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Excellent

ORAL MEDICINE

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Oral appliances in the management of temporomandibular disorders

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Various types of oral appliances (OAs) have been used for over half a century to treat temporomandibular disorders (TMDs), but there has been considerable debate about how OAs should be designed, how they should be used, and what they actually do therapeutically. However, there is enough information in the scientific literature at this time to reach some evidence-based conclusions about these issues. The main focus of this review is on the materials and designs of various OAs in terms of their proposed mechanisms of action and their claimed clinical objectives. Based on current scientific evidence, an analysis is presented regarding the role that OAs can or cannot play in the management of TMDs. Finally, the concept that OAs may be an effective treatment modality for some TMDs owing to their potential for acting as an elaborate placebo rather than any specific therapeutic mechanism is considered. (*Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009;107:212-223)

In the 21st century, it is safe to assume that dentists are familiar with 2 terms: oral appliances (OAs) and temporomandibular disorders (TMDs). However, some clinicians may be surprised to learn that each of these terms has been redefined in light of research findings from the past 10-20 years. Oral appliances, which used to be simple processed acrylic devices that covered all or most of the teeth in 1 arch, are now available in a variety of materials and designs. The conceptual basis for designing and using OAs as treatment devices also has changed considerably, ranging from simple jaw relaxation concepts to complex jaw repositioning rationales. Temporomandibular disorders, which used to be viewed as problems related to some type of occlusal or skeletal disharmony, have undergone a rather substantial paradigm shift. As the classic dental and skeletal etiologic theories have been challenged and refuted by studies conducted around the world, a biopsychosocial medical model of orthopedics, pain phenomenology, and behavioral factors has gradually replaced them.

The aim of this paper is to review the literature on

OAs, with a specific focus on their use in the treatment of TMDs resulting in evidence-based conclusions regarding these issues. In addition to describing the differences in materials used in the fabrication of OAs, the various designs of OAs are analyzed regarding their proposed mechanisms of action and their claimed clinical objectives. Based on current scientific evidence, the role that OAs can or cannot play in the management of TMDs is defined. Finally, the concept that OAs are effective primarily owing to their potential for acting as elaborate placebos will be considered. To avoid confusion, the term "splints" (which often appears in the dental literature as a synonym for OAs) will not be used, because it has several other definitions in dentistry that are unrelated to the management of TMDs.

TEMPOROMANDIBULAR DISORDERS

The first 50 years of interest in TMDs were characterized by a narrow focus on mechanistic theories of etiology.^{1,2} In addition, these complex problems were often described in simplistic terms with diagnostic labels such as temporomandibular joint (TMJ) syndrome, myofascial pain-dysfunction syndrome, or even just TMJ problems. Because these early etiologic concepts revolved mostly around theories of occlusal disharmonies and/or skeletal malalignments, dentists became almost exclusively responsible for their management and OAs became a major treatment modality for TMD patients. The application of OAs as a treatment was

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generally discussed in terms of producing occlusal disengagement, relaxing jaw musculature, restoring vertical dimension of occlusion (VDO), unloading the joint(s), or TMJ repositioning. Even today, OAs are described as deprogrammers or jaw repositioners that can establish ideal craniomandibular relationships while also relieving pain and restoring function. These mechanistic concepts are seriously flawed for 3 reasons: their underlying assumptions that both myogenous and arthrogenous pain and dysfunction arise primarily from the "strain" of dealing with improper occlusal or craniomandibular relationships; their failure to recognize the multiple effects that OAs can produce, instead attributing all positive responses to their occlusion-changing or maxillomandibular repositioning effects; and their presumption that, if the temporary occlusal changes produced by the OAs result in symptomatic improvement, they must be followed by permanent alterations to the patient's occlusion through extensive and irreversible dental treatment(s).

Until the 1960s no systematic well controlled or properly designed clinical studies had been conducted to evaluate the efficacy of treatments for patients with TMDs. Instead, there were a number of "scorecard" studies and anecdotal papers published that reported high levels of successful treatment for the majority of these patients, using a variety of mechanical (dental) approaches.³⁻⁷ Many of these treatment protocols included the use of OAs, not only to relieve signs and symptoms, but also to establish "ideal" or "correct" jaw relationships. For many practitioners, these clinical successes endorsed their assumptions about how OAs function while also appearing to confirm their opinions about TMD etiology.

Unfortunately, the failure of a minority of patients to respond positively to such treatments was seen as a sign of psychologic disturbance (hypochondriasis, depression, malingering, secondary gain), rather than as a sign of inappropriate or ineffective diagnosis and/or treatment. Even worse, failure to respond to occlusal therapy often was used as the basis for attempting more aggressive and invasive therapies, up to and including surgical procedures.^{8,9}

When some early TMD studies in the 1960s and 1970s were conducted using placebo drugs or sham procedures as controls, the investigators reported rather high levels of positive response to those placebo treatments.¹⁰⁻¹² At first, these findings were dismissed as being some type of trickery, and some investigators were even accused of misleading or duping patients by using placebos instead of "real" treatments. When Greene and Laskin¹³ and Goodman et al.¹⁰ reported using "placebo splints" as well as "placebo equilibrations" as forms of mock treatment for TMD patients, these outcomes were widely denounced; however, the fact that nonoccluding OAs helped over 40% of the patients, while mock equilibration helped

nearly two-thirds of them, made it difficult to ignore those findings. Subsequent researchers using both of these placebo controls in their studies have reproduced similar results.¹⁴ These findings obviously have required clinicians to rethink the mechanisms of appliance efficacy, and to re-evaluate what the role of OAs might be in treating TMD patients.

During that same time period, a number of other placebo-controlled or comparative TMD treatment studies were producing high rates of positive response, without performing any irreversible dental or skeletal corrective procedures.¹⁵⁻²⁰ In addition, longitudinal follow-up studies showed that these short-term favorable responses to conservative treatments often persisted over periods of many years, even if the original treatment was only a placebo.²¹⁻³⁰ This accumulating evidence presented a powerful argument against the use of traditional mechanical TMD therapies, especially because the irreversible nature of those treatments could significantly complicate a nonresponding patient's condition physically, psychologically, and economically.³¹⁻³³ An in-depth discussion regarding this topic is beyond the scope of the present article, but for most TMD patients it has become clear that the line between reversible and irreversible treatments does not often need to be crossed to produce good clinical outcomes.³³

In recent years there has been an explosion in our knowledge regarding the biochemical and neurophysiologic basis for musculoskeletal pain,³⁴⁻³⁷ making some of the old notions about why joints or muscles hurt seem very naive and simplistic (for example, terms such as capsulitis, lactic acid buildup, or muscle spasms). Likewise, the explanations for why pains persist in some people and not others has switched almost completely from the field of psychology to the field of neuroscience,³⁸ where extensive studies have shown that neuroplastic changes in the nervous system are the most likely reason for developing chronic pain. In addition, it appears that genetic factors may determine in part who will develop such chronic pain conditions.³⁹⁻⁴¹ There is little doubt that future therapies in the pain field will be targeted more precisely toward underlying pathophysiologic mechanisms of joint pain, muscle pain, and chronic pain, rather than at simple analgesia or other pain control strategies.

Do these fascinating scientific findings mean that oral appliances no longer have any place in a dentist's armamentarium for managing TMD patients? The answer at this point in time is clearly No, because OAs still can be a valuable adjunct in the management of certain subgroups of TMD patients, as will be discussed subsequently.

ORAL APPLIANCES

The changes in our understanding of the pathophysiology of TMDs require that traditional ideas about using OAs also must be reconsidered. Not only are

Table I. Hypotheses for efficacy of oral appliances⁴²

<i>Dental reasons for efficacy</i>	<i>Nondental reasons for efficacy</i>
Alteration of the occlusal condition	Cognitive awareness
Alteration of the condylar position	Placebo effect
Increase in the vertical dimension of occlusion	Increased peripheral input to the central nervous system decreases motor activity
	Regression to the mean (natural fluctuation of symptoms)

many of the old concepts mistaken or obsolete, but in addition the semantics of describing OAs needs to be modified. For example, calling an OA an occlusal appliance may have seemed appropriate because it alters occlusion while wearing it; however, this is akin to calling a back brace a dermatologic device because it rests on the skin of the torso while wearing it. As Okeson⁴² has pointed out (Table I), there are at least 7 hypotheses that have been offered to explain the effects that OAs can have on TMDs, but most of them simply reflect the bias of certain clinical approaches. For example, if you presume that a patient has a vertical dimension problem, you might attribute the clinical success of OAs to the thickness of the plastic.

Oral appliance materials—fabrication issues

There are basically 2 different materials, based upon consistency, which are used in the fabrication of OAs. First, there are hard acrylic resin OAs that are either chemically cured or heat/pressure processed, resulting in hard and rigid tooth-borne and occlusal surfaces. Alternatively, there are soft or resilient OAs manufactured from plastics or polymers, producing an appliance which has a somewhat flexible and pliable tooth-borne and occlusal surface. There exists a third variation of material known as dual laminated, because it consists of hard acrylic resin on the occlusal surface and a soft material on the inner aspect (tooth-borne surface). This produces an OA with the positive qualities of a soft material (fitting well and providing comfort for the supporting teeth), with the versatility of a hard acrylic resin adjustable occlusal surface. For our purposes, this style of OA will be discussed as belonging to the hard acrylic resin group.

Hard acrylic resin OAs can be custom fabricated at chairside and/or produced at a commercial laboratory with the use of stone casts. The material for making certain types of soft OAs can be purchased from dental supply houses or found over the counter in many sporting goods stores and pharmacies, in a prefabricated form. This type of OA ("boil and bite") is molded and adapted by the purchaser by boiling the product in

water and then placing the material intraorally with a biting force to establish the "correct" occlusion. Another variation of the soft OA is a dental office-fabricated version, whereby the material is vacuum formed to fit stone casts, and the occlusion is later established at chairside. A third variety involves a similar processing technique which occurs at a commercial laboratory, with the occlusion established once again at chairside.

Hard acrylic resin OAs appear to have several advantages over their soft counterparts. The fit of a hard acrylic resin OA, be it a hard or a hard-soft tooth-borne interface, is generally more stable and more retentive owing to the material(s) used and to the more accurate, consistent, and reliable method of fabrication. Adjustment to the occlusal surface of these OAs, using rotary instruments, can be accomplished more easily, quickly, and efficiently than with a soft material because of the hardness and resistance of the acrylic resin. Doing this type of adjustment with a soft material often results in a less than adequate occlusal scheme. Furthermore, there is a possibility that wearing soft appliances may be associated with occlusal changes.^{43,44}

Owing to the hardness of the acrylic resin, a rigid type of OA will provide greater longevity and durability than the soft version. The hard acrylic resin variety is also less prone to discoloration as well as accumulation of food debris and resultant malodors, owing to the porosity differences inherent in the composition of the different materials. Lastly, repairing a hard acrylic resin OA is easily achievable either at chairside or with reprocessing at a commercial laboratory, but this is not achievable with the soft type of OA. The advantages of the soft OA compared with the hard OA seem to be mainly economics and chairside adjustment time, because the softer versions are usually less expensive for the patient and less time consuming for the practitioner than the more labor-intensive hard acrylic resin types.

Oral appliance materials—utilization issues

The question of which material to use for the management of TMDs as well as for sleep bruxism (SB) has been and continues to be rather controversial. Soft OAs have been recommended by some investigators for the reduction of both myogenous and arthrogenous TMD symptoms.^{43,45-47} However, in an electromyography (EMG) study comparing hard and soft OAs involving 10 bruxism subjects who wore hard appliances at first and then were switched to soft appliances after a washout period, it was found that 8 of the 10 subjects experienced a significantly reduced nocturnal muscle activity with the use of hard OAs. In comparison, the soft OAs significantly reduced muscle activity in only 1 participant and caused a statistically significant increase in EMG activity in 5 of the participants.⁴⁸ In another EMG study comparing the ef-

fects of hard and soft OAs on the activity of the temporalis and masseter muscles during controlled clenching, it was found that activity of the studied muscles was decreased more with use of a hard OA, and the soft OAs produced a slight increase in activity of both muscles, but particularly the masseter muscle.⁴⁹ In another EMG study, it was found that activity of the masseter muscle was increased after the immediate insertion of a soft OA during maximum clenching.⁵⁰

Contrary to these outcomes, other studies involving direct comparisons between hard and soft OAs in TMD subjects found no differences in either self-reported symptoms or in clinical findings between each OA group.^{45,47} Additionally, in a study by Wright et al.⁴⁶ where 30 masticatory muscle pain subjects were randomly assigned to receive either a soft OA, palliative treatment, or no treatment, it was found that those assigned to the soft OA group had a greater reduction in the signs and symptoms of their muscle pain over the short term.

It might seem from these studies that differences between the use of soft and hard OAs in the management of TMDs are not significant. However, the majority of scientific evidence^{48,51-53} has shown more consistent support for the use of hard acrylic resin OAs rather than soft ones for the reduction of TMD symptoms. Additionally, owing to the material and adjustability advantages discussed earlier, it seems reasonable to recommend the use of a hard acrylic resin OA over a soft version for most patients with appropriate TMD signs and symptoms. However, soft OAs may be useful as a short-term treatment measure in certain acute-onset TMD patients, as well as for those patients where cost is a concern.^{45,47} Because the most common and well validated indication for appliances made with soft materials is as athletic mouthguards to protect against and diminish injury to the oral structures,^{54,55} they still have an important role in the dental armamentarium.

Oral appliance designs and related concepts

Flat plane stabilization appliance. The flat plane stabilization appliance (also known as the Michigan splint, muscle relaxation appliance, or gnathologic splint) is generally fabricated for the maxillary arch. Alternatively, some clinicians have argued that for reasons of enhanced esthetics and less effect on speech, this type of appliance should be fabricated for the mandibular arch. The evidence from various studies suggests no differences in reduction of symptoms between either of these 2 designs.⁵⁶ The appliance is fabricated so that the opposing dentition occludes uniformly, evenly, and simultaneously with the occluding surface of the appliance.

Many practitioners advocate the incorporation of canine-protected articulation to disocclude the posterior

teeth during eccentric movements. Some studies suggest that the use of this design in asymptomatic individuals is more effective in reducing muscle activity.^{57,58} However, several other studies have shown no differences in muscle activity in healthy subjects⁵⁹ or in TMD symptom reduction^{60,61} by adding the canine-protected articulation feature to an appliance.

Ideally, when a stabilization type of appliance is placed intraorally, there is minimal change to the maxillomandibular relationship other than that produced by the thickness of the material. This is the most commonly used type of intraoral appliance, and when properly fabricated it has the least potential for adverse effects to the oral structures. The intent of this appliance as outlined by the American Academy of Orofacial Pain guidelines⁶² is to "provide joint stabilization, protect the teeth, redistribute the [occlusal] forces, relax the elevator muscles, and decrease bruxism." Additionally, it is stated that "wearing the appliance increases the patient's awareness of jaw habits and helps alter the rest position of the mandible to a more relaxed, open position."

Traditional anterior bite plane. The use of anterior platform appliances seems to have originated within the orthodontic profession many years ago. Various clinicians' names (e.g., Hawley, Sved, Shore) have been associated with these OAs, and in many cases the appliances were modified to either move or retain maxillary anterior teeth. In general, they are designed as a palatal-coverage horseshoe shape with an occlusal platform covering 6 or 8 maxillary anterior teeth. Advocates for using such appliances to treat TMDs have argued that they prevent clenching, because posterior teeth are not engaged in closing or in parafunctional activities. However, some critics have argued that these appliances can lead to overeruption of posterior teeth (which is extremely unlikely if worn only at night) and others have worried that the TMJs will be overloaded without posterior support.

Minianterior appliances. The concept of making an oral appliance that engaged only a small number of maxillary anterior teeth (usually 2-4 incisors) was first introduced in the mid 1900s as the Lucia jig. Within the past several years, there have been several variations that have appeared on the market. They include the Nociceptive Trigeminal Inhibition Tension Suppression System (NTI), the Best Bite, and the Anterior Midline Point Stop (AMPS) devices. All of these are hard acrylic resin appliances that are either developed directly at chairside or commercially produced in prefabricated designs. The commercial versions require custom fitting at chairside by relining the interior aspect with acrylic resin or hard elastic impression materials to fit on the maxillary incisors, after which the occluding

surface is adjusted to allow 2-4 mandibular incisors to contact a platform. According to the advocates of these OAs, their purpose is to disengage the posterior teeth, thereby eliminating the influences of the posterior occlusion on the masticatory system. This design is thought to be effective in treating TMDs, SB, and headaches. However, because of the recent popularity of these appliances, a more thorough discussion of the literature is required so that the profession can consider using them based on scientific evidence rather than on experience-based claims and business interests.

The initial study⁶³ which allowed the U.S. Food and Drug Administration (FDA) to categorize the NTI as a medical device and approve its marketing in the diagnosis and treatment of headaches was based on the reported results that the NTI was slightly more effective than a "full coverage appliance" for the reduction of headache pain. Interestingly, the control appliance was only a bleaching tray, for which no studies evaluating effectiveness in treating either TMDs or headache pain have ever been reported. Clearly, the study would have been vastly improved by comparing the NTI against a conventional flat plane stabilization appliance. Additionally, the approval of a medical device as opposed to a drug requires a much less stringent approval process, because new devices which are similar to previously approved devices can apply for the same FDA approval. Because the majority of the oral appliances being marketed for headache are categorized as "jaw repositioning" devices, and carry the FDA approval as such, it is easy to understand how the NTI and similar appliances were approved.

In a double-blind randomized parallel trial comparing the NTI to a flat plane stabilization appliance in TMD subjects with headache, no differences between appliances were reported over a 3-month period regarding muscle tenderness upon palpation, self-reported TMD-related pain and headache, or improvement on jaw opening.⁶⁴ In a study comparing the AMPS device to a flat plane stabilization appliance, there was no significant difference between the appliances in their efficiency in relieving myogenous pain.⁶⁵ In another well designed randomly controlled study, the NTI was found to be less effective than a flat plane stabilization appliance in the treatment of TMDs.⁶⁶

The possibility of adverse occlusal effects occurring with this type of minianterior appliance with continuous and long-term use is significant. Because the design of the appliance only covers the maxillary anterior teeth, there is the potential for overeruption of the unopposed posterior teeth resulting in an anterior open bite. Development of an anterior open bite also could result from the intrusion of the maxillary anterior teeth which retain the appliance, or from a combination of

both factors. It also is possible that the 1-point design for occlusal contact with the mandibular anterior teeth may create unfavorable mobility of these teeth, or instead the maxillary teeth supporting the appliance may be displaced by the occlusal forces. Furthermore, owing to the small size of these devices, there is a possibility of a serious life-threatening event in which the appliance may be swallowed or aspirated; reports of such catastrophic events have been recorded.⁶⁴

Anterior repositioning appliance. The anterior repositioning appliance (also known as an orthopedic repositioning appliance) purposefully alters the maxillo-mandibular relationship so that the mandible assumes a more anterior position. This is accomplished with the addition of an acrylic guiding ramp to the anterior one-third of the maxillary appliance which, upon closing, forces the mandible into a more forward position. ~~Originally, this type of appliance was supposed to be used to treat patients with internal derangements (usually anterior disk displacements with reduction).~~ It was thought that by altering the mandibular position in this manner, anteriorly displaced disks could be "recaptured," after which the new condyle-disk relationship could be "stabilized" through comprehensive dental or surgical occlusal procedures.⁶⁷ Currently it is recommended that repositioning appliances should be used primarily as a temporary therapeutic measure to allow for symptomatic control of painful internal derangements, but not to "permanently" recapture the TMJ disk. The potential dangers with long term use of this appliance are permanent and irreversible occlusal and even skeletal changes. Therefore, this type of appliance should be used with discretion, and only for short periods of time.

Neuromuscular appliances. Advocates of so-called neuromuscular dentistry (NMD) have claimed that the use of jaw muscle stimulators and jaw-tracking machines enables them to produce an oral appliance at the ideal vertical and horizontal position of the mandible relative to the cranium.⁶⁸ Space does not permit a full discussion of these complex issues, which have been reviewed elsewhere.⁶⁹⁻⁷² At the very least, one would have to accept the entire NMD concept to believe the notion that such appliances are the most ideal ones. After using these appliances to treat a TMD patient, proponents of this methodology usually recommend dental reconstruction at the new jaw relationship.

Posterior bite plane appliances. Posterior bite plane appliances (also known as mandibular orthopedic repositioning appliances) are customarily made to be worn on the mandibular arch. The design is bilateral hard acrylic resin platforms located over the mandibular posterior teeth (usually molars and premolars) and connected with a lingual metal bar. This design creates a

disocclusion of the anterior teeth. The purpose of this appliance is to produce changes to the vertical dimension and alter the horizontal maxillomandibular relationship. It also has been claimed that this type of appliance has the ability to increase overall physical strength and enhance athletic performance⁷³⁻⁷⁵; however, the scientific evidence does not support this claim.⁷⁶⁻⁷⁸

According to its supporters,⁷⁹ this type of appliance was supposed to produce an "ideal" maxillomandibular relationship, to be followed by occlusal procedures to permanently maintain that relationship. No evidence was offered to support this concept. The major concern regarding this appliance design is that occlusion only occurs on posterior teeth, thereby allowing for overeruption of the unopposed anterior teeth and/or intrusion of the opposing posterior teeth, resulting in an iatrogenically created posterior open bite.

Pivot appliances. The pivoting appliance is constructed with hard acrylic resin that covers either the maxillary or mandibular arch and incorporates a single posterior occlusal contact in each quadrant. This contact is placed as far posteriorly as possible. The purpose of this design is to reduce intra-articular pressure by condylar distraction as the mandible "fulcrums" around the pivot, resulting in an "unloading" of the articular surfaces of the joint. This appliance was recommended for patients with internal derangements and/or osteoarthritis. However, studies^{80,81} have indicated that occlusal pivots have no distractive effect on the TMJ and instead can actually lead to joint compression. A different version of this appliance involves the use of a unilateral pivot inserted in the posterior region. It is thought that closing the mandible on this pivot will load the contralateral joint and slightly distract the ipsilateral joint.⁸⁰ However, owing to biomechanical principles, it is not possible for a class III lever such as the mandible to rotate around a secondary fulcrum; all claims to the contrary are simply not plausible (see the next section). Because of the design and force vectors created by this appliance, a potential adverse effect with its use may be occlusal changes manifesting as a posterior open bite where the pivot was placed.

Hydrostatic appliance. This unique appliance was designed by Lerman⁸² over 30 years ago. In its original form, it consisted of bilateral water-filled plastic chambers attached to an acrylic palatal appliance, and the patient's posterior teeth would occlude with these chambers. Later this was modified to become a device that could be retained under the upper lip, while the fluid chambers could be positioned between maxillary and mandibular posterior teeth. The concept was that the mandible would automatically "find" its ideal position because the appliance was not directing where

Table II. Descriptions of appropriate uses and limitations for oral appliances (OAs)

What OAs can do	What OAs cannot do
Decrease/alter loading on TMJ by reducing force intensity, frequency, and/or duration of oral parafunctional activities	Unload the TMJ by distracting condyle or by pivoting on molar contacts
Briefly reduce muscle activity by introducing "foreign body" of occlusal platform	Retrain muscles to be less active after splint is removed
Reduce headache intensity or frequency if it is triggered by SB-induced myalgia or arthralgia	Relieve headache conditions that are primarily neurovascular or vascular in origin
Improve internal derangement symptoms of locking/catching upon awakening related to strong nocturnal muscle activity (clenching/grinding)	Recapture displaced disks, enhance retrodiskal tissue healing, prevent progression from ADD-R to ADD-NR
Disrupt neuromuscular engrams that determine TMJ-fossa relationships ("de-programming")	Produce an "ideal" neuromuscular/occlusal relationship
Protect occlusal surfaces of teeth and dental restorations from SB forces	Permanently reduce or eliminate SB activities
	Establish "correct" vertical dimension of occlusion

TMJ, temporomandibular joint; SB, sleep bruxism; ADD-R, anterior disk displacement with reduction; ADD-NR, anterior disk displacement without reduction.

the jaw should be. No independent research has been offered to substantiate this claim.

What oral appliances can and cannot do

As if it were not confusing enough to have so many different OA designs, the rationales offered for using them in the treatment of TMDs are wildly divergent. Part of this problem stems from different concepts and ideologies about what needs to be achieved to "successfully" treat a TMD patient. However, another important confounding issue arises from mistaken beliefs about what OAs can or cannot actually do. In this section, we discuss that topic in terms of the available scientific evidence (Table II).

Oral appliances and TMJ loading. It has been claimed that OAs can unload the normal pressure existing inside the human TMJ. As discussed above, one type of appliance was designed with "pivots" placed in the molar area to create a fulcrum that would distract the condyle from its fossa upon jaw closing. Unfortunately, this concept ignores a fundamental biomechanical fact that has been demonstrated repeatedly by Hylander^{83,84} and other anatomists, namely, that the human mandible is a class III lever, and as such it

cannot fulcrum around any point that is anterior to the masticatory muscles. Therefore, neither a pivot appliance nor any other type of OA can possibly "unload" the human TMJ. However, it can be argued that loading inside the TMJ could be reduced or redirected by the presence of an OA. This may occur due to a reduction in the amount and intensity of muscle activity, or it may be due to the condylar loading area being shifted elsewhere.

Oral appliances and muscle activity. There is both empirical and experimental evidence that OAs can produce a decrease in nocturnal muscle activity in many patients. Clark et al.⁵¹ have explained this as a reflexive response to the presence of a "foreign object" between the teeth, leading to an avoidance behavior. This effect also has been observed and measured in sleep laboratory studies.⁸⁵ However, it also has been shown that nocturnal muscle activity returns to baseline levels in nearly all patients shortly after discontinuing OA usage, and in some patients that may occur even while still using the OA. Therefore, if long-term pain relief and/or protection of teeth are needed, those patients must wear OAs indefinitely. Clinicians also need to be aware that, in a small percentage of cases, paradoxical results may occur when patients are given OAs, with previously painless sleep bruxers developing symptoms of TMD; this is thought to be due to a reflexive increase in muscle activity rather than the expected decrease, and it requires a change of treatment strategy for those patients.

Oral appliances and headache. Several studies have found associations between TMDs and headache.⁸⁶⁻⁸⁸ In patients referred for treatment of TMDs, headache has been reported in more than 70%.^{89,90} This complicates the differential diagnosis of head and facial pain, but fortunately there is an extensive classification of headache disorders with detailed diagnostic criteria that has been developed by the International Headache Society.⁹¹ This classification includes both primary and secondary headaches, with the spectrum of etiologies ranging from neurovascular and vascular causes to central nervous system lesions. In the section describing diagnostic criteria for tension-type headache (TTH), the IHS material states that increased pericranial tenderness elicited by manual palpation is the most significant abnormal finding in patients with this form of headache. In addition, a common finding in patients with TMDs and TTH is masticatory muscle pain upon palpation.⁹² However, no clear causal relationship has been found between these 2 conditions, so this finding may simply reflect a comorbid situation. Another theory is that the jaw muscle pain generated by SB may serve as a trigger to both TTH and migraine headaches in susceptible patients, but it should be remembered that the majority of SB patients do not experience any craniofacial pain problems.^{93,94}

Randomized controlled treatment studies have found a decrease in intensity and frequency of TTH when patients with TMDs of myogenous and/or arthrogenous origin are successfully treated with OAs.^{89,95} A common finding in each study was a reduction in the number of masticatory muscles tender to palpation. Therefore, if pain in the masticatory or pericranial muscles is reported by a patient upon awakening, those pains may be related to muscle activity associated with SB. Although the mechanism for OAs providing headache reduction is unknown, one possible theory (as discussed above) is that this kind of positive outcome may be due to a reduction in nocturnal jaw muscle activity. Therefore, OAs should be viewed as an adjunctive treatment for TMD management in those patients who also present with headache, rather than as a specific treatment for primary headache conditions.

Oral appliances and internal derangements. The use of OAs to treat internal derangements of the TMJ has led to many problematic outcomes, mainly due to misconceptions about why TMJ disks become displaced as well as what should be done about it. Beginning in the 1970s, disk displacements (even in painless clicking patients) were thought to be forerunners of degenerative disease and painful dysfunctions. Therefore, some clinicians advocated early intervention to avoid such developments, and the primary treatment tool was a so-called anterior repositioning appliance (ARA). The concept was to "recapture" the displaced disk and to gradually "walk it back" to a normal position, but when this proved to be nearly impossible, some clinicians advocated major occlusion-changing procedures to "stabilize the recaptured disk" in its new anterior position.⁹⁶

As evidence continued to mount showing the futility (not to mention the non-necessity) of this extremely invasive approach,⁹⁷ some modified concepts of ARA utilization became popular. For example, some people argued that wearing an ARA⁹⁸ could help patients avoid progression from clicking to "locking" (nonreducing disk displacement), and others argued that an ARA should be worn for 6-12 months to permit retrodiskal tissues to heal.⁹⁸

Obviously, what was missing from those clinical arguments was the evidence needed to support any of the treatment approaches. Over time, several studies of conservatively treated (and even untreated) patients showed that a series of fairly predictable adaptations were likely to occur in the majority of internal derangement patients.⁹⁹ Therefore, what patients actually needed from clinicians was symptomatic relief from painful episodes, as well as proper counseling about what was happening inside their joints.¹⁰⁰ As a result, the role that either conventional or repositioning OAs

could play became much more limited, and today there are only 3 likely indications for their use in internal derangement cases. First, for patients with acute TMJ pain, OAs may reduce muscle activity and redirect loading inside the TMJ; second, for sleep bruxers who awaken with TMJ pain due to nocturnal muscle activity, an OA worn at night could be helpful to reduce pain and dysfunction; and third, for patients whose TMJs become "locked" at night, but who are able to successfully click open during the day, an OA can reduce the frequency of these episodes or prevent their occurrence in some cases.

Oral appliances and "deprogramming" concepts. One popular idea about OAs is that they can "deprogram" the TMJ musculature, and thereby produce "ideal" jaw relationships. This is a good example of an idea that contains a kernel of truth, but which has serious theoretic and practical flaws when applied to actual patients. It is true that every patient's brain is "programmed" by their occlusion to guide the various movements of the mandible; the scientific term for this program is "engram," which means that neuromuscular activity is determined in large part by the morphology of the moving structures. This type of brain program is very stable as long as morphology remains unchanged, but it is capable of changing as peripheral structures undergo changes.

Therefore, if you interfere with the engram produced by occlusal contact (e.g., by wearing an OA), the mandible will close in a different manner. The problem lies in making an assumption that the new version is better than the original one, an assumption that exists at the core of all centric occlusion-centric relation or other jaw-repositioning occlusion concepts in dentistry. By describing the new position as ideal, the teeth are cast in the role of "interfering" with proper closure of the mandible and the need arises to do something about that. An in-depth discussion regarding deprogramming concepts is beyond the scope of the present article, but it should be recognized that they have played a huge role in all of the occlusal/skeletal theories of TMD etiology. Although readers are encouraged to pursue this debate¹⁰¹⁻¹⁰³ about which occlusal concepts and procedures are best for treating their regular dental patients, they should not interpret success of OAs in treating certain TMD patients in terms of deprogramming concepts.

Oral appliances and establishing "correct" vertical dimension. There were reports in the early TMD literature that OAs can reduce "abnormal muscle activity" and associated pain by restoring the patient's original VDO that was reduced by tooth wear or loss of posterior support.^{3,104} That belief is based on the premise that a loss in VDO is an etiologic factor for TMD, as originally pro-

posed by Costen in 1934.¹⁰⁵ However, so-called normal VDO has been found to be a highly variable measurement in the general population, and regardless of the measurement or apparent loss of occlusal tooth structure, most individuals do not report signs and symptoms of TMD.¹⁰⁶ Therefore, the success of an OA in reducing pain should not be interpreted as a confirmation of lost VDO simply because the occlusion has been temporarily elevated. Obviously, the danger of interpreting outcomes this way is that clinicians might conclude that permanent changes in VDO will be required to establish long-term health, and this always requires some type of major invasive dental intervention.

Nonoccluding appliances and placebo effects

Nonoccluding OAs, as the name implies, do not have an occlusal platform that contacts the opposing dentition, so they cannot directly alter either condylar positioning or vertical dimension. In the first study to investigate the clinical efficacy of nonoccluding OAs, Greene and Laskin¹³ studied 71 patients with myogenous TMDs (masticatory muscle pain, limitation, deviation, and/or tenderness) who were treated by different OA designs. They found that 40% of the patients showed remission or noticeable improvement in their symptoms with the use of a nonoccluding OA. In the first random-assignment placebo-controlled study of OAs for treating myogenous TMD,¹⁰⁷ one group received a traditional OA and the other group a nonoccluding OA; the results showed improvement in both groups without any statistically significant before or after treatment differences between the groups. Dao et al.¹⁰⁸ evaluated the therapeutic efficacy of OAs using a parallel, randomized, controlled, and blind design by assigning masticatory myalgia subjects to 1 of 3 groups: 1) passive control: full occlusal OA worn only 30 min at each appointment; 2) active control: nonoccluding OA worn 24 h/day; and 3) treatment: full occlusal OA worn 24 h/day. They found that all pain ratings decreased significantly with time, and quality of life improved for all 3 groups. However, there were no significant differences between groups in any of the assessment variables. They concluded that the reduction in intensity and unpleasantness of muscle pain and improvement in quality of life was nonspecific and not directly related to the type of treatment. Additional studies in myalgia and arthralgia subjects reported no significant differences in overall reduction of subjective and objective measures of pain and dysfunction (except for TMJ clicking) after treatment with either nonoccluding or occluding OAs, both resulting in positive outcomes.^{109,110} In studies evaluating EMG masseter muscle activity in SB patients, it was found that occluding and nonoccluding OAs were equally effective

in reducing nocturnal muscle activity in certain individuals for a period of time.^{85,111,112}

Contrary to the above studies, Ekberg et al.¹¹³ evaluated the efficacy of a traditional OA (treatment group) compared with a nonoccluding OA (control group) in arthrogenous TMD subjects using a randomized double-blind controlled protocol. They found improvement of overall subjective symptoms in both groups, but significantly more often in the treatment group than in the control group ($P = .006$). Additionally, the frequency of daily or constant pain showed a significant reduction in the treatment group compared with the control group ($P = .02$). However, they concluded that both the stabilization appliance and the control appliance had some amount of positive effect on TMJ pain. Similar findings by these investigators and others¹¹⁴⁻¹¹⁷ have been reported regarding the treatment of signs and symptoms of myogenous pain. The results from both short-term and long-term trials led those authors to conclude that traditional OAs are more efficacious than nonoccluding OAs.

Implications of current placebo theory for the clinical use of OAs

Caution must be advised regarding interpretation of the numerous studies that have looked at the issue of occluding versus nonoccluding OAs. Those studies have various methodologic limitations; for example, different inclusion and exclusion criteria were used in the various studies, with some poorly defining the targeted study population. Furthermore, there may have been several confounding variables influencing the treatment outcomes, some of which were not recorded or accounted for in presenting the results of the studies. In spite of these potential shortcomings, it appears that the general trend reported from these studies is that non-occluding OAs, at the minimum, have a considerable amount of positive effect on TMD signs and symptoms in a significant percentage of subjects. Because these nonoccluding OAs are not altering the occlusion or maxillomandibular relationships of patients, their mechanism of action must be at least partially due to their ability to function as a behavioral intervention rather than as a mechanical device.

Recent research into the mechanisms of placebo effects has broadened our understanding of how placebos work. Brain imaging studies using functional magnetic resonance imaging and positron-emission tomographic scanning have made it possible to better understand the very specific biologic activity occurring in the brains of both pain patients and volunteer subjects. When subjects are exposed to painful stimuli, their responses to both placebo treatments and "real" treatments are influenced by their pre-existing pain condition as well as

by the context of each treatment. A recent paper by Goddard et al. (G. Goddard, DDS, personal communication, February 15, 2008) summarizes these developments in the placebo field and presents implications for the management of TMD patients. Dao and Lavigne,¹¹⁸ in a review paper regarding the use of OAs, commented that despite their lack of true efficacy, splints should be used as a treatment modality for some subgroups of TMD patients because they are "effective" treatments (that is, they produce positive subjective responses), and they are harmless when properly used. Obviously, this implies that as long as clinicians stay in the domain of conservative and reversible care, there will be a variety of other effective treatments available in addition to OAs that are likely to be helpful in treating their TMD patients. Combined with cognitive-behavioral education of patients and an awareness of important psychosocial factors (especially in chronic TMD patients), this approach should lead to "effective" treatment protocols and the avoidance of aggressive ones.

CONCLUSIONS

Over the past 10-20 years, the conceptual basis for using oral appliances in treating temporomandibular disorders and SB has been dramatically redefined. This has happened largely as a consequence of extensive research conducted around the world during that period, which has led to new understandings of these conditions. Currently, OAs are still regarded as useful adjuncts for treating certain kinds of TMD patients, but the emphasis is entirely on their conservative application. Evidence derived from clinical studies suggests that OAs are more effective for treating myogenous TMD problems than they are for intracapsular conditions, but they can be helpful for both in properly selected patients. Rather than trying to establish new horizontal or vertical jaw relationships, OAs today should be viewed as "oromandibular crutches," which are analogous to back braces or ankle support orthotics because they provide symptomatic relief while patients are recovering.

Thinking about OAs this way will enable clinicians to use OAs as they treat TMD patients conservatively and reversibly, as long as they avoid full-time wear or specific designs that lead to permanent occlusal changes; the worst-case outcome should be nothing more than a failure to relieve symptoms. As for treating sleep bruxism, there is no question that OAs can provide protection against excessive attrition of patients' teeth. They do not stop people from performing parafunctional activities at night, but they may diminish the duration, frequency, or intensity of those activities for some patients and for variable amounts of time. The only negative possibility is development or continua-

tion of morning muscular pain in a small number of patients, which requires a change of strategy; for the majority of SB patients, however, these devices can be very helpful.

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