Since its advent in 1981, continuous positive airway pressure (CPAP) has been the cornerstone of treatment for obstructive sleep apnea. To determine the lowest true effective pressure required to abolish apneas (Peff) for home use, a CPAP titration is performed, during which the pressure is varied until apneas are abolished.

There is no standard CPAP titration protocol. Occasionally the titration is unsuccessful: it is possible to run out of sleep time before Peff is determined. Considering this, the prediction algorithms are attractive because they provide a convenient starting point for CPAP titration. Ideally, this should reduce the number of incremental pressure changes during the night and increase the amount of sleep time spent at each pressure, particularly at the effective pressure that will be recommended for home use. There are several algorithms based on anthropometric, clinical, and baseline polysomnographic data. However, the predictive utility of these algorithms has not been assessed in large prospective studies. Consequently, the main purpose of the present study was to test such an algorithm in a large group of patients with sleep apnea undergoing CPAP titration study.

**Materials and Methods**

We studied 329 patients with diagnosed sleep apnea undergoing CPAP titration study at St. Michael’s Hospital sleep laboratory. All of them had sleep apnea, defined as an apnea/hypopnea index (AHI) of > 10, confirmed by the initial diagnostic polysomnography performed in the same laboratory.

A standard procedure, described previously, was employed.
The starting pressure was determined from the prediction formula utilizing body mass index (BMI), neck circumference (NC), and the AHI determined during diagnostic polysomnography:

$$P_{\text{pred}} = (0.16 \times \text{BMI}) + (0.13 \times \text{NC}) + (0.04 \times \text{AHI}) - 5.12$$

CPAP titration study began with the pressure set to $P_{\text{pred}}$ rounded off to the nearest integer. If the AHI at this pressure was < 10, the pressure was decreased in 1 cm H$_2$O increments until the AHI became > 10. If the AHI at $P_{\text{pred}}$ was > 10, the pressure was increased in 1 cm H$_2$O increments until the AHI became < 10. The effective CPAP ($P_{\text{eff}}$) was defined as the lowest pressure at which the patient had an AHI of < 10.

To study the relationship between $P_{\text{pred}}$ and the measured $P_{\text{eff}}$, the data were analyzed in several ways. First, we compared mean values of $P_{\text{eff}}$ and $P_{\text{pred}}$ using the paired $t$ test. Second, we used correlation analysis to determine the relationship between these two pressures. Lastly, we examined the histogram of ($P_{\text{eff}} - P_{\text{pred}}$) to determine how well $P_{\text{pred}}$ approximated $P_{\text{eff}}$ in individual patients.

**RESULTS**

There were 54 women and 275 men. Their anthropometric and sleep data are given in Table 1. As a group, the patients were obese, middle-aged, and had moderately severe sleep apnea.

Adequate titrations were achieved in 276 patients. In the remaining 53 patients, the optimum pressure could not be determined. Table 2 summarizes the results for all patients grouped according to the success of titration. Those with unsuccessful titration are further divided into groups. One group are “overestimated” patients, *ie*, those in whom AHI was < 10 at $P_{\text{pred}}$, with an AHI of > 10 not achieved at any pressure. The other group are the “underestimated” patients, *ie*, those with an AHI > 10 at $P_{\text{pred}}$, in whom an AHI of < 10 was not achieved at any pressure.

Generally, patients in whom the algorithm overestimated the pressure tended to be less overweight and had milder sleep apnea than patients in the other two groups. This is may be seen from the mean values for AHI given in Table 2, and also from the fact that 50% of the overpredicted group had an AHI of < 27, whereas 50% of the underpredicted and successful groups had AHI of > 44 and > 41, respectively.

### Table 1—Anthropometric and Sleep Data in All Patients

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>50 ± 11</td>
<td>17–80</td>
</tr>
<tr>
<td>BMI, kg/m$^2$</td>
<td>33 ± 7</td>
<td>20–69</td>
</tr>
<tr>
<td>AHI</td>
<td>47 ± 27</td>
<td>10–134</td>
</tr>
<tr>
<td>Lowest O$_2$ saturation, %</td>
<td>70 ± 17</td>
<td>10–93</td>
</tr>
<tr>
<td>Mean O$_2$ saturation, %</td>
<td>91 ± 5</td>
<td>54–97</td>
</tr>
<tr>
<td>NC, cm</td>
<td>43 ± 4</td>
<td>30–57</td>
</tr>
</tbody>
</table>

### Table 2—Anthropometric and Sleep Data in Patients According to Success of CPAP Titration*

<table>
<thead>
<tr>
<th>Patients, No.</th>
<th>Overprediction</th>
<th>Underprediction</th>
<th>Successful</th>
</tr>
</thead>
<tbody>
<tr>
<td>P$_{\text{pred}}$</td>
<td>7.1 ± 1.9</td>
<td>8.2 ± 3.2</td>
<td>8.1 ± 2.2</td>
</tr>
<tr>
<td>AHI at P$_{\text{pred}}$</td>
<td>2.5 ± 2.2</td>
<td>35 ± 20</td>
<td>13.6 ± 17.5</td>
</tr>
<tr>
<td>Final pressure</td>
<td>5.2 ± 1.7</td>
<td>10.9 ± 3.4</td>
<td>8.1 ± 2.6</td>
</tr>
<tr>
<td>AHI at final pressure</td>
<td>3.4 ± 1.9</td>
<td>28.4 ± 13.7</td>
<td>4.7 ± 2.9</td>
</tr>
<tr>
<td>Age, yr</td>
<td>49 ± 11</td>
<td>60 ± 15</td>
<td>50 ± 11</td>
</tr>
<tr>
<td>BMI, kg/m$^2$</td>
<td>32 ± 7</td>
<td>35 ± 14</td>
<td>34 ± 7</td>
</tr>
<tr>
<td>AHI</td>
<td>36 ± 25</td>
<td>45 ± 31</td>
<td>49 ± 27</td>
</tr>
<tr>
<td>NC, cm</td>
<td>42 ± 4</td>
<td>43 ± 5</td>
<td>43 ± 4</td>
</tr>
</tbody>
</table>

*Data expressed as mean ± SD.

In the remaining 276 patients, the titration (whether up or down from the predicted value) was adequate, with the results summarized in Table 3.

There was no significant difference between $P_{\text{eff}}$ and $P_{\text{pred}}$ ($p = 0.46$); both variables were significantly correlated ($r = 0.73$; $p = 0.0001$).

The relationship between the $P_{\text{pred}}$ and $P_{\text{eff}}$ is better seen by examining the distribution of the differences between these two pressures (Fig 1).

We note that in 63% of patients, $P_{\text{pred}}$ was within ± 1 cm H$_2$O of $P_{\text{eff}}$; in 83% of patients, the two pressures were within ± 2 cm H$_2$O; and in 95%, within ± 3 cm H$_2$O.

### Discussion

We examined a large group of patients with sleep apnea undergoing CPAP titration study, using a method that employed a predicted formula to initiate the titration. We found that (1) adequate CPAP titration can be achieved in 84% of patients; and (2) in 83% of patients, the optimum pressure lies within ± 2 cm H$_2$O of the predicted pressure.

We employed a relatively unique, individualized, manual CPAP titration protocol, and did not compare it with any other methods simply because there are no standard protocols. Many laboratories begin titration at 4 or 5 cm H$_2$O, increasing pressures in increments of 1 or 2 cm H$_2$O every 10 to 60 min. However, for a patient who requires > 10 cm H$_2$O pressure to abolish his/her sleep apnea, such a
protocol may be inadequate. There may not be enough time for proper titration, or sleep time spent at each pressure may be too short to sample all sleep stages and all positions. There is the danger that the effective pressure determined during the CPAP titration study will be inadequate during a full night of sleep at home. Using the algorithm proposed here would allow Peff to be reached sooner and minimize the risk of running out of time.

Because there is no standard CPAP titration protocol, the criteria for an effective protocol are not clear. It seems reasonable to assume that an effective protocol will have the following: (1) a low rate of unsuccessful titrations, (2) little difference between AHI at Peff as determined during the titration night and AHI at the same pressure during all-night polysomnography, and (3) few pressure increments required to attain Peff during the titration night. There are no data in the literature regarding the first two points. However, there are recent studies3–6 that allow one to determine the number of pressure increments. All of these studies were performed for the purpose of assessing auto-titrating devices, and in some of them manual CPAP titrations were also carried out. Although none of the authors commented on the number of pressure changes required to achieve the optimum CPAP, we can estimate this from the knowledge of starting pressure, optimum pressure, and pressure increment. In all studies, the initial pressure was 3 to 5 cm H2O, and the final effective pressure was between 7 and 12 cm H2O. Assuming the pressure increment of 1 cm H2O, the number of pressure changes necessary to achieve the effective pressure would be between 3 and 10. In the present study, using a CPAP titration protocol based on the predicted pressure, we found that the mean number of pressure changes was one, ranging from zero to five.

With the development of auto-titrating CPAP systems, manual titrations may soon become a relic of the past. Is it therefore futile to develop and test prediction algorithms for calculating effective CPAP? We do not think so, because even the automated systems require the user to specify starting, minimum, and maximum pressures. Our results indicate that using Ppred to start auto-CAP and specifying a ± 4 cm H2O range around it will ensure resolution of sleep apnea in almost all patients. In fact, Series and Marc7 concluded in a recent study that the prediction algorithm tested here can be used together with an automatic CPAP system to initiate CPAP titration at home, without a separate titration study.

Another potential use of prediction algorithm is during split-night studies8 and daytime titrations,9 when sleep time available for CPAP titration is short. In such studies, the likelihood of successful titration is increased when the starting pressure is close to the effective pressure, thus requiring fewer pressure increments and increasing the likelihood of successful titration.

We found that in 53 of 329 patients (16%), CPAP titration was inadequate. It is difficult to put this result in proper perspective, because there is no information in the literature on the rate of titration failures seen in sleep laboratories. We attempted to uncover the reasons for this by carefully reviewing the records of patients with failed titrations with respect to the diagnosis, severity of apnea, or anthropometric variables. Although no consistent pattern emerged for all patients, the following facts may explain some of the failures.

There were 11 patients in whom the algorithm was a gross underestimate: AHI was > 10 at Ppred and never dropped to < 10 during titration. However, these patients all belong to a group of apneics in whom CPAP titration may be expected to be difficult. Four had central sleep apnea (which frequently does not respond to CPAP), one had inadequate titration due to persistent leak around the mask, two did not sleep at higher pressures, two had mild sleep apnea (initial AHIs, 14 and 20; final AHIs, 12 and 13) and did not tolerate further increases in pressure, and the remaining two had severe sleep apnea (initial AHIs, 99 and 108, dropping to 25 and 24 at pressures of 15 and 16 cm H2O). In the two patients with severe sleep apnea, there was every indication that with further increases in pressure, AHI would fall to < 10.

There were 42 patients with mild sleep apnea (median AHI, 27) in whom the algorithm produced a gross overestimate of pressure. These patients had AHIs of < 10 at Ppred and never developed sleep apnea despite the pressure being lowered to as low as 3 cm H2O. In 27 of them, loud
snoring reappeared during reduction in pressure to < 5 cm H₂O; the sleep technologist decided against further reductions in pressure and stopped the titration protocol. In the other 15 patients, no consistent distinct pattern was found; perhaps these patients demonstrated a “false-positive” result during their diagnostic night. We reviewed their weight, alcohol intake, and medications, but could find no difference in these variables between the diagnostic and CPAP titration nights. It is possible that physiologic night-to-night variability in breathing in these patients with mild sleep apnea accounts for our findings.

We conclude that the prediction algorithm based on NC, BMI, and AHI is useful in calculating the starting pressure for initiating CPAP titration in the majority of patients with sleep apnea. Based on previous investigations, it may also be useful for autotitrination at home. We must emphasize that the algorithm cannot replace a proper CPAP titration study; its usefulness lies in facilitating the titration protocol, not in replacing it.

REFERENCES
2 Hoheisel GB, Teschler H. Clinical parameters for the prescription of minimal effective CPAP for the treatment of obstructive sleep apnea [abstract]. Am J Respir Crit Care Med 1994; 149:A496