Sleep-disordered breathing and hypoxemia frequently underlie many common medical conditions for which patients require hospitalization. Sleep apnea is associated with adverse cardiovascular, neurovascular, inflammatory, and metabolic consequences, many of which can be reversed with nasal continuous positive airway pressure. Although polysomnography is the gold standard for outpatient evaluation of sleep apnea, it has not been used for establishing the diagnosis or as a means to intervene with evidence-based therapy in the hospital setting.

Setting: A 468-bed tertiary-care facility for adults in which an 801.11b wireless network supplements a typical hardwired local area network.

Methodology: We developed a technique to perform 16-channel polysomnography on any patient in any location in the hospital without interfering with routine nursing care. Qualified sleep technicians are able to remotely adjust electrophysiologic and respiratory parameters, as well as control continuous positive airway pressure titration. The study can also be monitored from any location with Internet access using a HIPAA-compliant virtual private network.

Results: Polysomnography was performed on 51 inpatients (age 26 to 89 years; 31 men). Mean (SD) body mass index measured 34.1 kg/m² (12.4). Cardiac disease (47%) and neurologic disease (27%) were the most frequent primary indications for admission. Data acquisition was not disrupted due to connectivity problems. The most frequent deficiencies were reduced sleep time (range 0.8-6.5 hours; mean [SD] 3.3 hours [1.6]) and reduced or absent rapid eye movement sleep. Mean (SD) apnea-hypopnea index measured 35.9 events per hour of sleep (SD 26.3) and 19.4 events per hour of total recording time (SD 17.5).

Conclusions: Polysomnography measurements transmitted across a wireless wide area network increases the capacity of the traditional hospital-based sleep laboratory. This technique can facilitate early implementation of appropriate therapy and may reverse underlying factors associated with the primary cause of hospitalization. Indications and standards of practice need to be specifically established for inpatient polysomnography.

Keywords: Polysomnography, local area network, wireless network, obstructive sleep apnea syndrome, cerebrovascular disease, cardiovascular disease

Citation: Farney RJ; Walker JM; Cloward TV et al. Polysomnography in hospitalized patients using a wireless wide area network. J Clin Sleep Med 2006;2(1):28-34.
ordered breathing in hospitalized patients have received scant attention. PSG has not been routinely used as a means to intervene with evidence-based therapy. A Medline search of the literature failed to identify a single journal article that discussed the practical diagnosis and subsequent treatment of sleep apnea in the hospitalized patient. It is clear that these patients are underserved by the present system. A method in which patients could remain in a safe environment be tested objectively to quantify the degree of sleep-disordered breathing and to define appropriate therapy, during which the state of sleep could be verified, would provide invaluable clinical information.

In response to increasing awareness of OSA and requests for inpatient consultations, we have developed methodology for performing complete attended PSG on patients anywhere in the hospital. Wireless wide area network technology enables complete high-fidelity data acquisition while patients remain in the most appropriate nursing environment, according to their particular needs, and are simultaneously monitored by qualified sleep personnel from remote sites. The purpose of this report is to describe the methodology of PSG using a wireless network for testing inpatients and to illustrate the potential of this technology for clinical and research applications.

Anticipated Problems

We were concerned that acquisition of electroencephalogram (EEG) data could be suboptimal due to electrical interference, sweat artifact, or poor transmission of data between the primary computer and the wireless system. Sleep technicians might not be able to interact effectively with the nursing or respiratory therapy staff in a timely fashion. We were also concerned that data might not be clinically useful because of inadequate sleep time or highly fragmented sleep structure. We herein report our procedure and experience to date on inpatient PSG on the first 51 patients who underwent baseline PSG.

PATIENTS AND METHODS

Setting

The Intermountain Sleep Disorders Center is located at the LDS Hospital, an urban, 468-bed, tertiary-care, facility for adults in Salt Lake City, UT (elevation 1500 m). A hardwired local area network (LAN) is in general use within the hospital. It is supplemented by an 802.11b wireless wide area network with 162 wireless access points located approximately 200 feet apart throughout the hospital (Cisco 1200, Cisco, Inc., San Jose, CA). Consequently, there is wireless coverage of every room within the hospital, including the intensive care units, general medicine wards, surgical wards, and psychiatric and rehabilitation units.

Patients

All patients studied with PSG were seen for comprehensive consultation by any 1 of 3 sleep medicine consultants (2 board certified in critical care and all board certified in internal, pulmonary, and sleep medicine). The primary reason for hospital admission of these patients was classified as cardiac, neurologic, respiratory, psychiatric, orthopedic, or miscellaneous. The decisions to obtain PSG were based strictly upon the presence of well-known and significant risk factors for sleep apnea and the physician’s judgment that polysomnographic confirmation of the diagnosis or implementation of respiratory therapy (oxygen, CPAP, or bilevel positive airway pressure) would be clinically necessary and appropriate in each circumstance. In some cases, oxygen therapy was required during the baseline PSG. Although not reported here, more than 1 study was often performed in order to first make a diagnosis and then to determine or adjust therapy.

Data Acquisition

A schematic of the wireless PSG is shown in Figure 1. Patients were studied in their own hospital rooms and were attended by their usual nursing staff and respiratory therapists. Electrodes and sensors were placed by qualified sleep-laboratory technicians. Sixteen-channel PSG consisted of central (C3/A2 and C4/A1) and occipital (O1/A2 and O2/A1) EEG, right and left electrooculogram, submentalis and anterior tibialis electromyogram, airflow (nasal pressure transducer), respiratory effort (piezoelectric bands on the thorax and abdomen), finger pulse oximetry (SpO₂), snoring (tracheal microphone), electrocardiogram, and body position. When positive pressure therapy was titrated, air pressure and air leak were measured.

Data were acquired at the bedside with an Easy Sleep II system (Cadwell Laboratories, Inc; Kennewick, WA, version 2.01 software) consisting of DC and AC amplifiers interfaced to a Dell computer (Round Rock, TX with a 17-inch flat-panel display, 1600 × 1200 resolution) with a CAT5 cable. Synchronized video (Q-Video, Cadwell Laboratories) was also collected using an infrared bullet camera connected to the computer through a USB port (Belkin USB Video IIIF5U208, Belkin, Corp., Compton, CA). The computer system was placed on a portable Cadwell narrow trolley cart (Cadwell Laboratories, Inc.) Data were stored on the C drive of the bedside computer and at the same time mirrored to the LAN with 100 megabits per second bandwidth (Netware 5.1 Novell, Provo, UT, Xiotech San Disk array, Eden Prairie, MN).
The interface to the LAN was by means of an IBM PCI 802.11b wireless adapter that transmitted data (11 megabits per second) to 1 of the 162 wireless access points. Actual throughput to the remote viewing station in the sleep laboratory was constrained to 11 megabits per second by the wireless system.

PSG data collected at the patient’s bedside could be viewed remotely from the sleep laboratory during acquisition by means of a virtual network connection (Real VNC, RealVNC Ltd., Cambridge, UK), that was mapped to the acquisition computer’s Internet protocol address. This permitted viewing from the sleep lab, with control by keyboard and mouse of the bedside acquisition sleep computer, and the ability to view synchronized video, change montages, perform signal conditioning, and adjust CPAP therapy. Resperonics PC Direct software was used in conjunction with the BiPAP® Synchrony™ Lab System (Resperonics Inc., Murrysville, PA) to provide either CPAP or bilevel positive airway pressure therapy. This software allows complete computer control and monitoring of the Resperonics unit. Consequently, pressures can be adjusted and leaks monitored remotely by the sleep lab technician. Data can also be viewed remotely from anywhere else over the hospital’s intranet system. The bedside acquisition computer can be controlled and data monitored from outside the hospital over the Internet through the use of a HIPAA-compliant virtual private network (VPN, Nortel Connectivity Client). Thus, a physician could monitor the PSG from a location remote from the sleep laboratory. Data privacy is protected by the hospital’s LAN firewall.

Analysis

Sleep staging was scored page by page in 30-second epochs using standard criteria. Apneas were defined as an 80% to 100% reduction, and hypopneas were defined as a reduction in nasal pressure (airflow signal) from baseline for 10 seconds in conjunction with a 4% decrease in SpO₂. Obstructive and central apneas were differentiated on the basis of respiratory effort. The apnea-hypopnea index (AHI) was computed as the total of all respiratory events divided by the total sleep time (TST) (AHI_{TST}) and by the total recording time (TRT) (AHI_{TRT}).

Technical Quality

Record quality was assessed by means of a 5-point ordinal rating scale: (1) inadequate: studies without scorable respiration and SpO₂, whether or not electrophysiologic sleep measures were adequate; (2) suboptimal: scorable respiration (at least airflow and 1 respiratory effort channel), complete SpO₂ but without scorable sleep measures; (3) satisfactory: scorable respiration (at least airflow and 1 respiratory effort channel), complete SpO₂, with major EEG artifact, but sleep could be scored; (4) good: scorable respiration (at least airflow and 2 respiratory effort channels), complete SpO₂, and sleep could be scored but with minor EEG artifact present; (5) excellent: scorable respiration (at least airflow and 2 respiratory effort channels), complete SpO₂, and excellent EEG signals without artifact present. Signal loss was generally not an issue because studies were continuously monitored and sensors were replaced almost immediately, if needed. Replacing sensors is essentially the same as if the patient were studied in the sleep laboratory.

RESULTS

Patient Demographics

The demographics of the patients studied using the wireless system are shown in Table 1. There were 31 men (61%). The mean (SD) body mass index measured 34.1 kg/m² (12.4), indicating that obesity was a common factor, however the BMI measured less than 30 kg/m² in 20 patients (39%). There was a broad age range (26 to 89 years) with a mean (SD) of 59.1 (15.6) years. The primary indications for hospital admission were diverse, but cardiac disease was the most frequent (47%) compared with neurologic (27%), orthopedic (8%), psychiatric (4%), respiratory (2%), and miscellaneous (12%). All but 5 tests were performed in private rooms on the medicine ward (30), rehabilitation ward (16), intensive care unit (3), and psychiatry ward (2). There was no difference in technical quality comparing tests between intensive care unit and general medical beds, but the number in the intensive care unit was small.

Technical Issues

Technically adequate data were consistently obtained. There were no inadequate, suboptimal, or excellent studies. Twenty-nine studies (57%) were rated as satisfactory, and 22 (43%) were rated as good. There did not seem to be a difference in terms of study quality based upon hospital-room location. Of the 3 studies conducted in the intensive care unit, all were rated as satisfactory. Six studies were technically adequate, but the studies were terminated early by the patients (mean recording time 3.7 hours). Patients who were more cognitively impaired from a stroke, especially if there was receptive aphasia (but not expressive) or who had generalized confusion, tended to require more attention and would sometimes remove electrodes. Technicians simultaneously attended hospitalized patients, as well as those being tested in the laboratory. Staffing was adjusted so that there was continuous monitoring of the PSG records throughout the night from the sleep laboratory, and electrodes and sensors were adjusted or replaced as needed in every case. Sleep technicians were able to react and to intervene appropriately, particularly regarding attention to technical issues or adjusting therapy. Time from the sleep lab to the patient’s bedside was less than 5 minutes. Potential causes of poor-quality data (electrical interference, electrode problems, etc.) were not found. Very importantly, data acquisition was not disrupted due to communication or connectivity problems. There were no additional demands on technical and nursing staff involved. In fact, sleep technicians were under less stress because patients remained in acute-care environments where skilled nurses and respiratory therapists could attend.

Table 1—Demographics

<table>
<thead>
<tr>
<th>Sex</th>
<th>No. (%)</th>
<th>Age, y</th>
<th>Height, cm</th>
<th>Weight, kg</th>
<th>BMI, kg/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td>20 (39)</td>
<td>57.5 (18.7)</td>
<td>163.3 (11.7)</td>
<td>90.5 (25.7)</td>
<td>35.1 (15.3)</td>
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<tr>
<td>Men</td>
<td>31 (61)</td>
<td>60.2 (13.5)</td>
<td>177.3 (7.6)</td>
<td>104.5 (30.0)</td>
<td>33.4 (10.4)</td>
</tr>
<tr>
<td>All</td>
<td>51 (100)</td>
<td>59.1 (15.6)</td>
<td>172.0 (11.5)</td>
<td>99.0 (29.0)</td>
<td>34.1 (12.4)</td>
</tr>
</tbody>
</table>

Data are presented as mean (SD) unless otherwise noted. BMI refers to body mass index.
The results of 51 baseline wireless PSGs are shown in Table 2. The most frequent deficiency pertaining to clinical utility was the limited total sleep time. The TRT ranged from 2.3 to 8.4 hours, and the mean (SD) TST was 3.3 (1.6) hours. In 12 cases, less than 2 hours of sleep occurred, but some useful diagnostic information was still obtained (AHI TST 42.4 per hour sleep). In contrast, the AHI TRT measured 15.1 per hour of recording, and, therefore, the degree of sleep apnea would have been substantially underestimated without actual sleep measurements.

Sleep-disordered breathing was almost always present. The AHI TST measured at least 5 per hour of sleep in 48 patients (94%). The importance of having objective electrophysiologic measurements of sleep was evident by comparing the AHI TST versus the AHI TRT (see Table 2). The mean AHI TST measured 35.9 per hour of sleep, compared with the AHI TRT of 19.4 per hour of recording time. In 12 cases, less than 2 hours of sleep occurred, but some useful diagnostic information was still obtained (AHI TST 42.4 per hour sleep). In contrast, the AHI TRT measured 15.1 per hour of recording, and, therefore, the degree of sleep apnea would have been substantially underestimated without actual sleep measurements.

Outcome Data

Follow-up assessment indicated that 48% of patients were discharged on oxygen, 31% were discharged on CPAP, and 21% were discharged without therapy. The average time to discharge following PSG was 3 days for those on CPAP therapy, 10 days for those on oxygen therapy, and 12 days for those without therapy.

**Table 2—Polysomnography Results**

<table>
<thead>
<tr>
<th>No.</th>
<th>TST, h</th>
<th>TRT, h</th>
<th>SE, %</th>
<th>SL, min</th>
<th>REM latency, min</th>
<th>Sleep stage, % TST</th>
<th>OAI</th>
<th>CAI</th>
<th>HI</th>
<th>AHI TST</th>
<th>AHI TRT</th>
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<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3+4</td>
<td>REM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>51</td>
<td>3.3</td>
<td>5.9</td>
<td>55.2</td>
<td>37.7</td>
<td>122.9</td>
<td>11.2</td>
<td>69.6</td>
<td>3.4</td>
<td>9.7</td>
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<td>(22.7)</td>
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<td>(95.9)</td>
<td>(103.0)</td>
<td>(21.1)</td>
<td>(8.5)</td>
<td>(9.1)</td>
<td>(18.9)</td>
<td>(14.2)</td>
</tr>
<tr>
<td>Women</td>
<td>20</td>
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<td>57.8</td>
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<td>109.9</td>
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<td>7.8</td>
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<tr>
<td>Men</td>
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<td>53.6</td>
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<td>120.5</td>
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<td>(1.7)</td>
<td>(20.3)</td>
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<td>(97.8)</td>
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<td>(19.4)</td>
<td>(15.5)</td>
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<tr>
<td>TST ≥ 2 h</td>
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<td>6.3</td>
<td>62.0</td>
<td>41.4</td>
<td>112.6</td>
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<td>71.5</td>
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<td>11.5</td>
<td>27.1</td>
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<td>(1.3)</td>
<td>(20.5)</td>
<td>(50.0)</td>
<td>(88.9)</td>
<td>(9.4)</td>
<td>(18.3)</td>
<td>(9.6)</td>
<td>(9.2)</td>
<td>(17.5)</td>
<td>(26.4)</td>
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<tr>
<td>TST &lt; 2 h</td>
<td>12</td>
<td>1.2</td>
<td>4.6</td>
<td>35.1</td>
<td>25.5</td>
<td>190.8</td>
<td>17.9</td>
<td>63.3</td>
<td>0.9</td>
<td>3.8</td>
<td>17.3</td>
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<tr>
<td></td>
<td>(0.4)</td>
<td>(1.9)</td>
<td>(17.3)</td>
<td>(33.7)</td>
<td>(123.2)</td>
<td>(10.8)</td>
<td>(28.5)</td>
<td>(2.0)</td>
<td>(6.0)</td>
<td>(18.9)</td>
<td>(5.7)</td>
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<tr>
<td>AHITST &gt; 5/hr</td>
<td>48</td>
<td>3.3</td>
<td>5.9</td>
<td>55.5</td>
<td>37.7</td>
<td>122.9</td>
<td>11.5</td>
<td>70.6</td>
<td>3.6</td>
<td>9.4</td>
<td>20.0</td>
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<tr>
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<td>(1.6)</td>
<td>(22.0)</td>
<td>(46.9)</td>
<td>(97.8)</td>
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<td>(20.0)</td>
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<td>(8.9)</td>
<td>(18.7)</td>
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<tr>
<td>AHITRT &gt; 5/hr</td>
<td>40</td>
<td>3.4</td>
<td>5.9</td>
<td>58.3</td>
<td>35.3</td>
<td>125.7</td>
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<td>69.8</td>
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<td>7.9</td>
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<td>(21.1)</td>
<td>(9.4)</td>
<td>(7.9)</td>
<td>(19.4)</td>
<td>(15.4)</td>
</tr>
</tbody>
</table>

TST refers to total sleep time; TRT, total recording time; SE, sleep efficiency (TST/TRT) × 100; OAI, obstructive apnea index; CAI, central apnea index; HI, hypopnea index; AHI TST, apneas + hypopneas/TST; AHI TRT, apneas + hypopneas/TRT; SL, Sleep Latency.

**Polysonmography**

The results of 51 baseline wireless PSGs are shown in Table 2. The most frequent deficiency pertaining to clinical utility was the limited total sleep time. The TRT ranged from 2.3 to 8.4 hours, and the mean (SD) TST was 3.3 (1.6) hours. In 27 patients (53% of total), rapid eye movement (REM) sleep measured less than 10% of the TST; however, the presence and percentage of REM sleep is a function of TST. In patients with a TST of at least 120 minutes (39 or 77% of total), REM sleep measured less than 10% in 18 (46%) and was completely absent in 4 (15%). Various medications can also reduce REM sleep. However, of the 18 patients with TST of at least 120 minutes and REM sleep of less than 10%, only 6 (33%) were taking medications known to suppress REM sleep (antidepressants, opioids, or antipsychotics). Benzodiazepine medications were taken by only 4 (7.8% of total).

Sleep-disordered breathing was almost always present. The AHI TST measured at least 5 per hour of sleep in 48 patients (94%). The importance of having objective electrophysiologic measurements of sleep was evident by comparing the AHI TST versus the AHI TRT (see Table 2). The mean AHI TST measured 35.9 per hour of sleep, compared with the AHI TRT of 19.4 per hour of recording time. In 12 cases, less than 2 hours of sleep occurred, but some useful diagnostic information was still obtained (AHI TST 42.4 per hour sleep). In contrast, the AHI TRT measured 15.1 per hour of recording, and, therefore, the degree of sleep apnea would have been substantially underestimated without actual sleep measurements.

**Discussion**

The importance of early recognition of sleep apnea and implementation of appropriate therapy (e.g., CPAP) based upon objective documentation is an expected standard of medical practice. Sleep-disordered breathing in the outpatient setting continues to be frequently underdiagnosed. Therapy may be prescribed without proper objective verification of efficacy, and, in some locations, there may be scheduling delays of weeks to months for testing in a sleep center. Although it has been recognized that sleep apnea can pose an acute risk to certain patients in the hospital, full PSG performed in the inpatient setting has not been available in most institutions. Also, despite knowledge that sleep apnea is highly prevalent in distinct inpatient populations, such as those with congestive heart failure, acute coronary artery disease, and stroke and postoperative patients (especially those receiving opioid analgesia), and that the presence of sleep apnea poses adverse physiologic consequences in these patients, PSG may not even be considered possible or clinically relevant. In this study, we have shown that the type and severity of sleep-disordered breathing can be accurately defined and most optimally characterized using the current gold standard of PSG. The most appropriate type of evaluation for sleep apnea should not be denied high-risk patients merely because they are in the hospital.

The application of noninvasive positive pressure ventilation is certainly commonplace in the acute or semiacute patient to help prevent or treat respiratory failure in chronic obstructive pulmonary disease, acute pulmonary edema, and neuromuscular disease. Such patients usually receive empiric treatment guided by clinical response and close monitoring of vital signs and arterial blood gases. This practice is generally accepted as standard of care. Overnight oximetry is often used to screen for sleep apnea because it is less intrusive and should be less disruptive to sleep. In fact, we have obtained approximately 400 inpatient overnight oximetry measurements annually since 1990. Although useful information is often obtained for screening purposes in the outpatient environment, oximetry studies obtained on inpatients often cannot be interpreted due to poor technical quality and uncertainty.
of sleep or sleep stages. We have also used limited cardiopulmonary sleep studies (Embitella, Medcare Reykjavik, Iceland), but the interpretations of these tests are limited for the same reasons.

PSG based upon wireless technology immediately increases the capacity of the traditional hospital-based sleep laboratory to provide complete service to virtually any patient in any room in the hospital. The local area network of the hospital environment must include a wireless connectivity component. Benefits include reduction of backlog in the sleep laboratory, documentation of sleep-disordered breathing in a more timely fashion (rather than waiting until after discharge from the hospital), and provision of optimal therapy (while patients still require hospital-based therapy for their underlying condition). Potential problems regarding therapy (e.g., tolerance or mask fit) can be addressed prior to discharge rather than initiating unproven therapy. The above benefits are magnified further if the patient lives a significant distance from the hospital or in a community where sleep services are not available.

There may be various alternative configurations that could be used for inpatient PSG depending upon local resources, for example, positioning an acquisition station on the patient’s ward with a technician outside the room and the computer attached via cable directly to the LAN. However, the wireless system as described in this study offers numerous advantages. It provides a more favorable staffing ratio. Instead of 1 technician fixed overnight to a hallway for 1 patient, it is possible to conduct 2 inpatients with 1 technologist located in the sleep laboratory. Nursing and respiratory staff provide all of the immediate attendant needs of the patient, but the technologist is available for technical problems, such as to replace electrodes if required. The wireless system is simple, extremely portable, and flexible, with all required equipment, including a remotely controlled nasal CPAP system, on a cart. Therefore, equipment-preparation time is reduced, and more time can be spent attending to the patient.

There are 2 sources of potential electronic interference that could degrade the quality of data acquisition. The first involves the initial analog signal, which is always a concern when conducting PSG but might be more insidious when the study is performed in an electronically “noisy” environment outside of the sleep laboratory, such as a hospital ward or intensive care unit. The main source of interference is at the electrode interface and head box. Digital systems are less prone to this type of interference than are analog systems because amplification of the voltage signals takes place at the head box. By reducing impedances to as low as possible and by using the 60-cycle notch filter, undue artifact was not present in our experience.

The second source of potential interference is the transmission of digital data from the computer over the wireless system to the LAN. The 802.11b wireless transmission runs in the 2.4 GHz range and is susceptible to interference from cordless phones, microwave ovens, and other 802.11b applications. There is also competition for its use, since transmission is limited to 11 megabits per second, but there is perhaps less competition when used at night. Wireless data are transmitted in packets per transmission control protocol/internet protocol, which means that data are sent in packets with error checking, and, if packets are not received correctly, they are retransmitted. Consequently, there would only be a delay in data presentation to the remote site. In any case, data integrity is ensured by storage on the bedside computer, which does not require wireless transmission of data. In summary, we did not experience interference, and records were similar to those obtained in the sleep laboratory.

Another potential problem relates to performing sleep studies outside of a dedicated sleep laboratory, such as on the general medical wards or intensive care unit. In some cases, interventions for nursing care, such as giving medications or obtaining routine vital signs, sometimes disrupted the sleep study. In 1 case, a patient received a laxative in anticipation of a procedure for the following day. Consequently, additional specific precautions must be taken to avoid unnecessary disruptions of sleep by nonessential interruptions.

The quality of studies was slightly less than that obtained in the sleep laboratory, where most studies are rated in the good to excellent category. However, obtaining technically adequate data was not a serious or frequent obstacle in our group of patients. Standard 16-channel PSG was conducted on each of the subjects in this study. Out of 51 wireless PSGs, technical quality was sufficient to score sleep stages and respiratory events in all studies. Potential causes of poor-quality data (electrical interference, electrode problems, 60-Hz artifact) were not found. Data acquisition was not disrupted due to communication or connectivity problems. All data and live video could be reviewed remotely in “real time” by sleep technicians so that potential problems could be corrected in an immediate and timely fashion. By means of a virtual network connection, patients could be monitored, and by control with keyboard or mouse, technicians physically located elsewhere in the sleep laboratory could change montages, perform signal conditioning, or adjust CPAP therapy. Importantly, patients with complex nursing issues (e.g., traction, wound care, difficulties with ambulation) are most appropriately served while on their specialized hospital floor.

Some may argue that obtaining EEG and sleep data does not improve the overall level of care provided to the hospitalized patient and would, instead, advocate using oximetry to guide empiric therapy. This study clearly reveals the inadequacies of limited respiratory measurements and the importance of obtaining complete sleep and EEG measures. If limited cardiopulmonary studies had been performed instead of comprehensive PSG, the AHI would have been calculated using TRT rather than actual TST. The mean TST during the diagnostic studies measured 3.3 hours, compared with the TRT of 5.9 hours. Consequently, the AHI would have measured 19.4 per hour, compared with 35.4 per hour if electrophysiologic measures of sleep had not been recorded. This effect is even more pronounced in those with a marked reduction of sleep. TST was less than 2 hours in 12 of 51 subjects, 1 of whom had inadequate sleep for any conclusion. Clinically useful information was still obtained in 11 of these 12 patients, since a positive diagnosis of sleep apnea could be made (AHI TST 42.4 vs AHI TRT 15.1) and the degree of hypoxemia during sleep versus wakefulness could be verified. Oximetry data alone would have resulted in significant underestimation of the severity of disease.

The absence or marked reduction of REM sleep has potential importance in determining the level of sleep apnea, since the frequency of respiratory abnormalities and the degree of hypoxemia are often most severe in this sleep state. Consequently, the severity of sleep apnea was likely underestimated in some cases. Although reduction of REM sleep is not altogether unusual even when patients are tested in a dedicated sleep laboratory, REM sleep may also be reduced because of acute illness and various...
medications. It did not appear that medications were a significant factor in these cases. However, the true value of objective measurements of non-REM and REM sleep states in these settings may be even greater in assessing the response to CPAP titration or oxygen therapy. Unless there is objective verification of non-REM and REM sleep (i.e., the absence of wakefulness) at the time therapeutic changes are being made, then it is impossible to reliably know the effectiveness of therapy on sleep-induced respiratory disturbances and the impact of therapy on sleep architecture.

There are numerous practical benefits to performing diagnostic PSG and therapeutic PSG in the hospitalized patient. Empiric therapy with CPAP or bilevel positive airway pressure is not routinely paid for by insurance carriers or Medicare. Performance of PSG satisfies requirements for initiation of positive airway pressure therapy, therefore allowing a smooth transition from the hospital to home. Therapy would not be unnecessarily delayed as the patient waits for the next outpatient opening. Feedback from the patient, nursing staff, and respiratory therapists who directly observed the patient during sleep may be invaluable in determining the best mask interface or mode of therapy. Most patients studied were discharged on therapy (48% on oxygen, 31% with CPAP, and 21% with no therapy). Our data indicate that the mean time to discharge was less for those discharged on CPAP, longer for those discharged on oxygen, and longest for those discharged without any therapy. However, this finding should not be interpreted as indicating that CPAP decreased length of stay because the number of patients is relatively small and there were numerous clinical circumstances. In some cases, sleep testing was essential to document that therapy was not indicated at the time of discharge, and, in other cases, inpatient PSG made it possible to schedule testing with CPAP shortly after discharge. Larger appropriately designed studies are needed to assess the impact of inpatient PSG on clinical outcome measures.

Summary Comments and Recommendations

We have demonstrated that PSG using a wireless system is feasible and, in fact, has become a standard practice in our hospital. However, the decision to study any particular inpatient must be based upon having comprehensive clinical sleep medicine consultation. Clinical judgment needs to be exercised in determining who will benefit from inpatient PSG, and precautions must be taken to avoid unnecessary disruptions of sleep by nonessential interruptions. Split-night studies are not generally feasible and not recommended due to less-than-optimal sleep present in the hospital. Studies should not be performed on critically ill unstable patients or in situations in which the information would not provide important useful information regarding immediate therapy. Since the clinical conditions may change as the patient convalesces, repeat PSG may be necessary as an outpatient procedure (for example following a cerebrovascular accident or resolution of heart failure) to redefine correct therapy. The clinical value of inpatient wireless PSG appears obvious, but it must be emphasized that indications and standards of practice need to be specifically established for this unique population. The advent of new technologies such as WiMAX (IEEE 802.16) will allow a hospital to have broadband wireless access throughout, with a single base station, as opposed to 162 wireless access points required to cover the hospital in the present case. This could allow most hospitals in the relatively near future to provide inpatient PSG. The potential application of wireless PSG for clinical research should be obvious. Finally, diagnosing and optimizing treatment for sleep-disordered breathing in inpatients is sensible medical practice and should be done better.

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