Mandibular Advancement Devices in 630 Men and Women With Obstructive Sleep Apnea and Snoring*

Tolerability and Predictors of Treatment Success

Marie Marklund, DDS, PhD; Hans Stenlund, PhD; and Karl A. Franklin, MD, PhD, FCCP

Study objective: To evaluate the tolerability and to find predictors of treatment success for an individually adjusted, one-piece mandibular advancement device in patients with snoring and obstructive sleep apnea.

Design: Prospective study.

Setting: Departments of Respiratory Medicine and Orthodontics, Umeå University.

Patients: Six hundred nineteen of 630 patients (98%), who consecutively received treatment for sleep apnea and snoring from February 1989 to August 2000, were followed up. They had a mean apnea-hypopnea index of 16 (range, 0.0 to 76) and a mean body mass index of 28 (range, 19 to 42).

Measurements: Interviews, questionnaires, and overnight sleep apnea recordings. Patients with an apnea-hypopnea index of ≥ 10 in the supine and/or lateral position were considered to have obstructive sleep apnea. A lateral apnea-hypopnea index of < 10, together with a supine apnea-hypopnea index of ≥ 10, defined supine-dependent sleep apneas.

Results: One hundred forty-eight of the 619 patients (24%) discontinued treatment. Female gender predicted treatment success, defined as an apnea-hypopnea index of < 10 in both the supine and lateral positions, with an odds ratio of 2.4 (p = 0.01). In the women, the odds ratios for treatment success were 12 for mild sleep apnea (p = 0.04), and 0.1 for complaints of nasal obstruction (p = 0.03). In the men, the odds ratios for treatment success were 6.0 for supine-dependent sleep apneas (p < 0.001), 2.5 for mild sleep apnea (p = 0.04), 1.3 for each millimeter of mandibular advancement (p = 0.03), and 0.8 for each kilogram of weight increase (p = 0.001).

Conclusions: The mandibular advancement device is recommended for women with sleep apnea, for men with supine-dependent sleep apneas defined by a lateral apnea-hypopnea index of < 10, and for snorers without sleep apnea. Men who increase in weight during treatment reduce their chance of treatment success and are advised to be followed up with a new sleep apnea recording with the device.

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Key words: activator appliances; mandibular advancement; nasal obstruction; sex; sleep apnea syndromes; supine position

There is clear evidence to support the positive effects of a mandibular advancement device in the treatment obstructive sleep apnea.1–4 In spite of this, nasal continuous positive airway pressure is more effective in reducing apneas and symptoms in unselected patients with obstructive sleep apnea.4–8

Predictors of treatment success with the mandibular advancement device are therefore important when it comes to selecting the patients who will particularly benefit from this treatment.

Large samples are needed to evaluate the predictors of success in the treatment of obstructive sleep apnea. The largest study so far comprised 256 patients with sleep apnea treated with mandibular advancement devices.9 Fifty-four percent of these

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patients had a reduction in their total apnea-hypopnea index from ≥10 to below that level. This can be compared with success rates between 14% and 78% in patients reported in other studies.\textsuperscript{4–8,10–16} The success rate, defined as a reduction in the total apnea-hypopnea index, is influenced by the percentage of specific subgroups of patients in the studied sample. The inclusion of more patients with milder disease will therefore increase the success rate and \textit{vice versa}.\textsuperscript{12,13,16–19} In addition, patients who do not tolerate the device are usually not considered in these evaluations. No study has evaluated the predictors of treatment success controlled for sleep position in a large cohort of patients treated for snoring and sleep apnea with mandibular advancement devices by one and the same dentist using the same methodology for all treatments. The results from our first 26 evaluated patients have been presented in a previous study.\textsuperscript{20} The aim of the present study was to evaluate the tolerability of treatment and to find predictors of treatment success with a mandibular advancement device in all patients who consecutively received treatment with mandibular advancement devices for obstructive sleep apnea or snoring at one sleep apnea clinic during a 10-year period.

### Materials and Methods

#### Patients

Six hundred thirty patients who consecutively received treatment with mandibular advancement devices for obstructive sleep apnea and habitual snoring from February 1989 to August 2000 were included (Fig 1). All the patients underwent medical examinations and sleep apnea recordings at the Department of Respiratory Medicine, and they were then referred for treatment by the same dentist. Patients with Cheyne-Stokes respiration, arthralgia, or myofascial pain from the craniomandibular system, edentulous jaws, class III malocclusion, or acute periodontal disease were excluded from the treatment. The sample consisted of patients who were recommended the mandibular advancement device as the first treatment of choice because of snoring or mild sleep apnea, and patients with more severe disease who did not tolerate nasal continuous positive airway pressure. There were 457 patients with an apnea-hypopnea index <20, 130 patients with an apnea-hypopnea index between 20 and 40, while the remaining 43 patients had an apnea-hypopnea index ≥40 without the device. Before the start of treatment, the patients were asked about their smoking habits, complaints of excessive daytime sleepiness, headache, and nasal obstruction.

Six hundred nineteen of the 630 patients (98%) were followed up after using the device for 1 year. Nine patients had moved and two patients had died during this period (Fig 1). Four hundred ninety-nine men and 120 women continued with the device. The men had a mean age of 51 years (range, 25 to 74 years), while the women were older, with a mean age of 55 years (range, 30 to 75 years) \(p<0.001\). The body mass index, apnea-hypopnea index, and percentage of supine-dependent patients did not differ between the men and the women. A check of the subjective effects of the device on symptoms and side effects was performed every second year after the start. All the patients who were re-evaluated with sleep apnea recordings with the device before January 2002 were analyzed to determine predictors of treatment success. Approval for the study was obtained from the Medical Ethics Committee at Umeå University.

#### Mandibular Advancement Device

The mandibular advancement devices were fabricated by dental technicians from plaster casts of the teeth and construction bites obtained by the dentist. The devices were made of SR-Ivocap or SR-Ivocap elastomer (Ivoclar; Schaan, Liechtenstein).\textsuperscript{21} Similar designs for the device were used in all patients, but before 1993 all patients received devices made of hard acrylic, and from 1995 the patients were treated with soft elastomeric devices.\textsuperscript{21}

The advancement and opening of the mandible by the device was designed to move the tongue and soft palate in an anterior position with a subsequent increase in pharyngeal airway space.
but also to allow mouth breathing and speech with the appliance in place. The mandibular advancement was intended to be between 4 mm and 6 mm, and the mandibular opening at least 5 mm between the incisors. Patients with a limited capacity to move the mandible forward were asked to advance their mandibles as much as they could without discomfort. After 1 to 2 months, the patients were asked about their tolerance of the device and the subjective effects of the treatment. The advancement was further increased in patients who reported an insufficient improvement on snoring or apneas, and the advancement was reduced in patients who experienced pain from the craniomandibular system. Adjustments were offered until the patients were satisfied with the effects of the device or chose to discontinue treatment. Patients who did not tolerate the device after 1 year were regarded as having discontinued treatment.

The degree of mandibular advancement was measured on plaster casts in the premolar area and along an occlusal plane from the upper right central incisor to the mesial cusp of the upper first molar or premolar if the molar was missing. The mandibular opening was measured as the distance between the upper right and lower central incisor edge plus the overbite. These measurements were performed on the initial plaster casts using the most recent construction bite at the time of the sleep apnea recording with the device.

Sleep Apnea Recordings

The patients underwent sleep apnea recordings including nasal and oronasal air flow using a three-way thermistor (Nihon Kohden Ze-732A, Nihon Kohden; Tokyo, Japan), abdominal and chest movements (Resp-EZ; EPM Systems; Midlothian, VA), finger oximetry (Ohmeda Bios 3740; Ohmeda; Louisville, CO), body position (Vitalog Monitoring; Redwood City, CA), and ECGs (V5). An obstructive event was scored if respiratory efforts continued during apnea. An apnea was defined as a cessation of air flow lasting at least 10 s, and a hypopnea was defined as a decrease of ≥ 50% in the thermistor tracing compared with baseline, combined with an oxygen desaturation of ≥ 3%. The estimated sleep time was evaluated from the respiratory sleep recordings and body position sensors.22 The apnea-hypopnea index was the average number of apneas and hypopneas per hour of estimated sleep time. The supine apnea-hypopnea index was defined using the average number of apneas and hypopneas per hour of estimated sleep time in the supine position. The lateral apnea-hypopnea index was the average number of apneas and hypopneas per hour of estimated sleep time in the lateral and prone positions.

Patients with an apnea-hypopnea index of ≥ 10 in the supine and/or lateral position were considered to have sleep apnea. Supine-dependent sleep apneas were defined by a supine apnea-hypopnea index of ≥ 10, together with a lateral index of < 10. Nonsupine-dependent sleep apneas were considered in patients with a lateral apnea-hypopnea index of ≥ 10. Mild sleep apnea was defined by a total apnea-hypopnea index of < 20, severe sleep apnea as an index of ≥ 40, while moderate sleep apnea was defined as the values between mild and moderate sleep apnea.

Treatment Success

A reduction in the apnea-hypopnea index from ≥ 10 in the lateral and/or supine sleep position to an index of < 10 in both the supine and lateral positions during treatment defined treatment success with the device. Patients with an apnea-hypopnea index of ≥ 10 in the supine and/or lateral position with the device were regarded as having an insufficient apnea reduction.

T tolerability

Patients who did not use the device after 1 year were regarded as having poor tolerability of the treatment. These patients were interviewed about the reason for discontinuing treatment.

Statistical Methods

The Wilcoxon signed rank test for paired observations was used to analyze the effects of the device on respiratory variables. Differences between subgroups of patients and factors related to the poor tolerability of the treatment were analyzed using the Mann-Whitney U test for independent samples or the χ² test. Factors related to the changes in sleep positioning during treatment were analyzed using multivariate linear regression analysis. The associations between treatment success and age, gender, nonobesity (body mass index < 30), weight increase, and time between the evaluation without the device and with it, supine-dependent sleep apneas, mild sleep apnea, nonsmoking, nasal obstruction, mandibular displacement, and the year of treatment start were estimated by odds ratios using the logistic regression analysis. Missing values for predictor variables were coded to the reference category in the logistic regression models. The weight change variable was categorized into steps of 1 kg and was compared with a reference category including patients with a variability of between ± 2 kg in the analysis of cutoff points for the influence of weight changes on the treatment outcome. The SPSS 11.0 Statistical Software Package (SPSS, Chicago, IL) was used in all calculations; p < 0.05 was considered significant.

RESULTS

Patients Who Did Not Tolerate the Device

One hundred forty-eight of the 619 patients (24%) did not tolerate the device and discontinued the treatment (Fig 1). Discomfort, including excessive salivation or a feeling of awkwardness when wearing the device, was the main cause of a poor tolerability of the device (Table 1). Insufficient effects on snoring or odontologic problems, ie, symptoms from the craniomandibular system, periodontal disease, or changes in occlusion during treatment, were other explanations for a failure to accept the device. A few patients stopped using the device, as they had had unrealistic expectations of the treatment in terms of cured tinnitus or dysphagia (Table 1). Poor tolerability of the treatment was unrelated to the severity of the disease, supine-dependent sleep apneas, age,

<table>
<thead>
<tr>
<th>Causes</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discomfort</td>
<td>86 (58.1)</td>
</tr>
<tr>
<td>Poor effect on snoring</td>
<td>22 (14.9)</td>
</tr>
<tr>
<td>Odontologic problems</td>
<td>13 (8.7)</td>
</tr>
<tr>
<td>Another treatment demanded</td>
<td>10 (6.8)</td>
</tr>
<tr>
<td>Other causes</td>
<td>3 (2.0)</td>
</tr>
<tr>
<td>Unknown</td>
<td>14 (9.5)</td>
</tr>
</tbody>
</table>
nonobesity, gender, treatment start before 1995 or after, smoking or complaints of excessive daytime sleepiness, nasal obstruction, or headache before the start of treatment.

Re-evaluated Patients

Sleep apnea recordings with the device were performed in 263 of 356 patients with sleep apnea and in 14 of 115 snoring patients without sleep apnea (Fig 1, Table 2). No re-evaluation with the device was later performed in otherwise healthy patients with supine-dependent sleep apnea and milder disease, who were subjectively satisfied with the treatment,20 or in the snorers. The re-evaluated sleep apnea patients were older (p = 0.024) and included a higher percentage of women (p = 0.003), patients with nonsupine-dependent apneas (p = 0.001), and patients who started treatment before 1995 (p < 0.001) than the patients who were not re-evaluated. There was a mean of 573 ± 521 days (± SD) between the sleep apnea recording with the device and that without it.

Two hundred thirty-seven of the 263 re-evaluated patients with sleep apnea had sufficient data in the supine and lateral positions to define treatment success in the sleep apnea recording with the device (Fig 1). One hundred eighty-eight of these 237 patients had sufficient data for all variables for the logistic regression models (Fig 1).

Effects of the Device on Sleep Apnea

Treatment success with an apnea-hypopnea index of < 10 in both the supine and lateral positions was found in 129 of the 237 (54%) re-evaluated patients with sleep apnea. Ninety-seven of 192 men (51%) and 32 of 45 women (71%) were successfully treated with the device. Forty-four of 112 (39%) re-evaluated patients with supine-dependent sleep apnea and milder disease were successfully treated by the device. A total apnea-hypopnea index of 10 in both the supine and lateral positions was found in 129 of the 237 (54%) re-evaluated patients with sleep apnea. Ninety-seven of 192 men (51%) and 32 of 45 women (71%) were successfully treated with the device. Forty-four of 112 (39%) re-evaluated patients with supine-dependent sleep apnea and milder disease were successfully treated by the device.

Predictors of Treatment Success With the Device

The univariate odds ratios for treatment success were 4.9 for supine-dependent sleep apneas (p < 0.001), 3.3 for mild sleep apnea (p < 0.001), 2.4 for female gender (p = 0.01), and 0.9 for each kilogram of increase in weight (p = 0.001) between the evaluations in the 237 re-evaluated patients with sleep apnea (Table 3).

Predictors of Treatment Success in Men

Supine-dependent sleep apnea was the strongest predictor of treatment success in men (odds ratio, 6.0; p < 0.001), according to a logistic regression model including all predictor variables. Mild sleep apnea (odds ratio, 2.5; p = 0.04) and the degree of mandibular advancement (odds ratio, 1.3; p = 0.03) for each millimeter were also related to treatment success with the device. Weight increase among the men related to an insufficient apnea reduction by the device. Weight increase among the men related to an insufficient apnea reduction by the device. The reduced chance of treatment success appeared at a weight increase of between 3 kg and 4 kg (odds ratio, 0.1; p = 0.021).

Predictors of Treatment Success in Women

Mild sleep apnea predicted treatment success in the women, according to a logistic regression model including all predictor variables (Table 5). Complaints of nasal obstruction were related to an insufficient apnea reduction by the device. Supine dependence did not relate to treatment success among the present women. Among the patients with nonsupine-dependent sleep apneas, women were more often successful with the device than men (odds ratio, 6.1; p = 0.039; n = 60).

Predictors of Treatment Success in Patients With More Severe Disease

Supine dependence was the strongest predictor of treatment success in patients with a total apnea-

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Table 2—Effects of the Device on Respiratory Variables (n = 277)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Without the Device</th>
<th>With the Device</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>Apnea-hypopnea index</td>
<td>277</td>
<td>21</td>
<td>1.1–74</td>
</tr>
<tr>
<td>Supine apnea-hypopnea index</td>
<td>222</td>
<td>37</td>
<td>0.0–114</td>
</tr>
<tr>
<td>Nonsupine apnea-hypopnea index</td>
<td>211</td>
<td>10</td>
<td>0.0–74</td>
</tr>
<tr>
<td>Supine time, %</td>
<td>225</td>
<td>49</td>
<td>0.0–100</td>
</tr>
<tr>
<td>Total sleep time, minutes</td>
<td>236</td>
<td>400</td>
<td>240–760</td>
</tr>
<tr>
<td>Lowest oxygen saturation, %</td>
<td>238</td>
<td>83</td>
<td>48–98</td>
</tr>
<tr>
<td>Longest apnea, s</td>
<td>127</td>
<td>45</td>
<td>13–111</td>
</tr>
</tbody>
</table>

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hypopnea index of \( \geq 20 \) (odds ratio, 3.1; \( p = 0.024 \)), according to a logistic regression model including all predictor variables including gender (\( n = 81 \)). A reduced chance of treatment success was found together with complaints of nasal congestion (odds ratio, 0.3; \( p = 0.026 \)) or increases in weight (odds ratio, 0.8; \( p = 0.044 \)) for each kilogram.

**Estimated Treatment Outcome in the Whole Sample**

It was estimated that 50% of the 619 snorers and sleep apnea patients had treatment success or subjective beneficial effects from the treatment. This calculation was based on the assumption that snoring patients without sleep apnea experienced subjective beneficial effects from the treatment, if they continued treatment after 1 year. It was estimated that 26% of all 619 patients had an insufficient apnea reduction by the device and that 24% had discontinued treatment.

**Mandibular Displacement**

The mean mandibular advancement by the device was 5.3 mm (range, 0.0 to 10 mm), and the mean mandibular opening was 11 mm (range, 4.0 to 17 mm), which corresponded to a mean of 8.2 mm (range, 1.3 to 13 mm) between the incisor edges. The mean mandibular advancement was 5.4 mm (range, 0.0 to 10 mm) in patients with treatment success, and 5.2 mm (range, 0.0 to 9 mm) in patients with an insufficient apnea reduction by the device. The mean mandibular opening was 11 mm (range, 6.0 to 17 mm) or a mean of 8.3 mm (range, 3.3 to 12 mm) between the incisors in patients with treatment success, and 11 mm (range, 4.0 to 16 mm) or a mean of 8.3 mm (range, 1.3 to 13 mm) between the incisors in patients with an insufficient apnea reduction by the device.

**Changes in Sleep Position During Treatment**

The patients increased their percentage of sleep in the supine position when they used their devices (Table 2). A multivariate linear regression analysis revealed a relationship between the reduction in the

**Table 3—Univariate Logistic Regression Analysis of Predictors of Treatment Success With the Device**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
<th>( p ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background predictors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female gender*</td>
<td>2.41</td>
<td>1.19–4.77</td>
<td>0.014</td>
</tr>
<tr>
<td>Nonobesity, body mass index &lt; 30 at start</td>
<td>1.45</td>
<td>0.81–2.59</td>
<td>0.21</td>
</tr>
<tr>
<td>Age</td>
<td>0.99</td>
<td>0.96–1.02</td>
<td>0.42</td>
</tr>
<tr>
<td>Treatment start 1995 or later</td>
<td>1.46</td>
<td>0.85–2.53</td>
<td>0.17</td>
</tr>
<tr>
<td>Predictors from the sleep apnea recording</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supine-dependent sleep apneas</td>
<td>4.86</td>
<td>2.57–9.18</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Mild sleep apnea (total apnea-hypopnea index &lt; 20)</td>
<td>3.28</td>
<td>1.93–5.60</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Predictors from symptoms at start</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonsmoker during the last year before treatment start</td>
<td>1.39</td>
<td>0.75–2.59</td>
<td>0.30</td>
</tr>
<tr>
<td>Complaints of nasal obstruction</td>
<td>0.71</td>
<td>0.42–1.20</td>
<td>0.21</td>
</tr>
<tr>
<td>Predictors from mandibular position</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mandibular advancement, mm</td>
<td>1.06</td>
<td>0.91–1.24</td>
<td>0.44</td>
</tr>
<tr>
<td>Mandibular opening, mm</td>
<td>1.04</td>
<td>0.91–1.18</td>
<td>0.56</td>
</tr>
<tr>
<td>Control predictor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase in weight, kg</td>
<td>0.86</td>
<td>0.79–0.94</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*The odds ratio was 2.49 (\( p = 0.04 \)) controlling for age, body mass index, supine and lateral apnea-hypopnea indices, and supine-dependent sleep apneas.

**Table 4—Predictors of Treatment Success With the Device in Men (\( n = 155 \))**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
<th>( p ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supine-dependent sleep apneas</td>
<td>5.97</td>
<td>2.43–14.7</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Mild sleep apnea</td>
<td>2.50</td>
<td>1.06–5.91</td>
<td>0.036</td>
</tr>
<tr>
<td>Mandibular advancement, mm</td>
<td>1.31</td>
<td>1.02–1.68</td>
<td>0.034</td>
</tr>
<tr>
<td>Mandibular opening, mm</td>
<td>1.21</td>
<td>0.98–1.50</td>
<td>0.08</td>
</tr>
<tr>
<td>Age</td>
<td>0.96</td>
<td>0.92–1.00</td>
<td>0.08</td>
</tr>
<tr>
<td>Increase in weight, kg</td>
<td>0.81</td>
<td>0.71–0.92</td>
<td>0.001</td>
</tr>
</tbody>
</table>

**Table 5—Predictors of Treatment Success With the Device in Women (\( n = 33 \))**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
<th>( p ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild sleep apnea</td>
<td>12.1</td>
<td>1.51–97.8</td>
<td>0.019</td>
</tr>
<tr>
<td>Complaints of nasal obstruction</td>
<td>0.11</td>
<td>0.02–0.79</td>
<td>0.028</td>
</tr>
</tbody>
</table>
supine apnea-hypopnea index and an increase in the supine sleeping time (p < 0.001), controlled for changes in oxygen saturation levels and weight, time between the evaluations, and mandibular displacement by the device.

**Obesity and Nonsupine-Dependent Sleep Apnea**

Obesity defined as a body mass index of ≥ 30 was found in 37% of the patients with nonsupindependent sleep apneas and in 23% of the patients with supine-dependent sleep apneas (p = 0.006).

**Discussion**

Women with sleep apnea were more likely than men with sleep apnea to have treatment success with the mandibular advancement device. Supine-dependent sleep apneas, mild disease, and an increase in mandibular advancement predicted treatment success among the men, while mild sleep apnea was associated with treatment success in the women. An insufficient apnea reduction by the device, however, related to an increase in weight among the men and complaints of nasal obstruction among the women. The discontinuation of treatment during the first year was not related to the severity of the disease.

The present results were based on prospective investigations of 619 of 630 patients (98%) with snoring and obstructive sleep apnea who were treated consecutively by one dentist using the same methodology for all patients. All the sleep apnea recordings were performed at the Department of Respiratory Medicine in Umeå, which is the center for the treatment of snoring and sleep apnea in the County of Västerbotten, which has 255,000 inhabitants. This is the largest study of patients treated with mandibular advancement devices for snoring and obstructive sleep apnea so far.

Twenty-four percent of the patients in the present sample stopped using their devices during the first year, which is comparable to the discontinuation of treatment of between 18% and 45% among the patients in other reports. Neither disease severity, age, or sex, nor complaints of nasal obstruction or smoking habits were related to poor tolerability in the present sample. McGown et al report that patients who are satisfied with the effect of the device on symptoms of sleep apnea have a higher tolerance than the remainder. Personal preferences, such as a feeling of awkwardness when using the device, side effects from the treatment, or the relief of symptoms, are probably the main reasons for poor or good tolerance of the mandibular advancement device.

Seventy-two percent of the patients with sleep apnea experienced a good effect with the device using the definition for treatment success, including a reduction in the total apnea-hypopnea index from > 10 to below that level. One problem with this definition is that a poor effect with the device may be undetected in patients who have a large positional difference in apnea frequency, together with a short sleeping time in the position with the most frequent apneas. We therefore required an index of < 10 in both the supine and lateral positions for treatment success with the device. This definition reduced the success rate to 54% of the present patients with sleep apnea. If the snorers and the patients who discontinued treatment were also considered, we estimated that half the patients in the present sample had improvements as a result of their mandibular advancement devices. This calculation was based on the assumption that the sleep apnea patients who were not re-evaluated had the same success rate as the re-evaluated patients. In fact, the patients who were not re-evaluated had milder disease than the re-evaluated patients. Consequently, the treatment outcome might have been slightly better in the present sample of patients with predominantly mild disease. Even so, these figures illustrate that there is a need for the establishment of more precise indications for the mandibular advancement device in order to increase the success rate.

In our male subjects, supine dependence was the best predictor of treatment success with the device (odds ratio, 6.0; p < 0.001), compared with an odds ratio of 2.5 for mild sleep apnea defined by a total apnea-hypopnea index of < 20. In contrast, men who increased their weight substantially reduced their chance of treatment success with the device, as there was a 19% reduction in the odds ratio for each additional kilogram between the sleep apnea recording without the device and that with it. This reduced efficacy of the device may be explained by the fact that these men may have increased their apnea frequency, particularly in the lateral position. Obesity has been associated with nonsupine-dependent sleep apneas in previous studies, as well as in the present study. It is advisable to follow up men whose weight increases by > 3 kg during treatment with a renewed sleep apnea recording with the device, as these men reduce their chance of treatment success and may therefore require treatment with nasal continuous positive airway pressure.

Mild sleep apnea with a total index of < 20 was the best predictor of treatment success, while supine dependence was unrelated to the efficacy of the device among the women in the present sample. In fact, the women with nonsupine-dependent sleep apneas had a significantly higher success rate than
the men with nonsupine-dependent sleep apneas (odds ratio, 6.1). An insufficient apnea reduction by the device, however, related to complaints of nasal obstruction among the women.

The more than twofold increase in the success rate in the women in the present study compared with the men is a new finding. Battagel et al report that women enlarge their pharynx more during mandibular advancement than men. This mechanism may explain the gender difference in terms of the efficacy of the device, in spite of the fact that men have a wider pharynx than women. Moreover, men tend to accumulate more fat in the pharynx than women, which will further impair the opportunity for men to maintain airway patency. Consequently, a stiffer, less collapsible airway among the women may explain why the mandibular advancement device is more effective among women.

The high predictive value of supine-dependent sleep apneas for treatment success among the men, including patients with more severe disease in the present large sample, supports the results of a previous study from our sleep apnea center comprising 23 men and 3 women with mild-to-severe obstructive sleep apnea. In that study, the odds ratio for treatment success was 30 in the patients with supine-dependent sleep apneas and 7.5 in patients with mild sleep apnea (apnea-hypopnea index < 20). Supine-dependent sleep apneas are therefore a better predictor of treatment success than the disease severity measured by the total apnea-hypopnea index. A diagnosis of supine dependence probably reflects a normal pharyngeal morphology with a wide airway in the lateral dimension, while lateral sleep apneas indicate lateral narrowings. Problems maintaining airway patency in the lateral sleep position indicate a high risk of sleep apneas, as the airway is usually more stable in the lateral than in the supine position. The simple forward movement of the mandible by a device will be insufficient and there is a need for nasal continuous positive airway pressure to keep the airways open at night in men with nonsupine-dependent sleep apneas.

The nasal airway patency increases during mandibular advancement in healthy subjects. Improved nasal patency may also be part of the mechanism of action of the device in the treatment of snoring and sleep apnea. This probably explains the reduced chance of treatment success with the device in the women in the present sample and patients with more severe disease with complaints of nasal obstruction. More studies of the influence of nasal obstruction on the efficacy of the device on sleep apnea are needed, as the present results were based on regression models, including subjective reports from the patients.

An increased percentage of sleeping time in the supine position and a reduced amount of total sleeping time were found during treatment with the mandibular advancement device in the present study. The increase in the percentage of supine sleeping time was directly associated with the reduction in the supine apnea-hypopnea index. Sleeping in the lateral position is probably a protective mechanism against sleep apnea, as the pharynx is more collapsible in the supine than the lateral position, and supine sleep apneas are therefore more severe and produce longer sleep arousals than lateral sleep apneas. Sleeping position training has also been advocated for the treatment of supine-dependent sleep apneas. The results indicate short-term positive effects on apneas and symptoms, but the longer-term success rate is uncertain. A mandibular advancement device is a better treatment alternative, as it effectively reduces supine sleep apneas in patients with supine-dependent sleep apnea. The device also gives these patients the freedom to choose their favorite sleep positions instead of being forced to sleep in the lateral position.

Many different designs have been suggested for mandibular advancement devices. Comparisons of different devices in terms of their effects on sleep apnea have indicated that a one-piece, individually designed mandibular advancement device is more effective than a two-piece adjustable device or a prefabricated appliance. We used an individually designed, one-piece device of a similar type throughout the entire 10.5-year period, even when we changed the material from hard acrylic to soft elastomer in 1993 to 1994. From 1995 on, the soft elastomeric device became the predominant treatment method. The present results do not indicate any difference in treatment effect between these two appliances.

A larger degree of mandibular advancement improves the efficacy of a mandibular advancement device, while the degree of mandibular opening within a specific range is of less importance. Pétel et al evaluated the optimal degree of mandibular advancement by titration during sleep and found a mean of 13 mm (range, 9 to 17 mm), together with 2 mm of incisor opening in seven patients with severe sleep apnea. We used smaller mandibular advancements with a mean of 5.3 mm (range, 0.0 to 10 mm) and larger openings with a mean of 8.2 mm (range, 1.3 to 13 mm) between the incisors in our patients with predominantly mild or moderate sleep apnea. The mandibular displacements were similar in patients with treatment success and in patients with insufficient apnea reduction. In men, a larger mandibular advancement was beneficial, as the odds ratio was 1.3 for each millimeter of mandibular...
advancement (p = 0.03). This association may be explained by the large variability in treatment response among the men. The generally weak relationships between the degree of mandibular advancement and treatment success with the device indicate, however, that patient selection is more important than the exact amount of mandibular advancement.

One limitation of the present study was the selection of patients toward those with mild disease and those with more severe disease who did not tolerate nasal continuous positive airway pressure. In addition, the patients were no more than slightly overweight, with a mean body mass index of 28. Our patients served as their own controls in the study. We did not perform full polysomnographic sleep recordings including EEG. Instead, we estimated sleep time from the respiratory sleep recordings and body position sensors, according to the method presented by Svanborg et al. Moreover, we had to rely on patient reports for estimations of the tolerability of the device, as objective measurements, i.e., time counters, were not available.

Treatment with mandibular advancement devices is indicated in women with sleep apnea, in men with supine-dependent sleep apneas, and in snorers without sleep apnea. Follow-up sleep apnea recordings of men with nonsupine-dependent apneas (i.e., a lateral apnea-hypopnea index of ≥ 10) and women with more severe disease (i.e., a total apnea-hypopnea index of ≥ 20) are recommended. Men with sleep apnea who increase their weight reduce their chance of treatment success with the device. They are therefore advised to be followed up with a new sleep apnea recording with the device, and are offered treatment with nasal continuous positive airway pressure when needed.

REFERENCES