Evaluation of the Accuracy of SNAP Technology Sleep Sonography in Detecting Obstructive Sleep Apnea in Adults Compared to Standard Polysomnography*

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Objective: To determine the accuracy of snoring and apnea analysis by SNAP (SNAP Laboratories; Glenview, IL), a technology that uses snoring recorded by a home microphone system and nasal airflow, to diagnose obstructive sleep apnea (OSA) as well as determine its severity.

Methods: For all patients who had undergone a prior SNAP study and were referred to the Sleep Disorders Center of Lifespan Hospitals for polysomnography testing from January 2000 through December 2001, we compared the results of the SNAP study to standard polysomnography (polysomnography). The severity of each apnea-hypopnea index (AHI) [mild, moderate, or severe, as defined by the AHI Severity Task Force of the American Academy of Sleep Medicine] recorded by SNAP was compared to that of the polysomnography result. All polysomnography tests were scored independently and without the prior knowledge of any SNAP results.

Results: For the 31 patients on whom data were available, the mean age, body mass index, and Epworth sleepiness scale scores were 50.3 years (range, 29 to 77 years), 31.6 kg/m² (range, 24 to 44 kg/m²), and 11.3 (range, 1 to 20), respectively. The mean follow-up time between the two studies was 5 months. The severity criteria indicated by the SNAP study accurately assessed the true severity confirmed by polysomnography in only 11 of 31 patients (35.5%). When the AHI severity score from the SNAP study was compared to polysomnography using a statistic measure of agreement, there was overall agreement with a k value of 0.23 (p = 0.008), but the agreement was only fair. SNAP study severity scores were overestimated in 13 of 31 patients (41.9%) compared to the polysomnography results. In the majority of these subjects (8 of the 13 “overestimated” patients or 8 of 31 total patients [25.8%]), the SNAP study diagnosed OSA when the patient had a normal polysomnography finding.

Conclusion: Although there may be some night-to-night variability in polysomnography testing, these results suggest that SNAP studies do not appear to accurately assess the severity of OSA.

(CHEST 2004; 125:886–891)

Key words: obstructive sleep apnea; polysomnography; portable testing; sleep sonography; SNAP; snoring

Abbreviations: AHI = apnea-hypopnea index; EMG = electromyogram; OSA = obstructive sleep apnea; UPP = uvulopalatoplasty

Obstructive sleep apnea (OSA) is the most common sleep disorder for which polysomnography is conducted. In recent decades, however, the recognition of the high prevalence of OSA and its associated complications has led to an increased demand for polysomnography tests, resulting in limited access to diagnostic and treatment centers. The significant costs associated with polysomnography also may be a factor limiting access. As a result, alternative diagnostic methods to evaluate and treat patients with OSA have been investigated, including various methods administered in patients’ homes with minimal supervision by a trained sleep technician.

The recording and analysis of snoring, known as

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Manuscript received October 9, 2002; revision accepted September 30, 2003.
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Sleep sonography,3 is one potential home diagnostic tool for OSA screening. Specifically, sleep sonography testing by SNAP Laboratories (Glenview, IL) is a technology that uses snoring recorded by a home microphone system as a method to diagnose OSA, as well as to determine its severity and recommended level of continuous positive airway pressure. Our objective was to determine the accuracy of this technique for the diagnosis of OSA compared to that of standard polysomnography.

Materials and Methods

We retrospectively reviewed the charts of all patients who were referred to the Sleep Disorders Center of Lifespan Hospitals in Rhode Island for standard polysomnography testing after completing a sleep sonographic recorded test using SNAP. For all patients who had undergone a prior SNAP study during a defined 2-year period, the results of the SNAP study were compared to the result of subsequently performed standard polysomnography. Prior to initiating our investigation, the study was approved by the Investigational Review Board of Rhode Island Hospital.

Subjects

All patients who had undergone a prior sleep sonographic recorded test by SNAP and were subsequently referred to the Sleep Disorders Center of Lifespan Hospitals in Rhode Island for polysomnography testing from January 2000 through December 2001 were evaluated. The initial SNAP test was ordered by the primary physician based on their clinical suspicion for OSA. The patients were subsequently referred to our Sleep Disorders Center for standard polysomnography and complete evaluation by a board-certified sleep physician. Subjects were referred to the sleep disorders center solely at the discretion of the primary care physician. Patients who had undergone a prior SNAP test and were referred to our sleep laboratory but refused subsequent polysomnography testing and further diagnostic evaluation by the sleep specialist were excluded.

Sleep Sonography

The technique of sleep sonography used in this investigation was the sleep apnea and snoring analysis (SNAP) technology developed by SNAP Laboratories. This home system consists of a microphone cannula device that is placed on the subject’s upper lip during sleep. The apparatus collects oronasal respiratory sound and airflow information with monitors positioned over the oral and nasal apertures, and the collected data are digitally recorded on a portable device. All SNAP studies were conducted in a subject’s home during the course of a single night. The SNAP data collection apparatus was placed on the subjects themselves at bedtime. All subjects were studied while breathing room air and without the use of any positive-pressure system. The recorded data then were returned to SNAP Laboratories, where they were analyzed using proprietary computer technology and software algorithms. The final test results then were forwarded to the primary care physician who ordered the study.

Because the investigators in this study are independent from the personnel from SNAP Laboratories and from the development of its sleep sonographic technology, the specific methods of computer and software analysis were not disclosed by the company, as they are proprietary. However, similar algorithms that utilize the SNAP Laboratories technology have been described elsewhere.4–6 Specifically, the SNAP system identifies, counts, and characterizes all respiratory events (ie, quiet respirations, apnea, hypopnea, and snoring).4 In their description of the SNAP system, Weingarten and Raviv4 noted that apnea is defined as the cessation of sound for > 10 s. Hypopnea is defined as an event in which the sound amplitude is reduced to < 25% of the baseline (ie, quiet respiration) amplitude for at least 10 s. In order to qualify as a hypopnea, the event also must meet one of the following criteria: (1) the amplitude baseline of the sound is not secondary to snoring; (2) the reduction in sound is part of a cyclical change in amplitude; or (3) the respiratory rate is not significantly reduced during the event in question.4 The details of how oronasal airflow information is interpreted by SNAP were not detailed in the study by Weingarten and Raviv,4 nor was it provided by SNAP Laboratories. The apnea-hypopnea index (AHI) was defined as the total number of apneas and hypopneas per hour of the study.

Polysomnography

Overnight polysomnography conducted at the Sleep Disorders Center was performed in all subjects and has been described elsewhere.7 Specifically, polysomnography testing included standard EEG, electrooculogram, and submental electromyogram (EMG) monitoring for sleep staging. Respirations were monitored using chest and abdominal impedance plethysmography and surface intercostal EMGs. Airflow was assessed with thermistors and a nasal pressure transducer. Arterial oxygen saturation was monitored with continuous pulse oximetry. Baseline arterial oxygen saturation was measured while the subject was awake, and nadir arterial oxygen saturation levels were obtained from the polysomnogram. Heart rate and rhythm were recorded and monitored with continuous ECG. Periodic limb movements were monitored using bilateral tibial EMG leads.7 All polysomnography tests were administered by trained sleep laboratory technicians who were unaware of the specific objectives of our investigation.

All polysomnography results were scored independently by a physician trained in sleep medicine without prior knowledge of the SNAP results. For the purpose of this investigation, the American Academy of Sleep Medicine Task Force definition of an obstructive apnea/hypopnea event was used.8 Accordingly, an obstructive apnea/hypopnea event was defined by either a clear decrease (ie, > 50%) from baseline in the amplitude of the nasal pressure transducer signal during sleep, or by a clear amplitude reduction in the nasal pressure transducer signal during sleep that does not reach the > 50% criterion but is associated with either an oxygen desaturation of > 3% or an arousal. In either case, the event also must last ≥ 10 s.8 The AHI was defined as the number of apneas and hypopneas per hour of sleep and was used to diagnose OSA. The severity of the overnight polysomnography monitoring also was defined according to the standard of the AHI Severity Task Force of the American Academy of Sleep Medicine. The polysomnography study was considered to be negative if the AHI was less than five events per hour. An AHI of 5 to 15 events per hour was considered mild disease severity, an AHI from 15 to 30 events per hour was considered moderate disease severity, and an AHI of > 30 events per hour was considered to be severe disease.8

Statistical Analysis

All estimated AHI scores provided by the SNAP Laboratories report were statistically compared to those of polysomnography testing at our Sleep Disorders Center. Because the mean AHI...
values for both sleep study methods were non-normally distributed. Nonparametric methods were used when comparing the AHI results. The AHI results were further analyzed according to the AHI severity classification outlined above using the $\kappa$ statistic measure of agreement, which is scaled from zero (0.0) to one (1.0) [0 when the amount of agreement is what would be expected to be observed by chance; and 1.0 when there is perfect agreement]. Intermediate values of the $\kappa$ statistic were interpreted as follows: 0.0 to 0.20, slight agreement; 0.21 to 0.40, fair agreement; 0.41 to 0.60, moderate agreement; 0.61 to 0.80, substantial agreement; 0.81 to 0.99, almost perfect agreement. Because the patient population of this investigation included only those subjects referred to our Sleep Disorders Center who had a prior history of SNAP testing and did not include those patients who were tested by SNAP but were not referred to our institution, SNAP sensitivity and specificity could not be calculated.

**Results**

A total of 39 subjects with prior nocturnal sonographic testing by SNAP Laboratories were referred to the Sleep Disorders Center from January 1, 2000, through December 31, 2001, for further evaluation and polysomnography testing. Three of the 39 subjects were not analyzed because the patients refused further diagnostic evaluation or workup. Of the remaining 36 subjects, only 31 patients completed both baseline polysomnography and SNAP testing. Four of these remaining subjects could not be included in the AHI analysis because they did not undergo baseline polysomnography as they were all referred directly for split night continuous positive airway pressure titration sleep studies at the recommendation of the consulting sleep physician. One additional subject was also not included in the AHI analysis as the SNAP report did not provide an AHI value. As a result, the AHI analysis was limited to 31 patients.

For the 31 patients (14 men and 17 women) on whom data were available, the mean age, body mass index, and Epworth sleepiness scale scores were 50.3 years (range, 29 to 77 years), 31.6 kg/m² (range, 24 to 44 kg/m²), and 11.3 (range, 1 to 20), respectively. The mean follow-up time between the two studies was 5 months (range, 2 to 10 months).

**Accuracy of SNAP AHI Predicting Compared to Polysomnography**

The mean ($\pm$ SD) AHI result for SNAP and polysomnography were 19.8 ± 14.8 and 21.2 ± 21.5 events per hour, respectively, and the median AHI results for SNAP and polysomnography were 15.8 and 11.5 events per hour, respectively ($p = 0.42$). A comparison of the difference between the results from both diagnostic methods (AHI/SNAP − AHI/polysomnography) for each individual patient is illustrated in Figure 1. A positive value indicates an AHI that was overestimated by SNAP and is depicted as an upward-extending bar. A negative value indicates an AHI that was underestimated by SNAP and is depicted as a downward-extending bar.

Statistical analysis of the two AHI measurement technologies demonstrated some agreement with a $\kappa$ statistic of 0.23 ($p = 0.008$). However, this result corresponded to only a fair agreement. The specific
AHI severity criteria scores (as defined above per the AHI Task Force of the Academy of Sleep Medicine) predicted by SNAP for all patients are compared to that of polysomnography in Figure 2. Severity criteria indicated by the SNAP study accurately assessed the true severity confirmed by polysomnography in only 12 of 31 patients (38.7%). In only 17 of the 31 patients (54.8%) did the SNAP AHI result accurately predict the AHI found by polysomnography within 10 events per hour (ie, AHI/SNAP = AHI/polysomnography ± 10 events per hour or AHI/SNAP − AHI/polysomnography = 0 to 10). In the remaining 14 patients (45.2%), the AHI/SNAP differed from the AHI/polysomnography by >10 events per hour.

SNAP study severity scores were overestimated in 13 of 31 patients (41.9%) compared to the polysomnography results. In the majority of these patients (8 of the 13 “overestimated” patients or 8 of 31 total patients [25.8%]), the SNAP study diagnosed OSA when the patient had a normal polysomnography findings. Two patients in particular with normal polysomnography test results had moderate-to-severe AHI scores as determined by SNAP. For example, the SNAP test estimated AHI scores of 22 and 31 events per hour, respectively, for patient numbers 16 and 25, while the corresponding polysomnography test indicated AHI scores of 4 and 2 events per hour, respectively.

The severity criteria indicated by the SNAP study underestimated the severity of OSA in 6 of 31 patients (19.4%). All six of these patients had a SNAP test result that estimated an AHI of at least 10 events per hour less than that found on subsequent polysomnography testing. Specifically, the AHI score determined by the SNAP test in patient 6 indicated an AHI of 4.9 events per hour (normal) compared to 32 events per hour (severe severity score) found by polysomnography. The AHI score determined by the SNAP test in patient 22 indicated an AHI of 9.4 events per hour (mild severity score) compared to 34 events per hour (severe severity score) found by polysomnography.

**Discussion**

This study compared the results of a home SNAP study with standard polysomnography performed in a sleep disorders center. Our results demonstrate that the AHI determined by SNAP does not have a high level of agreement with the AHI score determined by polysomnography.

The SNAP technology analyzes snoring to determine the presence of apneas and hypopneas. While investigators have shown that habitual snoring is predictive of sleep apnea, there is a paucity of evidence demonstrating that the analysis of snore recordings (alone or together with airflow, as with SNAP) results in the accurate diagnosis of sleep apnea. To date, published studies on sleep sonography in the adult population can be divided into the following two groups: investigations that record tracheal airway sounds; and investigations that record on oral nas sounds.

The feasibility of monitoring breath sounds over the trachea to detect apneic events was perhaps first described by Krumpe and Cumniskey and Cumniskey et al. Subsequently, Hida et al reported their uncontrolled case series using tracheal sound recordings combined with airflow measures at the nose. Other studies included investigations comparing tracheal sound records to airflow detection plus continuous pulse oximetry. Unfortunately, however, the number of controlled trials comparing tracheal sonography to polysomnography is limited. In fact, excluding investigations evaluating tracheal sonography in children, the only existing control study evaluating tracheal sonography (known to us) compares tracheal sound records plus continuous pulse oximetry to polysomnography in 129 adult patients with symptoms suggestive of OSA. In this trial, the overall prevalence of OSA was 45%, and the two diagnostic methods correlated well, with a sensitivity and specificity of 84% and 97%, respectively. The sensitivity and specificity were clearly enhanced with the addition of continuous oximetry. While these results may be encouraging, their relevance to our current investigation is unclear, as the SNAP technology does not use tracheal sonography or continuous pulse oximetry.

![Figure 2](http://publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/20385/)

**Figure 2.** Disease severity found by polysomnography compared to that found by SNAP for all subjects (31 patients). The numbers in the unshaded areas reflect the number of patients whose SNAP testing results accurately predicted disease severity compared to polysomnography. The lightly shaded and darkly shaded areas reflect the number of patients whose SNAP test results did not accurately predict disease severity by underestimating and overestimating disease severity, respectively. There were a total of eight patients (ie, total of the first column) who had normal polysomnography results when their previous SNAP test results had indicated the presence of disease.

![Table](http://publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/20385/)

**Table 2.** Severity of OSA as determined by polysomnography. AHI scores determined by SNAP are compared to those determined by polysomnography.

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<tr>
<th>SNAP Severity</th>
<th>Polysomnography Severity</th>
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<tbody>
<tr>
<td>Normal</td>
<td>1</td>
</tr>
<tr>
<td>Moderate</td>
<td>5</td>
</tr>
<tr>
<td>Severe</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
</tr>
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</table>

**Figure 2**

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![SNAP](http://publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/20385/)

**SNAP**

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| Predictive of sleep apnea, there is a paucity of evidence demonstrating that the analysis of snore recordings (alone or together with airflow, as with SNAP) results in the accurate diagnosis of sleep apnea. To date, published studies on sleep sonography in the adult population can be divided into the following two groups: investigations that record tracheal airway sounds; and investigations that record on oral nas sounds. The feasibility of monitoring breath sounds over the trachea to detect apneic events was perhaps first described by Krumpe and Cumniskey and Cumniskey et al. Subsequently, Hida et al reported their uncontrolled case series using tracheal sound recordings combined with airflow measures at the nose. Other studies included investigations comparing tracheal sound records to airflow detection plus continuous pulse oximetry. Unfortunately, however, the number of controlled trials comparing tracheal sonography to polysomnography is limited. In fact, excluding investigations evaluating tracheal sonography in children, the only existing control study evaluating tracheal sonography (known to us) compares tracheal sound records plus continuous pulse oximetry to polysomnography in 129 adult patients with symptoms suggestive of OSA. In this trial, the overall prevalence of OSA was 45%, and the two diagnostic methods correlated well, with a sensitivity and specificity of 84% and 97%, respectively. The sensitivity and specificity were clearly enhanced with the addition of continuous oximetry. While these results may be encouraging, their relevance to our current investigation is unclear, as the SNAP technology does not use tracheal sonography or continuous pulse oximetry.**
Nasal sound recordings have been compared to expired carbon dioxide in sleeping and awake infants\textsuperscript{18} and in adults.\textsuperscript{19} The SNAP technology (utilizing oronasal recordings combined with nasal airflow) also has been used to compare OSA disease severity before and after uvulopalatoplasty (UPP),\textsuperscript{4} snare dissection UPP,\textsuperscript{5} and laser-assisted UPP.\textsuperscript{6} However, these investigations did not validate the ability of oronasal sonography plus nasal airflow monitoring to diagnose and accurately assess OSA disease severity. There are only three controlled studies that compare nasal sonography to polysomnography.\textsuperscript{20–22} Comparing more sound recordings alone to polysomnography in 56 patients with sleep symptoms, Strohs and Guillemainault\textsuperscript{20} found that sleep sonography had an overall impressive sensitivity of 96%, but a low specificity of 27%. The authors noted that the snoring index alone overestimated the total number of events by a mean of 133.3 events. Using a microphone suspended 0.6 m above the head of the bed, Van Brunt et al\textsuperscript{21} analyzed sound intensity and disturbance recordings in 69 patients with sleep symptoms and compared them to simultaneous polysomnography recordings. The sonography results correlated well to polysomnography with a Pearson correlation coefficient of 0.88 (p < 0.0001) and an accuracy of 85%. A poster presentation by Smith et al\textsuperscript{22} is the only investigation (known to us) that compares SNAP technology to simultaneous polysomnography. The authors reported 100% sensitivity and 91% specificity in diagnosing OSA in 18 patients. Unfortunately, diagnostic accuracy was not assessed.

In our study, overall agreement between the AHI predicted by SNAP and that predicted by polysomnography was significant. However, the agreement was less than modest and can only be characterized as fair. In fact, 25.8% of the patients had abnormal AHI results by SNAP, suggesting a need for therapeutic intervention, while the subsequent polysomnography test demonstrated a lack of sleep apnea all together. These data suggest that SNAP testing may not be accurate in predicting AHI severity, and, if used as a sole diagnostic study, they may result in inappropriate diagnoses of patients.

The most significant limitation of this study is that the SNAP and polysomnography tests were not conducted simultaneously. With this limitation, we cannot rule out that night-to-night variability between study dates may have contributed to varying results between the two test methods. Meyer et al\textsuperscript{7} suggested that a negative first-night study result is insufficient to exclude OSA in patients with multiple disease markers. However, another study from our laboratory\textsuperscript{23} suggested that night-to-night variability may not be as clinically significant as previously thought.

The SNAP studies were conducted at home, an atmosphere that is likely to mimic the patients’ typical sleeping atmosphere, while the polysomnography studies were conducted in our sleep laboratory, an atmosphere that is obviously different from patients’ home environments. Thus, an argument can be made that test results obtained from the sleep laboratory may not accurately reflect those found when patients are tested in their familiar home environments. While it is conceivable that the different atmospheres contribute to the possibility of different test results, previous work from our laboratory\textsuperscript{23} has demonstrated that there is a high level of agreement between the test results found by certain portable home devices compared to in-hospital polysomnography. In addition, Sériès and colleagues\textsuperscript{24} have demonstrated that the number of snores per hour (i.e., the snoring index) was not statistically different between home and in-laboratory studies. Nonetheless, several problems that are inherent to portable home diagnostic devices apply to SNAP technology and may present further limitations to the present study. These problems stem from the fact that the SNAP device is self-administered and not supervised by a sleep technician. As a result, the two diagnostic methods used different definitions for total sleep time. The resultant AHI reported by SNAP is based on total time in bed compared to the polysomnography reported AHI, which is based on actual total sleep time confirmed by EEG. This limitation lends itself to the tendency for SNAP to underestimate the AHI and may account for some of the 19.4% of subjects in whom the AHI determined by SNAP underestimated the AHI compared to that found by polysomnography. However, the different sleep time definitions cannot explain the significant number (41.9%) of SNAP-reported AHIs that were overestimated.

Another potential limitation of the present study is related to sleep position. Because the SNAP device is self-administered and unsupervised, interpretation of its results cannot account for sleep position where polysomnography testing can monitor sleep position. The inability to monitor the subject’s sleep position also could lead to the underestimation of AHI by SNAP. In addition, because the sleep testing locations were different, abstinence from alcohol use and other substances prior to undergoing the sleep study at home is difficult to confirm. Alcohol has been shown to increase upper airway resistance.\textsuperscript{25,26}

CONCLUSION

Given the high prevalence of OSA and the limited access to sleep laboratory testing, there is a clear role
for home diagnostic tests. However, SNAP does not appear to be an effective alternative. Although there may be some night-to-night variability in sleep testing, our results suggest that AHI by SNAP does not have a high degree of agreement with AHI by polysomnography for diagnosing OSA disease severity in patients referred to our sleep center. A larger blinded prospective investigation that simultaneously compares SNAP to polysomnography may be warranted if the SNAP test continues to be used by primary care physicians for the diagnosis and treatment of sleep apnea.

ACKNOWLEDGMENT: We thank Rod Warburton and Steven Reinert, Manager, Medical Computing Research, Lifespan Research Support Program, for their help with statistical analysis.

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