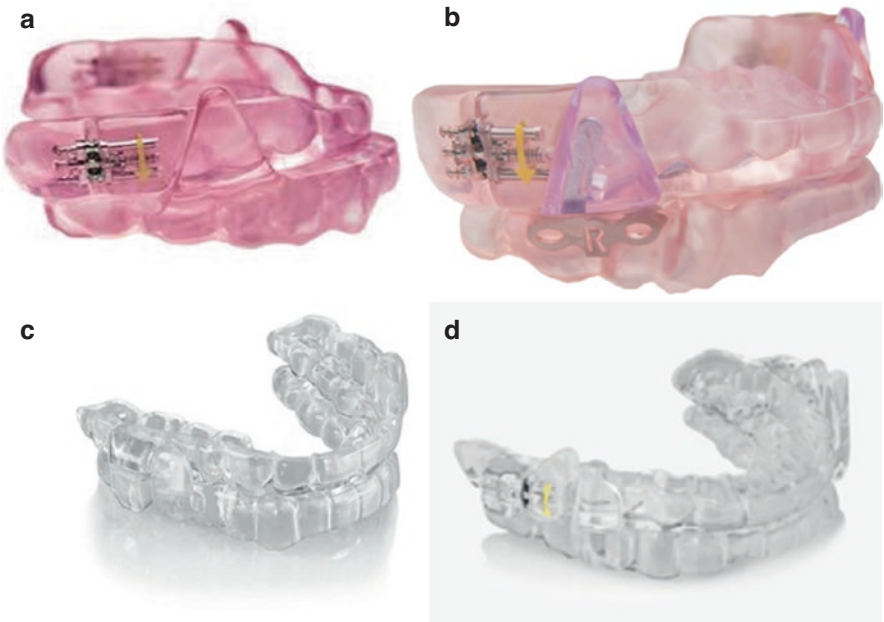

Fig. 10.6 Dorsal fin appliance: The dorsal fin is a dual-arch traction-based appliance. (**a**) The advancement mechanism is on the buccal surface, which consists of a block of acrylic on the mandibular arch in the form of a triangle or square and an orthodontic expansion screw on the upper arch as the advancement mechanism. (**b**) SomnoMed fusion not only has the expansion screws on the maxillary arch but interchangeable wings where the practitioner can choose the type of advancement based on the patient's ability. (**c**, **d**) ProSomnos (IA) and (CA): Two versions have minimal acrylic on the lingual surface for more tongue space from ProSomnos. SomnoMed Fusion also has a lingualess version with minimal acrylic. (**a** supplied by Apex Dental Sleep Laboratory, **b** supplied by SomnoMed laboratory, **c** supplied by ProSomnos Laboratory IA, **d** supplied by ProSomnos Laboratory CA)

Fig. 10.7 EMA appliance: The EMA is made from thermoplastic material which is heated and machine pressed to the shape of the teeth. Buttons are added at the maxillary cuspids and mandibular second molars. The advancement mechanism works by placement of different size and strength of straps. (Figure supplied by Apex Dental Sleep Laboratory)

Fig. 10.8 DreamTAP appliance: The DreamTAP is a dual-arch hinge-based appliance. The hinge can be placed on the maxillary or mandibular arch depending on the choice of the dentist. The advancement mechanism is a screw-type component. (Figure supplied by Airway management)

Fig. 10.9 Oasys Appliance has an upper essix-type retainer and a lower mandibular repositioner with nasal dilators attached to them to improve nasal breathing. Advancement is achieved by turning a screw on the lower component. Lingual buttons are positioned to assist with tongue posturing. (Figure supplied by Dr. Mark Abramson)

Fig. 10.10 Panthera appliance: The Panthera is dual-arch pull-based. It is made of type 12 polyamide, a resistant biocompatible nylon. There are wings on the buccal of the mandibular molars extending up to the level of the maxillary arch. A strap extends from the maxillary cuspids/bicuspids and attaches to the wings. There are different sizes of straps used to advance the mandible in 1 mm increments. (Figure supplied by Apex Dental Laboratories)

Fig. 10.11 Oventus appliance: The Oventus is a dual-arch pull-based appliance. The key feature of the appliance is the airway channel in the anterior section which allows the patient to breathe through their mouth. (Figure supplied by Oventus Medical)

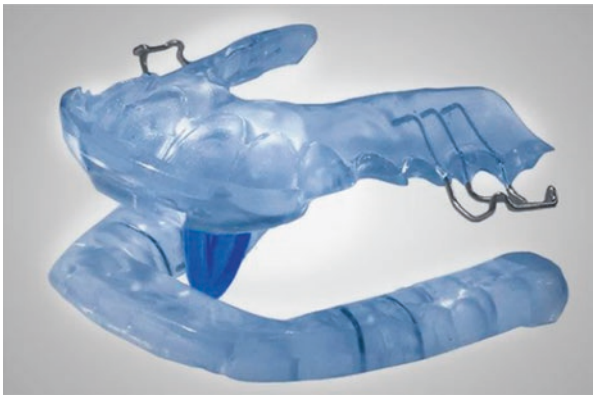

Fig. 10.12 Lamberg DSA: This a two-arch appliance intended for freedom of motion, minimal bulk, and minimal vertical opening. It has a protrusive element based on the arc of opening and closing. The vertical can be increased by adding inserts, and if the treating dentist desires protrusion, the protrusive elements can be changed (seen in blue). This DSA was inspired by the Kois deprogrammer. (Figure supplied by Dr. Steve Lamberg)

Fig. 10.13 Avant appliance: The Avant is a combination pull-base and hinge-based. The advancement mechanism is a long strap which extends from the bilateral mandibular molars and connects to the maxillary central incisors as a hinge. (Figure approved and supplied by SomnoMed Laboratory)

10.5 Combination Therapies

Attempts to use both DSA and CPAP concomitantly have shown that the combination helps reduce the required CPAP pressure, which increases patient comfort. In one pilot study of ten patients partially treated by DSA, but who failed CPAP due to intolerance to prescribed pressure, it was found auto-titration of CPAP pressure while wearing an DSA reduced the average pressure requirement from 9.4 to 7.3 and the residual apnea-hypopnea index from 11.2 ± 3.9 to 3.4 ± 1.5 on combination therapy [13, 48]. Further studies should be conducted to determine the effects of bite change due to limited protrusion in order for treatment to be effective.

10.6 Record Taking

10.6.1 Impression and Scanning

The current gold standard for a complete-arch intraoral impression is the conventional impression made with rigid impression trays and elastomeric impression material. Contrary to conventional impression methods, digital intraoral impression does not require pouring models. Each method has certain advantages and disadvantages. We recommend whatever technique works for you should be utilized. Digital scans offer speed, efficiency, and ability of storing captured information indefinitely and transferring digital images between the dental office and the laboratory. The advantages of the digital scanning systems are improving patient acceptance and reducing the distortion of impression materials and potential cost and time effectiveness.

The accuracy of master casts depends on numerous items, including the water/powder ratio, vacuum versus hand mixing, and the type of dental stone and its compatibility with impression materials. We suggest that impressions are sent to the dental laboratories for pouring and maintaining a consistent standard. Digital scanning resulted in a more time-efficient technique than conventional impressions. In some cases digital scanning may be difficult in capturing the distal buccal of the maxillary second molars.

10.6.2 Bite Registration Techniques

There are many proposed methods in recording the initial jaw position for a DSA. Generally, it is the clinician's experience level, any temporomandibular joint disorder symptoms, and severity of apnea that determines the initial protruded position. A dose-dependent effect of mandibular advancement was demonstrated using four randomized levels of advancement (0%, 25%, 50%, and 75% maximum), with the efficacy of 50–75% advancement greater than 25% and 25% greater than 0% [49]. However, above 50% of the patient's advancement range, there was an associated increase in reported side effects. As vertical dimension increases, the mandible

rotates posteriorly and places itself in a more retrusive location. With an increase in the vertical dimension, the range of mandibular advancement is reduced (0.3 mm for every 1 mm of vertical increase up to 8 mm of interincisal distance) [50]. In one study using MRI in nine subjects, it was observed that the oropharyngeal area tends to be more sensitive to vertical occlusal changes than the velopharynx and hypopharynx. Another important finding is that the greatest dimensional increase throughout the pharynx was obtained with the splint having the lowest amount of vertical occlusion among the splints with the highest degree of mandibular protrusion [51]. A titration approach to determine the optimal level of advancement with gradual increments over time is thought to optimize treatment outcome [52].

10.6.2.1 George Gauge

The George gauge is used with either a 2 mm or 5 mm intrinsical vertical dimension (Fig. 10.14). To use the gauge, start by loosening the lower screw to accommodate the mandibular incisors and tighten to correct fit. Add the 2 mm or 5 mm bite fork by loosening the maxillary knob. The decision on the 2 mm or 5 mm will be based on achieving a minimum of 4 mm clearance on the most posterior teeth interocclusal. Have the patient close into the upper fork (groove) (upper screw loosen) and record the most protrusive and retrusive measurement. For example, if the patient protrudes to the +8 mark on the millimeter scale and can retrude −6, then their protrusive range is 14 mm. Take 60% (this may or may not be your therapeutic position) of that range, which is approximately 9 mm. Add this number to the most retruded position (−6) which now gives you a setting of +3. Slide the marking end of the bite fork over the millimeter scale until its indicator rests over +3 mark, and tighten the upper screw to set the fork to this position. Return to the mouth and take bite registration with putty over the fork; ensure the gauge is in line with the skeletal midline.

10.6.2.2 Pro Gauge

Pro gauge from Airway Technologies varies slightly from the George gauge (Fig. 10.15). The vertical fork thickness openings of the Pro gauge are 4, 6, 9, and 12 mm. The steps in getting your construction bite are very similar to the method described above.

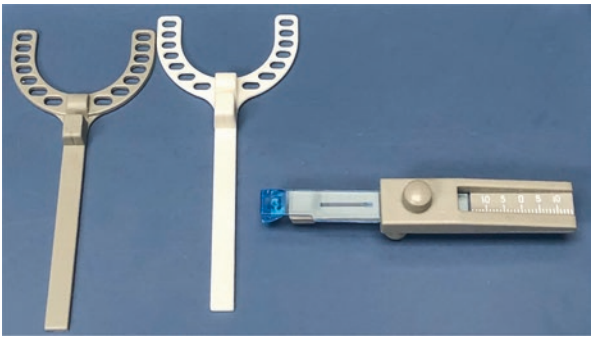

Fig. 10.14 George gauge. (Figure provided by Mayoor Patel)

Fig. 10.15 Pro gauge. (Figure provided by Mayoor Patel)

Fig. 10.16 SOMGauge, supplied by SomnoMed Laboratory

10.6.2.3 SOMGauge

SOMGauge from SomnoMed varies slightly from the George gauge (Fig. 10.16). It allows for an increased measurement of the vertical along with protrusive advancement using knobs to gauge the thickness and protrusion. Steps in getting your construction bite are very similar to the method described for the George gauge.

10.6.2.4 Andra Gauge

Andra gauge is a single compact device that adjusts anterior/posterior (A/P), vertical, and sagittal positions. This will allow you to precisely position the jaw in three dimensions; you use a step-back approach by decreasing the A/P and opening the vertical, so you can find a more compatible position. Unfortunately, the entire device goes to the lab which increases the cost.

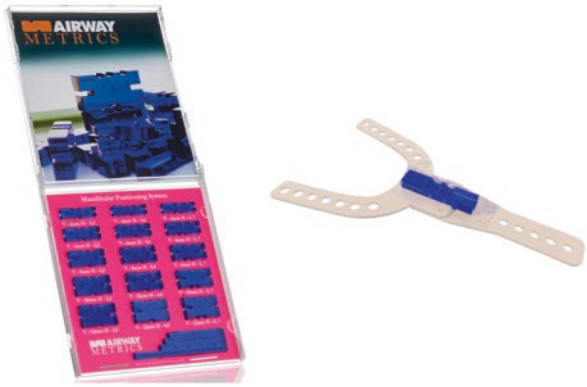

Fig. 10.17 Airway Metric cassette with various sizes and transfer bite fork. (Firude supplied by Airway Metrics)

10.6.2.5 Airway Metrics

This is a three-component system. The primary component consists of a snore screener (SS) and 15 mandibular positioning simulators (MPS) housed in a cassette. The secondary component includes nine vertical titration keys that will work with any device that opens in the anterior (Fig. 10.17). They quickly reveal how much certain anterior/vertical mandibular positions increase the airway and provide a guide for further tuning with the MPS. The SS locates a general airway for closer scrutiny with the MPS to identify a target treatment position and a comfortable starting position for the bite registration. It uses the patient's subjective feedback or quickly interfaces with a pharyngometry mouthpiece (see below). The patient then snores in selected anterior positions at 4, 8, and 12 mm vertical to locate the lowest/absent sound. The best (most quiet) position identified with the SS becomes the area for subsequent MPS tuning for the optimum airway and comfortable treatment position with a device. The 15 MPS allow positioning in over 50 positions in the anterior plane from habitual occlusion to 7 mm anterior of edge-to-edge combined with a vertical plane of 4–12 mm in 2 mm increments. A bite fork and handle quickly fit into the opposite end-slots of the selected MPS to obtain a bite registration at the desired anterior/vertical starting position.

10.6.2.6 Pharyngometer

The Eccovision Acoustic Pharyngometer (Sleep Group Solutions) is used by clinicians to establish a construction bite position. This device uses a wave tube with an attached mouthpiece on which the patient bites down. The mouthpiece consists of a bite plate for the teeth, as well as a flange that is placed between the anterior tooth surface and posterior lip mucosa to provide an acoustic seal. The nasal passages are occluded to prevent any sound waves from escaping. Sound waves are emitted from the wave tube, travel to the airway tissues, and reflect back to a sensor in the wave tube. The acoustic wave amplitude and associated timing is recorded, transmitted to a computer where the data are analyzed, and translated into a pharyngogram. The pharyngogram provides a graphic representation of the oropharyngeal airway anatomy. The *x*-axis corresponds to the distance from the teeth, and the cross-sectional

area (in square centimeters) is denoted on the *y*-axis. The amplitudes of the returning sound waves are converted into data points, which are then plotted on a graph in respect to the *x*- and *y*-axes. The resulting line graph correlates to anatomical landmarks and cavities: the oral cavity, oropharyngeal junction, oropharynx, epiglottis, glottis, and hypopharynx. By taking a baseline reading and several at different vertical and/or protrusive positions of the mandible, a comparison is made to determine the best position. This position is then captured using wax or bite registration methods which will be sent to the lab.

10.6.2.7 Phonetic Bite

This method is based on capturing a starting bite position based on the "S" sound being generated which places the condyle anterior to terminal hinge position [53]. A round separating device is used as a fulcrum on the anterior teeth to capture resting position between "S" sounds counting from 66 to 77. Patients are advised that a separating device would be placed between their front teeth and that, while counting, they would be asked to "stop counting" and allow the mandible to rest on the separating device. Once this position is established, bite registration material is expressed between the maxillary and mandibular teeth to capture the construction bite.

10.7 Managing Side Effects Associated with DSA Therapy

Short-term side effects of DSAs are usually described as mild and transient. Commonly reported in the initial period of DSA therapy include tooth sensitivity or pain, temporomandibular joint discomfort/pain, myofascial pain, dry mouth, excessive salivation, and gum irritation [53–59].

10.7.1 Short-Term Side Effects and Management

10.7.1.1 Tooth Sensitivity

This will be caused by a tight fit of the DSA over the dentition. Therefore, when fitting the DSA, the dental practitioner should make sure that the DSA is a comfortable fit for the patient. If a single tooth has a feeling of tightness using the buccal of the upper and lingual of the lower (BULL) rule is used to make the necessary adjustments on the appliance. If multiple teeth are feeling tightness or sensitivity, it is recommended that the dentist do internal adjustments using pressure indicating paste or articulating paper internally while fitting the DSA over the teeth. If the DSA does not fully seat over the dentition, a new impression and appliance must be fabricated. This is more likely due to an error in impression (distortion) or lab work that would be difficult to resolve chairside.

10.7.1.2 Temporomandibular Joint Dysfunction or Pain

A comprehensive examination should be noted and discussed for the possibility of exacerbation when wearing the DSA, as it does change the joint position. In most cases, advancement typically takes the pressure off retrodiscal tissue, and most patients do well with the use of the DSA. If a patient has a disc displacement without reduction, arthritis, or limited joint function, the advancement of the jaw can put forces on the joint that are not typical for that patient. If a patient develops temporomandibular joint (TMJ) pain or limited opening after wearing the DSA, the dentist should stop the use of the DSA and treat the acute TMJ problem, whether it be pain, inflammation, and/or limited opening with pain. Palliative care for persistent TMJ pain includes resting the joints as much as possible, intermittently applying ice to the affected joints, and adopting a soft diet until the pain resolves. The use of anti-inflammatory and pain medication may aid with resolution. In severe pain where all has failed, a Medrol dose pack may be recommended in accordance with pharmacological recommendations.

Transient jaw pain includes pain or discomfort occurring in the morning upon removal of DSA that disappears spontaneously during the day or with prescribed jaw or bite exercises/techniques. Pain or discomfort of short duration, generally less than a few weeks, may occur intermittently during the use of a DSA, likely occurring during acclimation and titration stages. It is considered to be mild in nature and unlikely to cause treatment abandonment.

A few things to consider when an acute pain is experienced by the patient are the following

1. Do the dental midlines (protruded with DSA) match with the habitual occlusion? If starting by correcting the midline. Dental sleep appliances that have independent right- and left-side advancement mechanisms may be adjusted if necessary to re-establish the midline relationship. If the discrepancy is significant, that appliance may need to be sent back to the dental lab for correcting.
2. The occlusion on the posterior should be evenly balanced. This should be checked with articulating paper. If it is not correct, then the DSA should be adjusted to even the forces placed on the dentition, muscles, and TMJ.
3. Did the symptoms of joint pain begin after several weeks of wearing the DSA? If so, was the patient titrating the appliance and at some point started to experience the pain? This may suggest over titration beyond the point that the TMJ can tolerate. DSA should be retruded to the previous position and determine if that resolves the pain.
4. If DSA is lacking posterior contacts, then adding them should be considered which may increase patient comfort in appliances whose design is limited to contact in the anterior region.
5. An anterior stop that produces posterior disclusion may be added to appliance designs where a flat contact of the maxillary and mandibular elements are present and pain still remains after all the above have been verified.

10.7.1.3 Myalgia/Myofascial Pain

Aarab et al. reported that tenderness in muscles of mastication was more prevalent at 50% and 75% maximum protrusion than at 25% maximum protrusion. However, this approach must be balanced against decreasing the optimal therapeutic effect [60].

First-line treatment considered for myalgia or myofascial pain should be palliative care such as massage, application of heat, and relaxation techniques. If inflammation is suspected, application of cold packs to the affected area may be helpful along with nonsteroidal anti-inflammatory drugs (NSAIDS). The verification and/or correction of midline position and balanced occlusion of the DSA may allow for a more comfortable position for the muscles and other soft tissues if they appear to be acentric. If tenderness in the muscles of mastication continues despite the aforementioned measures, second-line treatments include decreasing the rate of forward titration, decreasing DSA advancement, and reducing vertical dimension. A decrease in the titration rate may be appropriate if the optimal mandibular position has not yet been attained. Therefore, it may be beneficial to advance the appliance at a slower rate than usually prescribed. For example, if the patient is instructed to advance the appliance 0.5 mm twice a week, it may be helpful to decrease the advancement to 0.5 mm once a week.

If the appliance has already been advanced to maximum protrusive position, reducing the amount of advancement may be beneficial. Recommendation of a different DSA design may be necessary if the clinician judges that muscle tenderness is a result of the DSA design that maintains the jaws in a rigid relationship limiting lateral movements.

The practitioner may also consider referral to an additional healthcare provider such as a physical therapist to help alleviate muscle tenderness. If, after repeating the TMJ examination, the clinician is unable to determine the cause of muscle tenderness, referral to a dentist who has undergone advanced education in orofacial and/or craniofacial pain may be appropriate.

If none of the aforementioned options serve to manage the patient's muscle tenderness sufficiently to continue with DSA, permanent discontinuation may be necessary, and the patient should be referred back to the sleep physician to discuss other treatment options.

10.7.1.4 Joint Sounds

TMJ sounds (clicking, popping, or crepitus) secondary to DSA are usually transient and may resolve with time. It is important to understand why the sounds are occurring. Is it a result of a disc reduction that was not evident by examination prior to the initiation of DSA therapy. A past history of joint sounds which may have resolved could explain the pathogenesis of a displaced disc that was reducing leading to a total nonreducing condition which would not produce any sounds. The history would also suggest a period of limited opening which may have improved over time. When joint sounds occur, first-line treatment is to monitor the patient. This involves recording the type and location of the sounds and what movement or activity elicits the sounds. Patient reassurance and counseling

includes discussion about the uncertainty of joint sound resolution, either with continued use of the oral appliance or after discontinuation. If the joint sounds are accompanied by persistent TMJ pain, temporary or permanent discontinuation of the DSA may be warranted.

10.7.1.5 Salivation and Drooling

Salivation and drooling is common in the beginning due to a common reflex known as Pavlovian conditioning. When one places an object in the mouth, salivation begins to dissolve the bolus of food for digestion. Typically the drooling stops within a few hours to a few days. Studies have demonstrated that DSAs are well tolerated despite excessive salivation/drooling and only rarely preclude use. Patients should be informed in advance of possible excessive salivation and helped to understand that it is typically transient over the first few weeks [45, 61, 62].

10.7.1.6 Tongue, Soft Tissue, and Gingival Irritation

Intraoral soft tissue side effects including tongue irritation related to DSA are usually transient and minor if addressed promptly. Mechanical trauma is not unique to DSAs used to treat OSA as it commonly occurs with other oral devices such as night guards, dentures, and orthodontic appliances. Techniques for treating soft tissue irritation include patient reassurance; recommend saline rinse 2–3 times daily; appliance modification focused on recontouring the material to remove sharp, protruding, or offensive features that may impinge on the soft tissues; and application of topical medications. It may also involve the addition of material for the purpose of creating a physical protective barrier or more physiologic contour. Orthodontic wax may be recommended for use by the patient as needed over intrusive appliance components that cannot be recontoured or removed. Typically after some time, there is no need for the wax as the tissues adapt to the irritation. On occasion another DSA design may be selected with a different advancement component in a way that interferes less with the soft tissues.

10.7.1.7 Dry Mouth

Dry mouth can be due to nasal airway resistance, mouth opening from an improper lip seal, or opening during sleeping. The clinician should use rubber bands on the appliance to keep the mouth together or recommend a chin strap commonly used in CPAP therapy. Breathe Right strips or a nasal dilator ("Nose Cones or Mute") may be recommended to improve nasal breathing. When patients are struggling to continue appliance use due to dry mouth, conservative palliative care can be initiated by decreasing the vertical dimension and reducing labial acrylic of the appliance to encourage lip seal or keeping water by the bed for adequate hydration during the night. When it is believed that medications are responsible for dry mouth, consultation with the patient's local treating physician may be beneficial to see if medications can be changed. In some cases utilizing saliva substitutes may be necessary. Products like artificial saliva substitutes could be utilized prior to sleeping. These include Biotène® Oralbalance Moisturizing Gel, Xerostom® Saliva Substitute Gel Pack, and Oracoat XyliMelts.

Limiting tobacco, alcohol, caffeine, and sugary/acidic foods prior to bedtime may be effective in preventing dry mouth during sleep. Avoidance of commercial mouth rinses with alcohol and peroxide may be effective in some cases. When nasal airway resistance appears to be leading to mouth breathing during sleep, evaluation and treatment by an otolaryngologist may be effective.

10.7.1.8 Bite Instability

Bite instability is very common upon removal of the DSA as the jaw has been in a different position for several hours when sleeping. Patients may not be able to bite on their posterior teeth initially (habitual pretreatment position) due to shortening of the lateral pterygoid muscles. There are various methods used to re-establish the pretreatment position every morning. Bite exercises are recommended for the patient to do in the mornings and a few times during the day for a few minutes. These exercises will be discussed at the long-term management (Sect. 10.7.2).

10.7.1.9 Interproximal Gaps

Open interproximal contacts serve as food traps and may concern patients. Development of open contacts has been documented with DSA use and is associated with longer appliance use [36].

If the DSA relies on ball clasps for retention, adjustment or removal of retentive clasps may decrease the occurrence of interdental gaps, but it is noteworthy that interproximal gaps have occurred even when the device was acrylic retained and did not utilize ball clasps [33].

Judicious reduction of interproximal acrylic "fins" which aid in retention may also decrease the occurrence of interproximal gaps by reducing the interproximal forces from the wedging effect of these retentive fins. In addition any significant occlusal "fins" plunging between occlusal embrasures should also be removed.

Daytime use of a distal wraparound retainer, such as a vacuum-formed acrylic splint, to maintain or recapture initial tooth position may also be considered. An orthodontic-type retainer with a distal wraparound spring may also be effective in closing or preventing interproximal gaps.

10.7.2 Long-Term Side Effects and Management

10.7.2.1 Bite Changes

Studies examining long-term side effects of treatment over 5 years have shown significant decreases in overbite (OB) and overjet (OJ), ranging from 0.6–1.91 mm and 0.6–1.24 mm [36, 37, 63]. Pliska et al. demonstrated dental changes associated with DSA treatment of OSA over 11 years of treatment, indicating significant reductions of OB 2.3 mm and OJ 1.9 mm. Also it is clear that the changes in occlusion are

progressive in nature. Rather than reaching a discernible end-point, the reductions in OB and OJ and widening of the lower dental arch continue with ongoing DSA treatment [34].

10.7.2.2 Bite Exercises/Morning Repositioners

Various methods and guides are available to re-establish proper habitual occlusion the following morning after using a DSA. Bite exercises may include having the patient place their tongue up and back, pulling the jaw back and biting on the molars. Another way is to tilt the head back looking up, bite down on the molars clenching, and then bring the head down to a normal position as you look forward. Lastly, doing the chin rest, using the palm or fist pushing on the chin distal/ventral, and they bite down on the molars, clenching 5–10 s (5–10 min). A guide, positioner, or aligner is fabricated at chairside or custom made by a laboratory often made of hard acrylic, thermoplastic, or compressible materials. The guide is adapted to the patient's maxillary and mandibular teeth in habitual occlusion or to dental casts in maximum intercuspation (Fig. 10.18). The guide must be adapted to the patient's maxillary and mandibular teeth in habitual occlusion or to dental casts in maximum intercuspation. These guides are intended to address the occlusal discrepancy noted after the removal of the DSA each morning but also aids the patients to monitor their condition by allowing them to ascertain whether their mandible is correctly aligned every morning.

Each morning after the DSA is removed, the patient should wait a period of time (15–30 min), prior to using the guide. If the guide is used too soon, it may cause muscular and or joint discomfort. The bite exercises mentioned earlier should be done during this time to gradually have the bite start settling on its own. Each morning after the sleep appliance is worn, the patient should bite into the guide until the maxillary and mandibular teeth are fully seated for as long as it takes the teeth to re-establish occlusion. Typical guide use time is 5–10 min, but some rare cases may need longer (30–60 min). In the event that the patient is unable to attain proper habitual occlusion, the patient should contact the DSA provider.

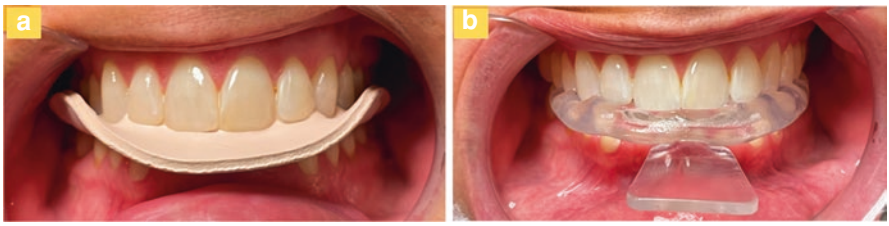

Fig. 10.18 (**a**) AM Aligner form Airway Management. (**b**) TFL Morning positioner from True Function Laboratory

10.8 Long-Term Follow-Up

The long-term efficacy of this intended lifelong treatment is uncertain. Marklund reviewed patients continuously treated with a DSA for at least 15 years and concluded that patients may experience worsening in disease severity and reduced treatment efficacy. Regularly scheduled follow-up visits with renewed sleep studies should be considered for these patients in order to avoid suboptimal or a total loss of effects on sleep apneas [64]. The American Academy of Sleep Medicine and American Academy of Dental Sleep Medicine clinical practice guidelines, published in 2015, "suggests that sleep physicians and qualified dentists instruct adult patients treated with oral appliances for obstructive sleep apnea to return for periodic office visits—as opposed to no follow-up" [65].

Discontinuation or withdrawal of effective CPAP treatment includes the return of sleep apneas in most patients, and the patients may experience the return of daytime symptoms [66, 67]. Moreover, during long-term DSA treatment, sleep apneas remain without the appliance in use [68]. This indicates that an improvement in disease severity is unlikely and further strengthens the need for continuing care.

10.9 Adherence

Effectiveness of the treatment for OSA with DSAs can only be achieved with the patients' adherence to treatment. Sutherland reported that CPAP compliance at 1 year is 58–78%, whereas DSA compliance at 1-year was 84% [28]. A 10-year follow-up prospective study reported 77% adherence with DSA use in 2014 [69]. This favorably compares to the most recently reported long-term CPAP adherence rate of 40% over a 6-year period [70]. Saglam-Aydinatay et al. found that the facilitators associated with continued usage of a DSA was its effectiveness, ease of use, support from their partner, shame caused by disease symptoms, and portability of the appliance [71]. The dropouts that occurred in the first year of DSA use were due to patient complaints of excessive salivation, xerostomia, tooth and gingival discomfort, and self-appreciated lack of efficacy [72–74]. A pictorial representation comparing the many adherence factors between OA and CPAP is found in Fig. 10.19. These results emphasize the need for good communication between the clinician, the patient, and their family.

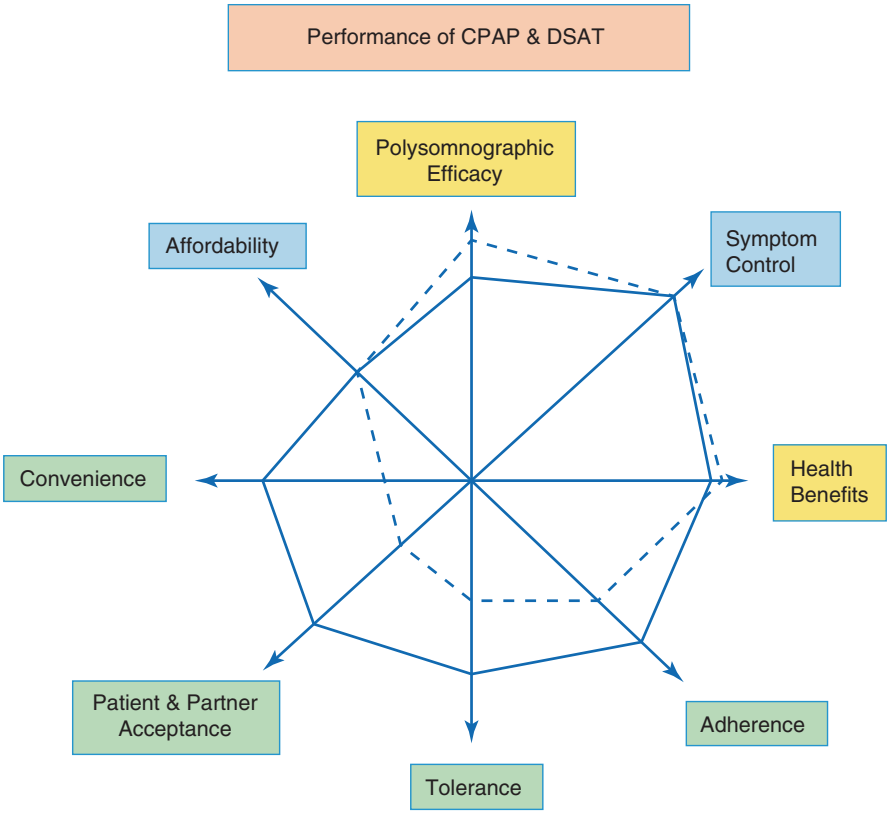

Fig. 10.19 A conceptualized comparison of treatment performance of CPAP and DSAT across various domains. Dotted line represents CPAP and the solid line represents the DSA. The blue represents CPAP and DSAT are viewed as equal. The green represents the DSA as more superior than CPAP and conversely in regard to the orange represents CPAP surpassing the DSA. (Figure adapted from [32])

10.10 Health Outcomes

Despite excessive sleepiness being one of the dominant symptoms of untreated OSA, the effect of treatment whether it be DSA therapy or CPAP appears only demonstrable in more severely affected patients. A recent meta-analysis reported no effect on the ESS score from either DSAs compared with placebo and DSAs compared with CPAP in a group of patients with moderate sleep apnea [9]. This same publication revealed that in contrast, patients with severe OSA experience a reduction in daytime sleepiness as a result of both DSA and CPAP compared with placebo intervention, with CPAP simply being more efficacious [9].

Patients using DSAs regularly describe improvements in somatic symptoms such as headaches, nasal congestion, and insomnia. In controlled studies using inactive

and active DSAs, no clear difference in somatic symptoms could be demonstrated suggesting a strong placebo effect [75]. Studies of OSA patients which assessed the quality of life and mood impacts have been able to demonstrate large effects of DSA therapy particularly when applying the Functional Outcomes of Sleep Questionnaire (FOSQ) and also the Profile of Mood States (POMS) questionnaire, vigor-activity and fatigue-inertia scales [76, 77].

Blood pressure outcomes in a crossover study which monitored 24-h ambulatory blood pressure after 4 weeks of DSA and inactive appliance wear in 61 patients found a reduction in 24-h diastolic but no change in systolic blood pressure [78]. A parallel group pilot study found a 1.8-mmHg reduction in 24-h mean systolic blood pressure with DSA treatment compared to control, with a greater reduction of 2.6 mmHg in a subgroup analysis of hypertensive patients [79]. Yet another study showed an equivalent reduction in morning diastolic blood pressure between DSA and CPAP treatment after 10 weeks [80]. Rietz, Helene et al. showed that women who were treated with DSAs at night experienced a reduction in their nighttime blood pressure compared with women who had used sham devices in a 4-month, randomized trial; men did not experience a reduction [81].

Endothelial dysfunction is recognized as a key early event that precedes or accelerates the development of atherosclerosis and may be predictive of future cardiovascular events. A small randomized crossover trial involving 12 OSA patients demonstrated an equivalent increase in acetylcholine-induced vasodilation between 2 months of DSA and CPAP, with the degree of improvement correlating with decrease in nocturnal oxygen desaturations [82].

Observational and randomized controlled trials have demonstrated beneficial impact of regular CPAP use on cardiovascular outcomes in OSA. Although there are currently no randomized trials comparing cardiovascular morbidity between CPAP and DSA treatment, a recent nonconcurrent cohort study monitored cardiovascular mortality in severe OSA patients on either CPAP or DSA treatment. The study followed 208 control subjects (AHI < 5) and 570 severe OSA patients (177 CPAP treated, 72 OA treated, and 212 untreated) for a median time of 6.6 years. The cardiovascular mortality rate was highest in the untreated OSA group and significantly lower in both treatment groups. There was no difference between CPAP and OA in incidence of fatal cardiovascular events, despite a higher residual AHI in the OA-treated patients [83, 84].

Van Haesendonck's 2015 systematic review of 11 articles addressing the cardiovascular benefits of oral appliance therapy concluded that improvement in blood pressure, endothelial function, and left ventricular function are proven in several independent studies [85]. A controversial study, McEvoy's 2016 study, CPAP for Prevention of Cardiovascular Events in OSA, now often referred to as the "SAVE" study, is significant for the following reason. Therapy with CPAP plus usual care, as compared with usual care alone, did not prevent cardiovascular events in patients with moderate-to-severe OSA and established cardiovascular disease. A significant co-founder was the poor average CPAP use (3.3 h/night) in the treatment group [86].

The different treatment profiles of CPAP (high efficacy/low adherence) and DSAs (moderate efficacy/high adherence) may conceptually result in similar

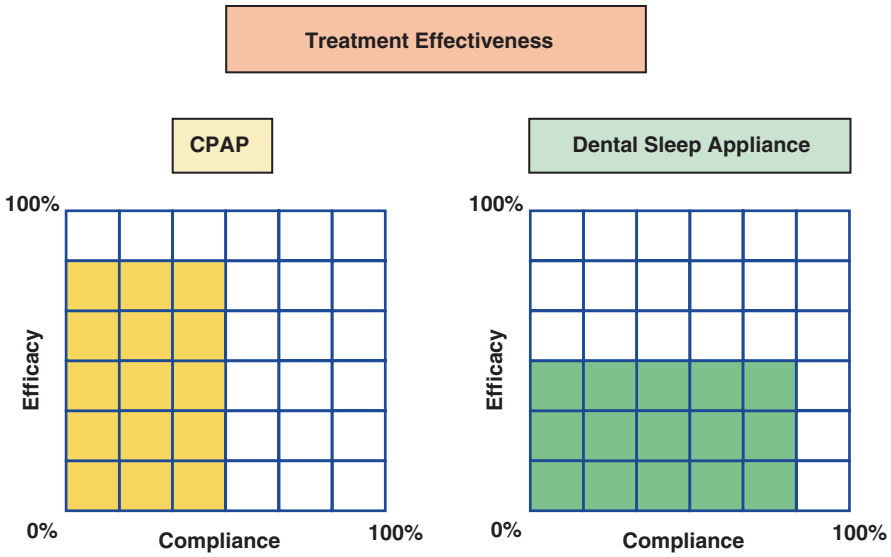

Fig. 10.20 Comparison of treatment effectiveness of CPAP vs. dental sleep appliances. The *x*-axis (compliance) reflects the hours of treatment applied for over the total sleep time when OSA can occur. The *y*-axis (efficacy) reflects the ability of treatment to prevent or treat OSA. "Effectiveness" requires both efficacy and compliance, and the balance of these likely reflects health outcomes. This figure illustrates the scenario of a DSA (green) which is only half as efficacious as CPAP (orange) but has twofold greater compliance which results in equivalent effectiveness. The empty boxes indicate sleep time vulnerable to diseases. (Figure adapted from [87])

profiles of treatment effectiveness. A likely explanation for similarity in key health outcomes is that DSAs are more consistently used for a greater proportion of the total sleep period, compared to CPAP, that is, approximately 6 h/night for 5 nights versus 4 h/night for 4 nights shown in Fig. 10.20 [28].

References

1. Pitcher ZP. Skeletal and dental components of Class II Division 1 correction with the MARA compared to the Standard Edgewise Appliance. 2012. Theses and Dissertations (ETD). Paper 199. https://doi.org/10.21007/etd.cghs.2012.0246.
2. Wahl N. Orthodontics in 3 millennia: functional appliances to midcentury. Am J Orthod Dentofacial Orthop. 2006;129:829–33.
3. Pancherz H, Fackel U. The skeletal growth pattern pre- and post-dentofacial orthopeadics. A long-term study of class II malocclusions treated with the Herbst appliance. Eur J Orthod. 1990;12(2):209–18.
4. Pancherz H. History, background, and development of the Herbst appliance. Semin Orthod. 2003;9:3–11. http://www.sleepscholar.com/wp-content/uploads/2014/10/History_herbst.pdf.
5. Illing HM, Morris DO, Lee RT. A prospective evaluation of bass, bionator and twin block appliances. Part I-the hard tissue. Eur J Orthod. 1998;20:501–16.
6. Edwards BA, Andara C, Landry S, Sands SA, Joosten SA, Owens RL, White DP, Hamilton GS, Wellman A. Upper-airway collapsibility and loop gain predict the response to oral

appliance therapy in patients with obstructive sleep apnea. Am J Respir Crit Care Med. 2016;194(11):1413–22.
7. Edwards BA, Eckert DJ, Jordan AS. Obstructive sleep apnoea pathogenesis from mild to severe: is it all the same? Respirology. 2017;22(1):33–42.
8. Gao YN, Wu YC, Lin SY, Chang JZC, Tu YK. Short-term efficacy of minimally invasive treatments for adult obstructive sleep apnea: a systematic review and network meta-analysis of randomized controlled trials. J Formos Med Assoc. 2018;118(4):750–65.
9. Marklund M. Update on Oral appliance therapy for OSA. Curr Sleep Med Rep. 2017;3:143–51.
10. Okuno K, Sasao Y, Nohara K, Sakai T, Pliska BT, Lowe AA, Ryan CF, Almeida F. Endoscopy evaluation to predict oral appliance outcomes in obstructive sleep apnoea. Eur Respir J. 2016;47(5):1410–9.
11. Okuno K, Pliska BT, Hamoda M, Lowe AA, Almeida FR. Prediction of oral appliance treatment outcomes in obstructive sleep apnea: a systematic review. Sleep Med Rev. 2016;30:25–33.
12. Chen H, Eckert DJ, van der Stelt PF, Guo J, Ge S, Emami E, Almeida FR, Huynh NT. Phenotypes of responders to mandibular advancement device therapy in obstructive sleep apnea patients: a systematic review and meta-analysis. Sleep Med Rev. 2019;6:101229. https://doi.org/10.1016/j.smrv.2019.101229.
13. Hamoda MM, Kohzuka Y, Almeida FR. Oral appliances for the management of OSA: an updated review of the literature. Chest. 2018;153(2):544–53.
14. Demko BG. Ten misconceptions that dentists have about treating obstructive. Sleep Apnea. 2018;5(3):90–103. https://doi.org/10.15331/jdsm.7036.
15. Storesund A, Johansson A, Bjorvatn B, Lehmann S. Oral appliance treatment outcome can be predicted by continuous positive airway pressure in moderate to severe obstructive sleep apnea. Sleep Breath. 2018;22(2):385–92.
16. Huntley C, Cooper J, Stiles M, Grewal R, Boon M. Predicting success of oral appliance therapy in treating obstructive sleep apnea using drug-induced sleep endoscopy. J Clin Sleep Med. 2018;14(8):1333–7.
17. Vonk PE, Beelen AMEH, de Vries N. Towards a prediction model for drug-induced sleep endoscopy as a selection tool for oral appliance treatment and positional therapy in obstructive sleep apnea. Sleep Breath. 2018;22(4):901–7.
18. Remmers J, Charkhandeh S, Grosse J, Topor Z, Brant R, Santosham P, Bruehlmann S. Remotely controlled mandibular protrusion during sleep predicts therapeutic success with oral appliances in patients with obstructive sleep apnea. Sleep. 2013;36(10):1517–25.
19. Bosshard V, Masse JF, Sériès F. Prediction of oral appliance efficiency in patients with apnoea using phrenic nerve stimulation while awake. Thorax. 2011;66(3):220–5.
20. Sutherland K, Chan ASL, Ngiam J, Darendeliler MA, Cistulli PA, Sutherland K. Qualitative assessment of awake nasopharyngoscopy for prediction of oral appliance treatment response in obstructive sleep apnoea. Sleep Breath. 2018;22(4):1029–36.
21. Remmers JE, Topor Z, Grosse J, Vranjes N, Mosca EV, Brant R, Bruehlmann S, Charkhandeh S, Jahromi SAZ. A feedback-controlled mandibular positioner identifies individuals with sleep apnea who will respond to oral appliance therapy. J Clin Sleep Med. 2017;13(7):871–80.
22. Aarab G, Lobbezoo F, Hamburger HL, Naeije M, Remmers JE, Topor Z, Grosse J, Vranjes N, Mosca EV, Brant R, et al. A feedback-controlled mandibular positioner identifies individuals with sleep apnea who will respond to oral appliance therapy. Chest. 2017;152(5):537–46.
23. Strohl KP, Yamauchi M, Dick TE. Loop gain and sleep disordered breathing. Curr Respir Med Rev. 2007;3:85–92.
24. White DP. Pathogenesis of obstructive and central sleep apnea. Am J Respir Crit Care Med. 2005;172(11):1363–70.
25. Burgess KR. New insights from the measurement of loop gain in obstructive sleep apnea. J Physiol. 2012;590(Pt 8):1781–2. https://doi.org/10.1113/jphysiol.2012.228643.
26. Messineo L, Taranto-Montemurro L, Azarbarzin A, Oliveira Marques MD, Calianese N, White DP, Wellman A, Sands SA. Breath-holding as a means to estimate the loop gain contribution to obstructive sleep apnea. J Physiol. 2018;596(17):4043–56.

27. Orr JE, Sands SA, Edwards BA, Deyoung PN, Deacon N, Jen R, Li Y, Owens RL, Malhotra A. Measuring loop gain via home sleep testing in patients with obstructive sleep apnea. Am J Respir Crit Care Med. 2018;197(10):1353–5.
28. Sutherland K, Vanderveken OMM, Tsuda H, Marklund M, Gagnadoux F, Kushida CAA, Cistulli PAA. Oral appliance treatment for obstructive sleep apnea: an update. J Clin Sleep. 2014;10(2):215–27.
29. 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(6):860–4.
30. Vroegop AVMT, Vanderveken OM, Van de Heyning PH, Braem MJ. Effects of vertical opening on pharyngeal dimensions in patients with obstructive sleep apnea. Sleep Med. 2012;13(3):314–6.
31. Milano F, Mutinelli S, Sutherland K, Milioli G, Scaramuzzino G, Cortesi AB, Siciliani G, Lombardo L, Cistulli P. Influence of vertical mouth opening on oral appliance treatment outcome in positional obstructive sleep apnea. J Dent Sleep Med. 2018;5(1):17–23. https://doi.org/10.15331/jdsm.6918.
32. Chan ASL, Cistulli PA. Oral appliance treatment of obstructive sleep apnea: an update. Curr Opin Pulm Med. 2009;15(6):591–6.
33. Doff MHJ, Finnema KJ, Hoekema A, Wijkstra PJ, de Bont LGM, Stegenga B. Long-term oral appliance therapy in obstructive sleep apnea syndrome: a controlled study on dental side effects. Clin Oral Investig. 2013;17(2):475–82.
34. Pliska BT, Nam H, Chen H, Lowe AA, Almeida FR. Obstructive sleep apnea and mandibular advancement splints: occlusal effects and progression of changes associated with a decade of treatment. J Clin Sleep Med. 2014;10(12):1285–91.
35. Gong X, Zhang J, Zhao Y, Gao X. Long-term therapeutic efficacy of oral appliances in treatment of obstructive sleep apnea–hypopnea syndrome. Angle Orthod. 2013;83(4):653–8.
36. de Almeida FR, Lowe AA, Otsuka R, Fastlicht S, Farbood M, Tsuiki S. Long-term sequelae of oral appliance therapy in obstructive sleep apnea patients: part 2. Study-model analysis. Am J Orthod Dentofacial Orthop. 2006;129(2):205–13. https://doi.org/10.1016/j.ajodo.2005.04.034.
37. Marklund M. Predictors of long-term orthodontic side effects from mandibular advancement devices in patients with snoring and obstructive sleep apnea. Am J Orthod Dentofacial Orthop. 2006;129(2):214–21.
38. Tsuda H, Almeida FR, Tsuda T, Moritsuchi Y, Lowe AA. Craniofacial changes after 2 years of nasal continuous positive airway pressure use in patients with obstructive sleep apnea. Chest. 2010;138(4):870–4.
39. Venema J, Stellingsma C, Doff M, Hoekema A. Dental side effects of long-term obstructive sleep apnea therapy: a comparison of three therapeutic modalities. J Dent Sleep Med. 2018;5(2):39–46. https://doi.org/10.15331/jdsm.7022.
40. Quinnell TG, Bennett M, Jordan J, Clutterbuck-James AL, Davies MG, Smith IE, Oscroft N, Pittman MA, Cameron M, Chadwick R, Morrell MJ. A crossover randomised controlled trial of oral mandibular advancement devices for obstructive sleep apnea–hypopnea (TOMADO). Thorax. 2014;69(10):938–45. https://doi.org/10.1136/thoraxjnl-2014-205464.
41. Sheats RD, Schell TG, Blanton AO, Braga PM, Demko BG, Dort LC, Farquhar D, Katz SG, Masse JF, Rogers RR, Scherr SC. Management of side effects of oral appliance therapy for sleep-disordered breathing. J Dent Sleep Med. 2017;4(4):111–25. https://doi.org/10.15331/jdsm.6746.
42. Vanderveken OM, Devolder A, Marklund M, Boudewyns AN, Braem MJ, Okkerse W, Verbraecken JA, Franklin KA, De Backer WA, Van de Heyning PH. Comparison of a custom-made and a thermoplastic oral appliance for the treatment of mild sleep apnea. Am J Respir Crit Care Med. 2008;178(2):197–202.
43. Cartwright RD, Samelson CF. The effects of a nonsurgical treatment for obstructive sleep apnea: the tongue-retaining device. JAMA. 1982;248(6):705–9.

44. 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 Med. 2000;1(4):299–305.
45. McGown AD, Makker HK, Battagel JM, L'Estrange PR, Grant HR, Spiro SG. Long-term use of mandibular advancement splints for snoring and obstructive sleep apnea: a questionnaire survey. Eur Respir J. 2001;17(3):462–6.
46. Schönhofer B, Stoohs RA, Rager H, Wenzel M, Wenzel G, Köhler D. A new tongue advancement technique for sleep-disordered breathing: side effects and efficacy. Am J Respir Crit Care Med. 1997;155(2):732–8.
47. Ahrens A, McGrath C, Hägg U. A systematic review of the efficacy of oral appliance design in the management of obstructive sleep apnea. Eur J Orthod. 2011;33(3):318–24.
48. El-Solh AA, Moitheennazima B, Akinnusi ME, Churder PM, Lafornara AM. Combined oral appliance and positive airway pressure therapy for obstructive sleep apnea: a pilot study. Sleep Breath. 2011;15(2):203–8.
49. Lowe A, Sjöholm T, Ryan C, et al. Treatment, airway and compliance effects of a titratable oral appliance. Sleep. 2000;23:S172–8.
50. Mayoral P, Lagravère MO, Míguez-Contreras M, Garcia M. Antero-posterior mandibular position at different vertical levels for mandibular advancing device design. BMC Oral Health. 2019;19(1):85. https://doi.org/10.1186/s12903-019-0783-8.
51. Piskin B, Karakoc O, Genc H, Akay S, Sipahi C, Erdem M, Karaman B, Gorgulu S, Yetkin S, Ayyildiz S. Effects of varying mandibular protrusion and degrees of vertical opening on upper airway dimensions in apneic dentate subjects. J Orofac Orthop Fortschritte der Kieferorthopädie. 2015;76(1):51–65. https://doi.org/10.1007/s00056-014-0259-z.
52. Ryan C, Love L, Peat D, Fleetham J, Lowe A. Mandibular advancement oral appliance therapy for obstructive sleep apnea: effect on awake calibre of the velopharynx. Thorax. 1999;54(11):972–7.
53. Pound E. Let/S/be your guide. J Prosthet Dent. 1977;38(5):482–9.
54. 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 apnea. Thorax. 1997;52:362–8.
55. Doff MH, Veldhuis SK, Hoekema A, Slater JJ, Wijkstra PJ, de Bont LG, Stegenga B. Long-term oral appliance therapy in obstructive sleep apnea syndrome: a controlled study on temporomandibular side effects. Clin Oral Investig. 2011;16(3):689–97.
56. Ringqvist M, Walker-Engstrom ML, Tegelberg A, Ringqvist I. Dental and skeletal changes after 4 years of obstructive sleep apnea treatment with a mandibular advancement device: a prospective, randomized study. Am J Orthod Dentofacial Orthop. 2003;124:53–60. https://doi.org/10.1016/S0889-5406(03)00240-3.
57. Tegelberg A, Wilhelmsson B, Walker-Engstrom ML, Ringqvist M, Andersson L, Krekmanov L, Ringqvist I. Effects and adverse events of a dental appliance for treatment of obstructive sleep apnea. Swed Dent J. 1999;23:117–26.
58. 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.
59. Walker-Engstrom ML, Ringqvist I, Vestling O, Wilhelmsson B, Tegelberg A. A prospective randomized study comparing two different degrees of mandibular advancement with a dental appliance in treatment of severe obstructive sleep apnea. Sleep Breath. 2003;7:119–30.
60. Aarab G, Lobbezoo F, Hamburger HL, Naeije M. Effects of an oral appliance with different mandibular protrusion positions at a constant vertical dimension on obstructive sleep apnea. Clin Oral Investig. 2010;14(3):339–45. https://doi.org/10.1007/s00784-009-0298-9.
61. 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(5):813–8.
62. Lazard DS, Blumen M, Levy P, et al. The tongue-retaining device: efficacy and side effects in obstructive sleep apnea syndrome. J Clin Sleep Med. 2009;5(5):431–8.

63. Martínez-Gomis J, Willaert E, Nogues L, Pascual M, Somoza M, Monasterio C. Five years of sleep apnea treatment with a mandibular advancement device. Side effects and technical complications. Angle Orthod. 2010;80:30–6. https://doi.org/10.2139/030309-122.1.
64. Marklund M. Long-term efficacy of an oral appliance in early treated patients with obstructive sleep apnea. Sleep Breath. 2016;20(2):689–94.
65. Ramar K, Dort LC, Katz SG, Lettieri CJ, Harrod CG, Thomas SM, Chervin RD. Clinical practice guideline for the treatment of obstructive sleep apnea and snoring with oral appliance therapy: an update for 2015. J Clin Sleep Med. 2015;11(7):773–827.
66. Filtness AJ, Reyner LA, Horne JA. One night's CPAP withdrawal in otherwise compliant OSA patients: marked driving impairment but good awareness of increased sleepiness. Sleep Breath. 2012;16(3):865–71.
67. Young LR, Taxin ZH, Norman RG, Walsleben JA, Rapoport DM, Ayappa I. Response to CPAP withdrawal in patients with mild versus severe obstructive sleep apnea/hypopnea syndrome. Sleep. 2013;36(3):405–12.
68. 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(1):162–9.
69. Eriksson EW, Leissner L, Isacsson G, Fransson A. A prospective 10-year follow-up polygraphic study of patients treated with a mandibular protruding device. Sleep Breath. 2015;19:393–401.
70. Baratta F, Pastori D, Bucci T, Fabiani M, Fabiani V, Brunori M, Loffredo L, Lillo R, Pannitteri G, Angelico F, et al. Long-term prediction of adherence to continuous positive air pressure therapy for the treatment of moderate/severe obstructive sleep apnea syndrome. Sleep Med. 2018;43:66–70.
71. Saglam-Aydinatay B, Taner T. Oral appliance therapy in obstructive sleep apnea: long-term adherence and patients' (TM) experiences. Med Oral Patol Oral Cir Bucal. 2017;23(1):e72–7.
72. de Almeida FR, Lowe AA, Tsuiki S, Otsuka R, Wong M, Fastlicht S, Ryan F. Long-term compliance and side effects of oral appliances used for the treatment of snoring and obstructive sleep apnea syndrome. J Clin Sleep Med. 2005;1(2):143–52.
73. Hoffstein V. Review of oral appliances for treatment of sleep-disordered breathing. Sleep Breath. 2007;11(1):1–22.
74. Nordin E, Stenberg M, Tegelberg Å. Obstructive sleep apnea: patients' experiences of oral appliance treatment. J Oral Rehabil. 2016;43(6):435–42.
75. Gotsopoulos H, Chen C, Qian J, Cistulli PA. Oral appliance therapy improves symptoms in obstructive sleep apnea a randomized, controlled trial an adequate therapeutic trial during the subsequent crossover phases. Am J Respir Crit Care Med. 2002;166(5):743–8.
76. Blanco J, Zamarrón C, Abeleira Pazos MT, Lamela C, Suarez QD. Prospective evaluation of an oral appliance in the treatment of obstructive sleep apnea syndrome. Sleep Breath. 2005;9(1):20–5.
77. Naismith SL, Winter VR, Hickie IB, Cistulli PA. Effect of oral appliance therapy on neurobehavioral functioning in obstructive sleep apnea: a randomized controlled trial. J Clin Sleep Med. 2005;1(4):374–80.
78. Gotsopoulos H, Kelly JJ, Cistulli PA. Oral appliance therapy reduces blood pressure in obstructive sleep apnea: a randomized, controlled trial. Sleep. 2004;27(5):934–41.
79. Andrén A, Hedberg P, Walker-Engström M-L, Wahlén P, Tegelberg A. Effects of treatment with oral appliance on 24-h blood pressure in patients with obstructive sleep apnea and hypertension: a randomized clinical trial. Sleep Breath. 2013;17(2):705–12.
80. Lam B, Sam K, Mok WYW, Cheung MT, Fong DYT, Lam JCM, Lam DCL, Yam LYC, Ip MSM. Randomised study of three non-surgical treatments in mild to moderate obstructive sleep apnea. Thorax. 2007;62(4):354–9.
81. Rietz H, Franklin KA, Carlberg B, Sahlin C, Marklund M. Nocturnal blood pressure is reduced by a mandibular advancement device for sleep apnea in women: findings from secondary analyses of a randomized trial. J Am Heart Assoc. 2018;7(13):e008642.

82. Trzepizur W, Gagnadoux F, Abraham P, Rousseau P, Meslier N, Saumet JL, Racineux JL. Microvascular endothelial function in obstructive sleep apnea: impact of continuous positive airway pressure and mandibular advancement. Sleep Med. 2009;10(7):746–52.
83. Anandam A, Patil M, Akinnusi M, Jaoude P, El-Solh AA. Cardiovascular mortality in obstructive sleep apnea treated with continuous positive airway pressure or oral appliance: an observational study. Respirology. 2013;18(8):1184–90.
84. Marin JM, Carrizo SJ, Vicente E, Agusti AGN. Long-term cardiovascular outcomes in men with obstructive sleep apnea-hypopnea with or without treatment with continuous positive airway pressure: an observational study. Lancet. 2005;365(9464):1046–53.
85. Van Haesendonck G, Dieltjens M, Kastoer C, Shivalkar B, Vrints C, Van De Heyning CM, Braem MJ, Vanderveken OM. Cardiovascular benefits of oral appliance therapy in obstructive sleep apnea: a systematic review. J Dent Sleep Med. 2015;2(1):9–14.
86. McEvoy RD, Antic NA, Heeley E, Luo Y, Ou Q, Zhang X, Mediano O, Chen R, Drager LF, Liu Z, et al. CPAP for prevention of cardiovascular events in obstructive sleep apnea. N Engl J Med. 2016;375(10):919–31.
87. Sutherland K, Philips CL, Cistulli PA. Efficacy versus effectiveness in the treatment of obstructive sleep apnea: CPAP and oral appliances. J Dent Sleep Med. 2015;2(4):175–81. https://doi.org/10.15331/jdsm.5120.