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Oral Appliance Treatment for Obstructive Sleep Apnea: An Update

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Oral appliances (OA) have emerged as an alternative to continuous positive airway pressure (CPAP) for obstructive sleep apnea (OSA) treatment. The most commonly used OA reduces upper airway collapse by advancing the mandible (OA_m). There is a strong evidence base demonstrating OA_m improve OSA in the majority of patients, including some with more severe disease. However OA_m are not efficacious for all, with approximately one-third of patients experiencing no therapeutic benefit. OA_m are generally well tolerated, although short-term adverse effects during acclimatization are common. Long-term dental changes do occur, but these are for the most part subclinical and do not preclude continued use. Patients often prefer OA_m to gold-standard CPAP treatment. Head-to-head trials confirm CPAP is superior in reducing OSA parameters on polysomnography; however, this greater efficacy does not necessarily translate into better health outcomes in clinical practice. Comparable effectiveness of OA_m and CPAP has been attributed to higher reported nightly use of OA_m, suggesting that inferiority in reducing apneic events may be counteracted by greater treatment adherence. Recently, significant advances in commercially available OA_m technologies have been made. Remotely controlled mandibular positioners have the potential to identify treatment responders and the level of therapeutic advancement required in single night titration polysomnography. Objective monitoring of OA_m adherence using small embedded temperature sensing data loggers is now available and will enhance clinical practice and research. These technologies will further enhance efficacy and effectiveness of OA_m treatment for OSA.

Keywords: Obstructive sleep apnea, oral appliance, mandibular advancement, adherence, effectiveness

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Obstructive sleep apnea (OSA) is a common sleep disorder characterized by recurring collapse of the upper airway during sleep, resulting in sleep fragmentation and oxygen desaturation. OSA is defined as the occurrence of 5 or more episodes of complete (apnea) or partial (hypopnea) upper airway obstruction per hour of sleep (apnea-hypopnea index [AHI]) and is estimated to occur in around 24% of middle-aged men and 9% of women.[1] Daytime symptoms such as sleepiness, cognitive impairment, and effects on quality of life require appropriate treatment. Furthermore the association of OSA with increased risk of motor vehicle accidents, cardiovascular morbidity, and all-cause mortality emphasize the need for effective long-term treatment.[2,3]

The gold standard treatment for OSA is to pneumatically splint open the upper airway during sleep using continuous positive airway pressure (CPAP). Although CPAP is highly efficacious in preventing upper airway collapse, patient acceptance, tolerance, and adherence is often low, thereby reducing effectiveness.[4] Hence, there is a major need for effective alternative treatments.

Oral appliances (OA) are designed to improve upper airway configuration and prevent collapse through alteration of jaw and tongue position. The most common mechanism of action is to hold the lower jaw in a more anterior position (OA_m). These appliances are variously termed "mandibular advancement devices (MAD)," "mandibular advancement splints (MAS)," or mandibular repositioning appliances (MRA)." Imaging studies show that mandibular advancement with OA_m enlarges the upper airway space, most notably in the lateral dimension of the velopharyngeal region.[5] Lateral expansion of the airway space is likely mediated through lateral tissue movement via direct tissue connections between the lateral walls and the ramus of the mandible.[6] Various amounts of anterior tongue movement also occur with mandibular advancement.[6] Alternative OA designs which protrude the tongue instead of the mandible (tongue-retaining device [TRD]) are also available.[7-9] TRDs feature an extra-oral flexible bulb and hold the tongue forward by suction, preventing its collapse into the airway. TRDs may be poorly tolerated, with inadequate device

retention a potential issue reducing effectiveness.[10] TRD do not form part of the evidence base on which current recommendations for oral appliance treatment are made[11] and are not further discussed in this review. Current practice parameters of the American Academy of Sleep Medicine (AASM) indicate OA_m as a first-line therapy in patients with mild-to-moderate OSA and in more severe OSA patients who fail treatment attempts with CPAP therapy.[11]

Recent advances in technologies including remotely controlled mandibular advancement sleep studies and objective adherence monitoring capabilities[12,13] are likely to further enhance and support the effectiveness of OA_m in treatment of OSA. In light of such recent advances, an international registry has been established to initiate a large prospective cohort to study OA_m effectiveness and long-term treatment outcomes. The ORANGE-Registry (Oral Appliance Network on Global Effectiveness) is a partnership between centers with research interest and established expertise in OA_m treatment. ORANGE comprises of a variety of specialists, including physicians, dentists and researchers from international centers including University of Sydney (Australia), University of Stanford and University of Pennsylvania (USA), Kaiser Permanente (CA-USA), Cambridge University (UK), Paris and Angers Hospital (France), Antwerp University (Belgium), Somnology Center and Kyushu University (Japan), University of British Columbia, University of Montreal and Laval University (Canada), Groennigen University (Netherlands), and Umea University (Sweden). This review was conducted within members of ORANGE to summarize the current evidence regarding efficacy and effectiveness of OA_m for the treatment of OSA as well as to highlight recent technological developments.

Oral Appliance Designs and Definitions of Treatment Success

There are numerous differences in the design features of commercially available OA_m. Differences predominantly relate to the degree of customization to the patient's dentition and one-piece (monobloc) designs (no mouth opening) 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 plates together. Other variations include the range of degree of advancement, amount of vertical opening, fabrication material, and the amount of occlusal coverage.

Definitions of treatment success in reports of OA_m efficacy also vary. Treatment success is predominantly defined by a reduction in AHI with or without requirement for symptomatic improvement. Treatment success in terms of AHI are variously expressed as a reduction in treatment AHI below a specified value, such as < 5 (resolution of OSA) or < 10 (very mild disease), or by a percentage reduction in AHI from baseline which is deemed to be clinically significant (typically 50% AHI reduction).

EFFICACY AND EFFECTIVENESS OF ORAL APPLIANCE TREATMENT FOR OSA

There is now a large body of research that demonstrates efficacy of OA_m in terms of reducing snoring and obstructive breathing events as well as showing beneficial effects on associated health outcomes such as daytime sleepiness.

Oral Appliances Compared to Inactive Appliances

Randomized controlled studies have established OA_m efficacy by comparison to placebo or inactive appliance (does not provide mandibular advancement).[14-20] Four parallel group randomized controlled trials have compared a monobloc appliance (75% of maximum mandibular advancement) to a control device over treatment periods from 2 weeks to 3 months. All studies found in favor of the active appliance in reduction in AHI[14,15,17,20] and arousal index,[15] and improving oxygen saturation.[20] Three crossover studies of active and inactive (single dental plate) OA_m also confirm OSA improvement specific to the mandibular advancement device,[16,18,19] with reductions in both NREM and REM AHI,[21] and improvement in arousal index, oxygen saturation, and REM sleep time. Reduced snoring was also found to be specifically related to the action of mandibular advancement both by objective measurement using a sound meter[16,19] and by subjective bed partner assessment.[15,18] These inactive-device controlled studies confirm that OA_m that jaw protrusion by OA_m is the key mechanism by which treatment is delivered.

Effects of Oral Appliance Treatment on Health Outcomes

Subjective daytime sleepiness, assessed by the Epworth Sleepiness Score (ESS), improves with OA_m compared to inactive appliances in the majority of studies,[14-20] although a placebo effect on ESS has been reported.[16,18] Objectively measured sleepiness by the multiple sleep latency test (MSLT) was improved only with active OA_m.[16]

Three placebo-controlled OA_m studies have included health related quality of life questionnaires in assessment of OA_m effectiveness. The Medical Outcome Survey Short Form 36 (SF-36) outcomes did not differ between OA_m and inactive device in one study,[15] although the vitality domain improved in another.[20] A large effect of OA_m therapy in improvements on The Functional Outcomes of Sleep Questionnaire (FOSQ) has been reported.[15] OA_m treatment also improved assessment on the Profile of Mood States (POMS) questionnaire, Vigor-Activity and Fatigue-Inertia scales.[21]

No differences in neurocognitive function by assessment of attention/working memory, verbal memory, visuospatial, or executive functioning between control and active treatment were found in one crossover study.[21] However OA_m treatment was associated with faster performance on tests of vigilance/psychomotor speed, although improvement did not correspond to reduced daytime sleepiness or AHI.

Blood pressure outcomes are reported in two placebo device-controlled studies.[14,22] A crossover study monitored 24-h ambulatory blood pressure after 4 weeks of OA_m and inactive appliance wear in 61 patients and found a reduction in 24-h diastolic but not systolic blood pressure.[22] Awake blood pressure was reduced on average by 3.3 mm Hg, although there was no effect on blood pressure measurements during sleep. A parallel group pilot study found a 1.8 mm Hg reduction in 24-h mean systolic blood pressure with OA_m treatment compared to control, with a greater reduction of 2.6 mm Hg in subgroup analysis of hypertensive patients.[14]

INFLUENCE OF ORAL APPLIANCE DESIGN FEATURES

Customization of Appliance

OA_m are generally customized devices fabricated from dental casts of a patient's dentition and bite registrations by a dentist, which is associated with expense and time. A lower cost alternative is a thermoplastic or "boil and bite" appliance. These devices are a thermoplastic polymer material, which becomes moldable when heated in boiling water. A patient bites into the softened material and advances the lower jaw to approximately 50% of maximum, and the device will set in this configuration with cooling. Direct comparison of the efficacy of thermoplastic and customized OA_m devices in a crossover study of 35 patients over 4 months of each device found post-treatment AHI was reduced only with the custom-made OA_m.[23] The thermoplastic device also showed a much lower rate of treatment success (60% vs. 31%). Lower adherence to the thermoplastic appliance was also evident, attributable to insufficient retention of the appliance during sleep. The overwhelming majority of patients (82%) preferred the customized OA_m at the end of the study. Hence customization to a patient's dentition is a key component of treatment success.

Degree of Mandibular Advancement

Generally the greater the level of advancement, the better the treatment effect, although this must be balanced against potential increase in side effects. A study of 3 levels of advancement (2, 4, and 6 mm) found dose dependence in improvement of overnight oximetry (25%, 48%, and 65% of patients showing improvement [> 50%] in desaturation, respectively).[24] Assessment of pharyngeal collapsibility during mandibular advancement has also shown a dose-dependent effect in improvement of upper airway closing pressures.[24] In a study of mild-to-moderate OSA patients randomized to either 50% or 75% of maximum advancement, there was no difference between these levels in treatment AHI or proportion of patients successfully treated (79% vs. 73%).[25] However in severe OSA, more patients achieved treatment success with 75% compared to 50% maximum advancement (52% vs. 31%),[26] suggesting maximizing advancement may be more important in severe disease. A dose-dependent effect of mandibular advancement was demonstrated using 4 randomized levels of advancement (0%, 25%, 50%, and 75% maximum), with the efficacy of 50% to 75% advancement greater than 25%, and 25% greater than 0%.[27] However above 50% of maximum advancement there was an associated increase in reported side effects. A titration approach to determine optimal level of advancement with gradual increments over time is thought to optimize treatment outcome.[28] Titration can be guided by a combination of both subjective symptomatic improvement and objective monitoring by overnight oximetry to find the optimally effective advancement level.[28] A newly available remotely controlled mandibular titration device[13] provides an objective mechanism by which to determine the maximal therapeutic level of mandibular protrusion during sleep. The target treatment protrusion identified by this method of sleep titration was found to result in effective treatment in 87% of patients predicted to be successfully treated OA_m in an initial study. Identification of therapeutic protrusion level by this method may help reduce side effects produced by further unnecessary titration. Optimizing mandibular advancement in individual patients is important for successful treatment, although no standardized titration procedure currently exists.[29] In the clinical setting, a follow-up sleep study to objectively verify satisfactory treatment is often not conducted; this is an area by which to improve clinical outcomes.

Degree of Vertical Opening

Opening of the bite occurs during OA_m treatment as all appliances have a given thickness causing vertical jaw displacement. A crossover trial compared 2 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.[30] However, increased vertical mouth opening has an adverse effect on upper airway patency in the majority of OSA patients.[31] Therefore amount of bite opening should be minimized to improve patient tolerance and increase the beneficial effect on upper airway dimensions.

COMPARISONS OF DIFFERENT CUSTOMIZED APPLIANCES

Differences in reported OA_m treatment efficacy potentially relate to different design features. There are a relatively limited number of trials which compare customized appliance designs for efficacy. However existing studies suggest different OA_m designs are similarly effective in treating OSA. Two-piece appliances are thought to improve comfort and wearability as lateral movement and jaw opening is possible, however monobloc appliances can be cheaper and easier to manufacture. A comparison of a monobloc and 2-piece OA_m found no difference in AHI reduction, improved sleepiness, or reported side effects, although patient preference in this study favored the monobloc appliance.[32] A recent retrospective analysis of 805 patients using either an adjustable OA_m (n = 602) or a fixed device (n = 203) found a higher treatment response rate for the adjustable device (56.8% *vs.* 47.0%).[33] A comparison of 2 adjustable OAs with different retention mechanisms (one with occlusal coverage and firm dental retention, the other more passive retention with a looser attachment to the dental arches) found no differences in subjective symptoms, but the passive appliance resulted in greater reduction in treatment AHI, although the difference is unlikely clinically significant.[34] Two crossover studies have compared 2-piece adjustable appliances with different advancement mechanisms and found similar improvements in AHI, symptomatic improvements, and side effects.[35,36]

New variations in customized OA_m designs may enhance effectiveness in the future. A recent cohort study tested the addition of tongue protrusion, via an anterior tongue bulb on an OA_m device and showed greater AHI reduction compared to mandibular advancement alone.[37] Simultaneous advancement of both the tongue and mandible, for example, may prove to increase therapeutic effect.

SIDE EFFECTS OF ORAL APPLIANCE TREATMENT

In initial acclimatization to OA_m therapy, adverse side effects are commonly experienced. Adverse effects primarily include excessive salivation, mouth dryness, tooth pain, gum irritation, headaches, and temporomandibular joint discomfort. Reported frequencies of side effects vary greatly,[38] potentially related to differences in device design. However adverse symptoms are usually transient, lasting around 2 months.[39] Temporomandibular disorder symptoms of pain and impairment in the initial treatment period tend to decrease over time and resolve after 6 to 12 months in the majority of patients.[39,40] Long-term persistence of side effects such as mouth dryness and tooth or jaw discomfort may lead to discontinuation of treatment.[41]

Assessment of dental changes with OA_m primarily relate to decreases in overbite and overjet,[42-47] retroclination of the upper incisor and proclination of the lower incisors,[43,46] changes in anterior-posterior occlusion, and reduction in the number of occlusal contacts.[42,45,46] Overbite and overjet changes are evident 6 months after initiation of treatment.[46] Duration of OA_m use is reported to correlate with dental changes such as decreased overbite,[48] suggesting progressive changes to the dentition over time. However generally occlusal changes are negligible and in over half of patients actually represent an improvement on baseline occlusion.[42] The initial type of bite, degree of mandibular advancement, adherence, and oral health will influence the amount of bite changes and discomfort produced during longer term treatment. Skeletal changes relating to prolonged OA_m use on lateral cephalometry, primarily report an increase in lower face height and a downward rotation of the mandible.[44,46,48] Skeletal changes are probably a result of the changes in dentition that occur with wear of the OA_m. Many patients are unaware of any changes in their bite and the majority of patients concur that positive effects of OSA treatment far outweigh any adverse effects related to dental changes.

LONG-TERM EFFECTIVENESS AND ADHERENCE

Overall long-term efficacy of OA_m treatment is fairly good. Repeat sleep studies show stability of AHI from 1 to 4 years after OA_m implementation in treatment responders.[25,49-52] Treatment AHI also has demonstrated stability between 6 monthly sleep studies.[25,49] In one study, OA_m treatment response was maintained despite an increase in BMI over time.[50] Improvements in health related quality of life and sleepiness symptoms are also sustained at long-term follow-up, and continued improvement over time is noted.[49,50] Diastolic and systolic blood pressure measurements are reduced after 2.5 to 4.5 years of OA_m treatment.[50] Although OA_m treatment appears to remain efficacious, usage may drop off somewhat over time. Seventy-six percent of patients report using their OA_m after one year[53] and 62% of patients after 4 years.[52] In patients who continue to use their device at 5 years, self-reported adherence is good, with over 90% of patients reporting usage rates > 4 nights per week for more than half the night.[41] Despite demonstrated long-term efficacy, the durability of different OA_m devices and the potential need for continuous adjustment over time has not been systematically evaluated. Currently there is little knowledge of how often to follow-up patients on OA_m treatment for device adjustment. More information about these aspects of OA_m therapy could help improve long-term effectiveness and adherence.

EFFICACY AND EFFECTIVENESS OF ORAL APPLIANCES COMPARED TO OTHER TREATMENTS

Oral Appliances Compared to CPAP

To our knowledge there are currently 11 published randomized controlled trials which compare efficacy of OA_m treatment with CPAP with polysomnographic outcomes (8 crossover trials, 3 parallel group trials) and variously evaluate aspects of clinical effectiveness with subjective and objective health outcome measures. Most studies have been limited to patients with mild-moderate OSA, although some did not include an upper AHI limit or allowed inclusion of patients with an AHI $\leq$ 60.[54-56] The most recent study specifically enriched the sample with moderate-severe patients.[57] Details of these studies are summarized in **Table 1**.

Polysomnographic Indices

General consensus from all trials to date is that both CPAP and OA improve sleep disordered breathing assessed in overnight sleep studies. However CPAP does so to a greater extent than OA_m, with a higher percentage of patients experiencing complete resolution of OSA.

Apnea Hypopnea Index

AHI improves on both CPAP and OA_m treatment; however, AHI is reduced to a greater extent with CPAP.[54-62] Differences in the proportion of patients achieving treatment success (variously defined) are also in favor of CPAP. Studies which report a complete response to treatment (AHI < 5/h) indicate that nearly double the number of patients are successfully treated on CPAP compared to OA_m (e.g., 34% CPAP vs. 19% OA,[54] 73% vs. 43%,[55] 75% vs. 40%[57]). With success defined as a post-treatment AHI < 10 events/h, success rates for OA_m are in the range of 30% to 85% and 62% to 100% for CPAP.[27,54,55,59,60] In one crossover study including a placebo tablet treatment arm, 65% of patients achieved their best response with CPAP, 25% with OA_m, and 10% with placebo.[58]

Oxygen Saturation

Only one parallel trial has found an equal improvement in minimum arterial oxygen saturation with CPAP and OA_m treatment.[61] All other studies report only CPAP improves minimum oxygen saturation.[57-60,62] In other oxygen measures, oxygen desaturation index (ODI) remains higher and mean oxygen saturation lower on OA_m treatment compared to CPAP.[55,57] CPAP treatment therefore appears to be superior in alleviating oxygen desaturation.

Arousal Index

Two studies have reported no difference between CPAP and OA_m treatment in improving arousal Index.[27,63] Neither treatment was found to decrease the number of awakenings compared

Table 1—Oral appliances versus CPAP treatment: results from randomized controlled trials

Study	Design	Subjects n (% male) [withdrawals]	Inclusion	Oral appliance	Treatment [washout] duration	Baseline AHI	Treatment AHI		OA vs. CPAP		
							CPAP	OA	AHI	ESS	Patient preference
Aarab 2010[27]	parallel (*placebo group included*)	57 (74%) (20 OA/18 CPAP) [7]	AHI 5-45 + ESS ≥ 10	Customized, Two-piece, set 25, 50, or 75% advancement depending on sleep study results at each level	24 weeks	CPAP: 20.9 ± 9.8 OA: 22.1 ± 10.8	1.4 ± 13.1	5.8 ± 14.9	↔ (p = 0.092)	↔	N/A – parallel groups
Barnes 2004[58]	crossover (*placebo group included*)	80 (79%) [24]	AHI 5-30	Customized, 4 week titration to maximum comfortable advancement	3x12 weeks [2 weeks]	21.5 ± 1.6^	4.8 ± 0.5^	14.0 ± 1.1^	CPAP	↔	CPAP
Engleman 2002[54]	crossover	48 (75%) [3]	AHI ≥ 5/h + ≥ 2 symptoms (including ESS ≥ 8)	Customized, one-piece, 80% maximal protrusion, two deigns a) complete occlusal coverage or b) no occlusal coverage, assigned randomly	2x8 weeks [not reported]	31 ± 26	8 ± 6	15 ± 16	CPAP	CPAP	↔
Ferguson 1996[60]	crossover	25 (89%) [2]	AHI 15-50 + OSA symptoms	Snore-Guard (Hays & Meade Inc), maximum comfortable advancement	2x16 weeks [2 weeks]	24.5 ± 8.8	3.6 ± 1.7	9.7 ± 7.3	CPAP	N/A	OA
Ferguson 1997[59]	crossover	20 (95%) [4]	AHI 15-55 + OSA symptoms	Customized, two-piece appliance, titration starting at 70% maximum advancement over 3 months	2x16 weeks [2 weeks]	26.8 ± 11.9	4.0 ± 2.2	14.2 ± 14.7	CPAP	↔	OA
Gagnadoux 2009[55]	crossover	59 (78%) [3]	AHI 10-60 + ≥ 2 symptoms, BMI ≥ 35 kg/m^2	AMC (Artech Medical), two-piece, advancement determined by single-night titration	2x8 weeks, [1 week]	34 ± 13	2 (1-8)#	6 (3-14)#	CPAP	↔	OA
Hoekema 2008[56]	parallel	103 (51 OA/52 CPAP) [4]	AHI ≥ 5	Thornton Adjustable Positioner type 1, titratable	8-12 weeks	CPAP: 40.3 ± 27.6 OA: 39.4 ± 30.8	2.4 ± 4.2	7.8 ± 14.4	CPAP	↔	N/A – parallel groups
Lam 2007[61]	parallel (*placebo group included*)	101 (79%) (34 OA/34 CPAP) [10]	AHI ≥ 5-40 + ESS > 9 if AHI 5-20	Customized, non-adjustable, set to maximum comfortable advancement	10 weeks (83% referred for concurrent weight loss program)	CPAP: 23.8 ± 1.9^ OA: 20.9 ± 1.7^	2.8 ± 1.1^	10.6 ± 1.7^	CPAP	CPAP	N/A – parallel groups
Phillips 2013[57]	crossover	108 (81%) [18]	AHI ≥ 10 + ≥ 2 symptoms	Customized, two-piece appliance (SomnoMed), titrated to maximum comfortable limit in acclimatization period before study	2x4 weeks [2 weeks]	25.6 ± 12.3	4.5 ± 6.6	11.1 ± 12.1	CPAP	↔	OA
Randerath 2002[62]	crossover	20 (80%)	AHI 5-30 + OSA symptoms	IST; Hinz; Herne, Germany, two piece, non-titratable, set to two-thirds of maximum advancement	2x6 weeks [not reported]	17.5 ± 7.7	3.2 ± 2.9	13.8 ± 11.1	CPAP	N/A	N/A
Tan 2002[63]	crossover	21 (83%) [3]	AHI 5-50	One-piece, 75% maximum advancement and Silensor (Erkodent Gmbh) two-piece, titratable	2x8 weeks, [2 weeks]	22.2 ± 9.6	3.1 ± 2.8	8.0 ± 10.9	↔	↔	N/A

↔, equivalent between treatments; AHI, apnea-hypopnea index; N/A, not applicable, not measured in study. Data presented as mean ± SD, unless denoted ^(mean ± SEM) or #(median [interquartile range]).

to baseline in 2 crossover trials.[59,60] A greater effect of CPAP in reducing arousal index has been reported in others.[57,58,61,62] Recent meta-analyses of these randomized trials found CPAP to be superior in reducing arousals from sleep.

Health Outcomes

Health outcome measures have been included in most comparisons of OA_m and CPAP treatment. Although CPAP is superior in reducing polysomnographic variables, the findings of subjective and objective health outcomes are not in favor of CPAP with improvements generally equivalent between treatments.

Daytime Sleepiness

All trials reporting Epworth Sleepiness Score (ESS) show improvement after both OA_m and CPAP. Two studies found a greater reduction in ESS after CPAP treatment by up to 4 points.[54,61] However the majority demonstrate no difference between OA_m and CPAP treatments in reduction of subjective sleepiness.[27,55-59,61] Recent meta-analyses have found no difference in ESS reduction between these treatments.[64-66]

No differences in objectively measured daytime sleepiness have been reported in three crossover trials of CPAP and OA_m. One study found no difference between OA_m and CPAP in increased sleep onset latency during the maintenance of

wakefulness test (MWT).[54] Another study found no improvement with either CPAP or OA_m on the MWT, although patients were not particularly sleepy at baseline.[58] Equal improvement in performance on the Oxford sleep resistance (OSLER) test was found after 2 months of treatment.[55]

Quality of Life

Health related quality of life outcomes, assessed by questionnaire, are relatively mixed in favoring either CPAP or OA_m treatment. Of 6 studies incorporating the SF-36, 2 report no difference in SF-36 scores.[27,56] Three report in favor of CPAP, one showing better scores on health transition and mental (but not physical) component scores,[54] and another an improvement in 6 domains (excluding social functioning and mental health) compared to 3 domains (general health perceptions, vitality, and emotional) with OA_m.[61] The third study found only CPAP showed improvement compared to placebo treatment, although both treatment scores improved from baseline.[58] Most recently OA_m were reported to perform better than CPAP in 4 of 8 domains (bodily pain, vitality, social function, mental health) and the overall mental component score.[57] OA_m treatment also improved more domains on the Nottingham Health Profile (NHP) with 4 of 6 domains (physical mobility, pain, emotional reaction, and sleep) compared to 2 (emotional reaction and energy) on CPAP.[55] In this crossover study there was a treatment-by-period effect for emotional reaction and subjective sleep quality with OA_m rating higher than CPAP when experienced as a second treatment but no difference between CPAP and OA_m as first treatments. A validated general health questionnaire administered to both OSA patients and their bed partners identified no differences between treatments by either self- or partner-assessment.[63] The Functional Outcomes of Sleep Questionnaire (FOSQ) did not differ between CPAP and OA_m treatment in 3 studies,[56-58] although CPAP was superior in another.[54] The Sleep Apnea Quality of Life Index (SAQLI) did not differ between CPAP and OA treated patients.[61] There have also been no reported differences between treatments in effects on anxiety and depression (Hospital Anxiety and Depression Score).[54,56]

Cognitive Performance

There was no difference in performance after CPAP and OA_m treatment in one administered cognitive battery (Performance IQ decrement score, Trails Making Test B, SteerClear Performance test, Paced Auditory Serial Addition Task [PASAT]).[54] Another assessment with the Trails Making Test found Test A improved equally with both treatments but Test B only improved following CPAP treatment.[55] A placebo-controlled study did not find any post-treatment improvement in a large number of cognitive tests (digit span backward, Trails Making B, Digit symbol substitution task, controlled word association task, Stroop color association test) although lapses on the psychomotor vigilance task were reduced after CPAP but not OA_m treatment.[58] No post-treatment differences were detected between CPAP and OA_m in performance on the Aus-Ed driving simulator.[57]

Blood Pressure Outcomes

Blood pressure monitoring in a limited number of trials suggest no overt differences between CPAP and OA_m treatment in short-term control of blood pressure. A parallel group study showed equivalent reduction in morning diastolic blood pressure between OA_m and CPAP treatment after 10 weeks.[61] Two crossover trials also report no difference between OA_m and CPAP treatment on blood pressure outcomes, although there was no reduction in blood pressure from baseline on either treatment.[57,58] However subgroup analysis of hypertensive patients have shown equivalent improvement in 24-h blood pressure between OA_m and CPAP treatment.[57]

Endothelial Function

Endothelial dysfunction is recognized as a key early event which precedes or accelerates the development of atherosclerosis and may be predictive of future cardiovascular events.[67,68] Endothelial dysfunction has been proposed as a potential mechanism in the pathogenesis of cardiovascular complications of OSA.[69] A small randomized crossover trial involving 12 OSA patients demonstrated an equivalent increase in acetylcholine-induced vasodilation between 2 months of OA_m and CPAP, with degree of improvement correlating with decrease in nocturnal oxygen desaturations.[70]

Cardiovascular Morbidity

Observational and randomized controlled trials have demonstrated beneficial impact of regular CPAP use on cardiovascular and metabolic outcomes in OSA.[71,72] Although there are currently no randomized trials comparing cardiovascular morbidity between CPAP and OA_m treatment, a recent non-concurrent cohort study monitored cardiovascular mortality in severe OSA patients on either CPAP or OA_m treatment.[73] The study followed 208 control subjects (AHI < 5) and 570 severe OSA patients (177 CPAP treated, 72 OA_m 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_m in incidence of fatal cardiovascular events, despite a higher residual AHI in the OA_m-treated patients. There is a clear need for additional observational and randomized studies comparing the effect of OA_m and CPAP treatments on cardiometabolic outcomes and surrogate markers of cardiovascular risk.

Treatment Usage and Patient Preference

Comparisons of treatment usage predominantly rely on self-reported adherence data. There was no difference in self-reported usage found between OA_m and CPAP either in the number of nights of treatment use per week or hours per night in 3 studies.[27,54,56,59,60] Other studies report greater adherence to OA_m, with 1.1 nights/week and 1.9 h/night more treatment time in patient diaries compared to objective CPAP usage data download.[58] Furthermore, based on definition of 4 h/night for effective treatment, 43% of patients on CPAP and 76% of patients on OA_m show good adherence. Greater adherence has been reported for OA_m compared to self-reported CPAP usage. However, it is known that self-reported CPAP adherence significantly overestimates nightly and weekly usage compared to objective monitoring data.[55,57]

Overall there is preference for OA_m over CPAP treatment but with much variation. Four of 6 crossover trials asking for

patient treatment preference at the end of the trial, found in favor of OA_m.[55,57,59,60] In another study, preference lay in favor of CPAP (44% vs. 30% preferring OA_m)[58]; in another preference was equally distributed between CPAP and OA.[54] In the former study, OA_m preference was associated with lower levels of obesity and less symptoms, including sleepiness. A recent qualitative analysis of patient treatment preference and experience of OA_m and CPAP treatments has been conducted using focus groups of OSA patients on either form of treatment.[74] CPAP and OA users described a similar amount of side effects, although the side effect profile differed between devices. The factors most frequently mentioned that influenced choice of treatment were effectiveness, transportability, embarrassment, cost, bed partner preference, access to power supply or hot water, convenience, and impact on bite. Patient choice of treatment may be influenced by an individual's personality, lifestyle, perceived stigma, and financial status, although patients reported effectiveness of the treatment as paramount in their decision.[74]

Combined Oral Appliance and CPAP Therapy

Although OA_m and CPAP have been considered as alternative treatment pathways, there is scope for a patient to alternate between them as needed in situations such as travel when CPAP may be inconvenient. Additionally there are some recent lines of evidence suggesting combining the 2 treatment modalities simultaneously may be of additional benefit. The effect of OA_m in opening the upper airway has been explored as a means to reduce CPAP pressure, as high pressure requirement can lead to intolerance and reduced adherence in some patients. A pilot study of 10 patients partially treated by OA_m but who failed CPAP due to intolerance to prescribed pressure, found auto-titration of CPAP pressure while wearing an OA_m reduced average pressure requirement from 9.4 to 7.3.[75] A physiological study of upper airway mechanics at various CPAP pressures delivered under conditions of (1) oronasal mask, (2) nasal mask and combined OA_m, and (3) nasal mask showed that velopharyngeal resistance was reduced in the OA_m/nasal mask condition compared to CPAP alone.[76] OA_m may prove to be a useful adjunct to CPAP therapy in reducing pressure requirements and preventing issues of mouth opening, leaks and chin retrusion which variously result from different CPAP masks.

Oral Appliances Compared to Surgery

There is currently only one prospective randomized trial of OA_m compared to surgical treatment for OSA.[77] The surgical procedure used in this study was uvulopalatopharyngoplasty (UPPP), which involves removal of upper airway soft tissues including the uvula, soft palate, tonsils, and adenoids. Ninety-five mild-moderate (apnea index > 5 and < 25 events/h) OSA male patients were randomized to receive either UPPP or OA_m treatment set to 50% of the patient's maximum level of mandibular advancement. Both treatments significantly reduced sleep disordered breathing events on polysomnography at 6 and 12 months, although at 12 months the OA_m group showed a greater reduction in AHI. Complete treatment response (AHI ≥ 10 events/h) also occurred in a greater proportion of patients using OA_m compared to the UPPP group (78% *vs*. 51%). At 4-year follow-up, AHI remained lower in the OA_m group, with a complete response sustained in 63% compared to 33% of the UPPP treated group.[52]

In terms of symptoms, both surgical and OA_m treatment reduced subjective daytime sleepiness assessed at 6 and 12 months.[77] Greater reduction in sleepiness was initially observed with OA_m treatment at 6 months, but this was not sustained at 12 months. Quality of life assessment performed before treatment and at 1-year follow-up found improvement in all 3 quality of life domains (quality, vitality, and contentment) with both treatments; however, the UPPP-treated group showed significantly more contentment than the OA_m group.[78]

Maxillomandibular advancement (MMA) surgery, to enlarge the pharyngeal space by expanding the skeletal boundaries of the maxilla and mandible, is currently considered the most efficacious surgical procedure for treatment of OSA, particularly severe OSA.[79,80] Although there are no randomized trials of MMA and OA_m, a French study offered MMA to 102 non-obese, severe OSA patients and treated those who refused surgery with an OA_m.[81] Polysomnography at 3 months found MMA reduced AHI (45 events/h *vs*. 7 events/h mean values, n = 25) with a 74% surgery success rate (AHI < 10/h). OA_m also reduced the AHI (41 events/h *vs*. 22 events/h mean values, n = 23) with a lower success rate (30%), although a significant number of OA_m patients did not complete the 3-month assessment. Hoekema and colleagues offered MMA to OSA patients who were successfully treated with an oral appliance (> 50% reduction in AHI).[82] Four (of 43) patients completed the surgery; AHI was significantly reduced, with a complete response (AHI < 5/h) in 3 of these patients. The authors suggest response to OA_m therapy may be a predictor of success of MMA surgery for OSA.

Overall, studies comparing OA_m with surgical treatment for OSA are extremely limited. Such comparisons of effectiveness should also take into account adherence factors. Surgery, as an irreversible intervention, has 100% adherence over all hours of sleep, whereas device therapy is dependent on patient adherence to be effective. Therefore treatment comparisons need to take into account not only efficacy on treatment but the percentage of sleep time for which a removable device is used, as a high proportion of sleep time not on treatment will reduce the overall effectiveness, even in a highly efficacious device.[83]

PATIENT SELECTION AND PREDICTION OF TREATMENT SUCCESS

Consistent in all studies of OA_m treatment efficacy is that OSA is not adequately alleviated in all patients, and therefore OA_m will have limited effectiveness in these patients. **Table 2** summarizes the proportion of OA_m treatment responders, by various definitions, from randomized controlled OA_m studies. Differences between studies likely relate to variations in definitions, appliance, and patient factors. On average, a complete response (resolution of OSA or an AHI < 5 events/h) occurs in around 48% of patients, with a range of 29% to 71% among studies (**Table 2**).

Individual variability in response to OA_m treatment represents a significant clinical challenge, as implementing therapy in patients who will ultimately not receive benefit is unsatisfactory from both a treatment and cost point of view. Therefore,

Table 2—Treatment success with oral appliances

Study	Oral appliance	Inclusion	Patients n (%male)	Pre-treatment AHI	Treatment success (%)		
					AHI < 5	AHI < 10	AHI ≥ 50%
Aarab 2010[27]	Two-piece (9.6 ± 2.1 mm)	AHI 5-45 + ≥ 2 symptoms	17 (71%)	21.6 ± 11.1	71	–	6
Andren 2012[14]	Monobloc (70-75% maximum advancement)	AHI > 10 + hypertension	30 (83%)	23 ± 16 (mild 39%, moderate 47%, severe 14%)	–	78	–
Blanco 2005[15]	Monobloc (75% maximum advancement)	AHI > 10 + ≥ 2 symptoms	8	33.8 ± 14.7	57	–	43
Bloch 2000[32]	Monobloc and Herbst (initial 75% of maximum advancement)	AHI > 5 + CPAP failure	24 (96%)	26.7 ± 3.3	–	88	–
Fleury 2004[28]	Two-piece (128.9 ± 23.8% maximum advancement)	AHI > 5 + CPAP failure	40	46 ± 21	–	64	18
Gotsopoulos 2002[16]	Two-piece (80 ± 9% maximum advancement)	AHI > 10 + ≥ 2 symptoms	73 (81%)	27.1 ± 15.3 (mild 15%, moderate 56%, severe 29%)	36	–	37
Mehta 2001[19]	Two-piece	AHI > 10	24	27 ± 17 (mild 46%, moderate 29%, severe 25%)	38	54	63
Petri 2008[20]	Monobloc (74% range 64-85% maximum advancement)	AHI > 5	27	39.1 ± 23.8 (mild-moderate 44%, severe 56%)	29	40	48
Pitsis 2001[30]	Two-piece (87 ± 4% advancement, 4 mm/14 mm vertical)	AHI > 5	23 (83%)	21 ± 12 (range 6-47)	57	–	26
Tegelberg 2003[25]	Monobloc (75% maximum advancement)	AI 5-25 (mild-moderate)	26	18.9 ± 4.7^ (mild-moderate)	–	73	62
Vanderveken 2008[23]	Monobloc	AHI < 40	35	13 ± 11 (range 0-40)	49	–	11
Walker-Engstrom 2003[26]	Monobloc (75% maximum advancement)	AI < 20 (severe)	40 (100%)	50.4 ± 4.7^	–	52	–
n					7	7	9
Mean					48%	64%	35%

All data presented as mean ± standard deviation, unless ^mean ± 95% confidence interval. AHI, apnea-hypopnea index; AI, apnea index, not reported (-). Treatment success definitions: AHI < 5; treatment AHI < 5 events/h; AHI < 10, treatment AHI < 10 events/h; AHI ≥ 50%, ≥ 50% reduction in treatment AHI from baseline AHI but treatment AHI remains above 5-10 events/h.

patient characteristics relating to treatment success and reliable prediction methods are a high research priority.

Various patient factors have been associated with treatment outcome. Less severe disease as well as supine-predominant OSA (a higher AHI in supine compared to lateral sleeping position) has been considered favorable for treatment success.[15,19,20,53,84] Younger age, female gender, and less obesity (lower BMI and neck circumference) are also suggested as indicators of treatment success.[19,53,85-87] Craniofacial features assessed by lateral cephalometry, including shorter soft palate length, lower hyoid bone position, greater angle between the cranial base and mandibular plane, and a retrognathic mandible, are also associated with favorable treatment outcome.[19,86-89] Although various patient phenotypes have been related to a higher likelihood of treatment success, these are not universal. Complete amelioration of OSA by OA_m therapy can occur in severe patients and overweight patients.[19,26,62] Anatomical characteristics appear to play a role in treatment outcome; however, the relatively weak and somewhat inconsistent cephalometric data suggest that decisions based solely on these factors cannot be recommended.[86]

Therefore reliable prediction tests are needed in order to discriminate treatment responders and non-responders. Although yet to be prospectively validated, various methods for prediction of OA_m treatment outcome have been proposed. There are some promising techniques assessing anatomical and functional characteristics of the upper airway response which may prove to have clinical utility.

Approaches to selecting suitable patients for OA_m treatment include imaging upper airway geometry and behavior with and without simulated mandibular advancement. Nasendoscopy during drug-induced sleep has been used to visualize magnitude

and patterns of pharyngeal collapse without and with a mandibular advancement simulation bite.[90] Patients with a greater improvement in pharyngeal patency under the mandibular advancement condition during drug induced sleep showed good sensitivity for treatment success. Drug-induced sleep endoscopy may have limitations, however awake nasendoscopy has also shown some predictive utility in demonstration of reduced upper airway collapsibility, simulated by the Mueller maneuver, with mandibular advancement.[5] Computational methods to simulate changes in airflow patterns with mandibular advancement based on patient-specific upper airway geometries from magnetic resonance or computed tomography scans have also been considered to predict treatment outcome.[91,92]

The region of pharyngeal airway collapse and its association with OA_m treatment outcome has also been considered as a predictor using awake assessments of flow-volume loops and phrenic nerve stimulation.[93-95] Other assessments of the airway during wakefulness have shown an association between higher nasal resistance and treatment failure with OA_m.[96] In OSA patients who have previously used CPAP treatment, a higher CPAP pressure requirement (> 10.5 cm H_2O) has been suggested as an indicator of lower likelihood of treatment success.[97]

Prediction of Treatment Success Using a Mandibular Titration Study

Another approach to predicting OA_m response is through a sleep study under the condition of mandibular advancement. This has been investigated by using a cheap "boil and bite" OA_m; however, results were not indicative of treatment outcome with a customized OA_m[23] limiting this approach as a reliable prediction method. Single-night titration methods, allowing advancement of the mandible during sleep, have shown more promise in indicating likely treatment success and therapeutic level of advancement in a small number of patients using prototype devices.[98,99] This method involves use of a remotely controlled intraoral device during an attended sleep study to incrementally advance the mandible until sleep disordered breathing events are eliminated, analogous to a CPAP pressure titration study.

A significant advance in single-night titration methodology has occurred with the recent development of a commercially available remotely controlled mandibular protrusion device.[13] This protrusion device connects to upper and lower dental trays containing impressions of the patient's dentition and advances the mandible by moving forward the lower tray during polysomnographic monitoring. This device has recently been tested as a prediction tool for OA_m treatment response in a prospective study of 67 patients. OSA patients were consecutively recruited with minimal exclusion criteria apart from severe obesity (BMI > 40 kg/m^2) and contraindications to OA_m. During the sleep titration the technologist remotely initiates forward movement of the lower dental tray in 0.2-0.6 mm increments in response to the appearance of apneas or hypopneas (halted in the event of an arousal until stable sleep had resumed). Protrusion is continued within the patient's predetermined range of motion until respiratory events are eliminated from sleep (both REM and NREM sleep stages and both lateral and supine body position) or until the patient's maximal protrusive level is reached. This mandibular titration study was used to predict treatment response based on a set prediction rule of ≤ 1 respiratory event/5 min supine REM sleep. Patients who met this criterion were predicted successes, and those with > 1 event were predicted failures. All patients went on to use a OA_m set at either the effective protrusion level from the titration night (predicted successes) or at a sham 70% of maximum protrusion (predicted failures). A follow-up sleep study wearing OA_m was used to determine actual response with a stringent definition of therapeutic success of treatment: AHI < 10/h plus 50% reduction in AHI from baseline. The mandibular titration prediction method correctly classified 30 of 32 patients as treatment responders. Five of the 29 predicted failures were found to treatment responders. The prediction method showed a rate of 9% for inconclusive tests because of failure to reach maximal protrusion during the titration (3%) or insufficient REM sleep (6%). Overall the initial study using this device as a prediction tool shows good accuracy in identifying patients who will be fully treated by OA_m. Interestingly, 20 of the patients correctly predicted to be treatment successes had OSA severity and BMI values above which would traditionally be considered appropriate for OA_m treatment. Initial investigation of this single night titration device therefore shows good utility as a prediction tool as well as the likely therapeutic mandibular protrusion level and has potential to improve patient selection via a single laboratory sleep study.

OBJECTIVE ADHERENCE MONITORS FOR ORAL APPLIANCES

Mounting evidence suggests that OA_m and CPAP treatment are comparatively effective in improving health outcomes, even in more severe OSA,[57] presumably due to greater overall usage of the OA_m device compared to CPAP. It has been possible to routinely objectively monitor CPAP adherence by machine usage since 1988.[100] However data from objective monitoring shows that less than half of CPAP users are good adherers, using the device < 4 h/night on < 70% of nights.[4] Until recently adherence data for OA_m therapy has essentially remained limited to patient self-report.[11,101] Although subjective adherence reports suggest short-term adherence is relatively good,[23,60,63,101] exceeding that of CPAP, the discrepancy between subjective and objective CPAP usage[4] suggests that better adherence to OA_m cannot be confirmed in the absence of objective monitoring. A true objective comparison between OA_m and CPAP treatment effectiveness to support the inference of inferior OA_m efficacy mitigated by superior adherence has been hindered by the lack of objective adherence data for OA_m.[57,101]

The recent introduction of objective monitoring capabilities in OA_m devices will be of great importance for both research and clinical purposes.[11,12,102] In research, objective adherence monitoring will help exclude overestimation by self-report bias. The hours and days in which a treatment is applied can be accurately monitored. Treatment usage time is important for adequate treatment,[83] and objective adherence data may be used to compare overall therapeutic effectiveness. The mean disease alleviation (MDA)[12,103] can be calculated, which takes into consideration not only the efficacy of treatment but the percentage of TST. Therefore a more accurate comparison of different therapies can be made, albeit subjective assessment of

Table 3—Adherence monitors for oral appliances

	Thermocron iButton[106]	Theramon[12,103]	DentiTrac[108]
Diameter (mm)	16.25	4.3	4
Length (mm)	17.35	13.0	10.5
Width (mm)	5.8	9.0	8.5
Weight (g)	3.3	0.4	0.5
Sample frequency (x/h)	3	4	60
Storage capacity (days)	21	100	180
Battery life expectancy			> 2 y
Temperature range	+15°C to +46°C	- 25°C to +60°C	

TST may be necessary. This will be invaluable for research in establishing the role of OA_m in treatment of OSA.

In clinical practice, adherence monitors may help encourage patients to use their device and objective data may help improve patient management. Furthermore adherence data may serve as a communication tool between physician and dentist. The ability to establish objective usage may also provide essential data for patients, for example in some countries commercial drivers are required to prove treatment usage for their reinstatement.

Adherence Monitoring Technology

Until recently, there have been limited reports of adherence monitoring technology for OA_m. Lowe and colleagues assessed an intra-oral temperature sensor for objective measurement of OA_m adherence in a study of 8 OSA patients[104]; however, this device was never commercially available. Subsequently, a commercially available temperature data logger was reported in terms of safety[105] and used to obtain objective data on OA_m treatment adherence in 7 patients.[106] However the dimensions and storage capacity of this particular temperature data logger were found to be problematic. Microsensor thermometers with on-chip integrated readout electronics, which are free of these issues, have been described in recent reports.[12,107] These microsensors, embedded into the OA_m, represent a significant technological advance and are commercially available. A recent technical report describes another novel patent-pending microrecorder which also may be embedded into an OA_m.[108] The specifications of different adherence monitors suitable for OA_m are described in **Table 3**.

Objective Monitoring of OA_m Adherence

Vanderveken and colleagues[12] recently described the first 3-month prospective clinical trial in which the Theramon monitor was used to covertly monitor OA_m adherence in 51 consecutive OSA patients. The study found that the overall objective mean rate of OA_m use was 6.6 ± 1.3 h per night, with 84% of patients fulfilling the criteria of "regular user" by completing ≥ 4 h of active OA_m treatment on > 70% of the days of the week.[4] At a one-year follow-up extension of the initial 3-month study, 89% of the 37 continuing OA_m users were still "regular users" with an overall rate of OA_m use of 6.4 ± 1.7 per night.[103] This objectively measured usage rate is relatively high compared to that with CPAP, in which regular usage occurs in 58% to 78 % of patients.[109,110]

Additionally objectively monitored OA_m adherence shows reasonable concordance with subjective self-report.[12,104] This contrasts CPAP treatment in which it has been consistently demonstrated that patients' own report of duration of CPAP use is an overestimation by approximately one hour,[4,55,57] corresponding to a significant amount of total treatment time. This suggests that there may be differences in the perceived and/or reported subjective assessment of usage between OA_m and CPAP treatments, with subjective compliance more accurate. This new data on concordance between subjective and objective OA_m adherence suggests that previous studies relying on self-reported OA_m use may be reasonably indicative of actual usage.

SUMMARY/CONCLUSIONS

OA_m are an effective treatment for OSA, not only improving AHI but also a variety of physiologic and behavioral outcomes. Recent comparative effectiveness trials have shown health outcomes between CPAP and OA_m treatments are equivalent, even in severe OSA, despite greater efficacy of CPAP in reducing AHI. This likely reflects greater nightly adherence to OA_m compared to CPAP therapy. Recent advances in technologies related to OA_m treatment have the potential to further improve their efficacy and effectiveness in clinical practice. Selection of appropriate patients who will respond to OA_m treatment is an ongoing barrier to use. The now commercially available remotely controlled mandibular positioner offers a means to predict response from a single-night mandibular titration study and has shown good positive predictive value in initial testing. The advent of new adherence monitoring technology that can be routinely incorporated into OA_m devices to objectively monitor treatment usage represents another advance in OSA treatment, which will be beneficial in practice and research. This will further help clarify the role of OA_m in OSA treatment next to CPAP. Establishing best quality devices that are objectively validated in terms of both efficacy and durability in combination with recent advances in patient selection and treatment monitoring, will continue to optimize OA_m as an effective and even first-line treatment for OSA.

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