CHEST Postgraduate Education Corner

CONTEMPORARY REVIEWS IN SLEEP MEDICINE

Wrist Actigraphy

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To record sleep, actigraph devices are worn on the wrist and record movements that can be used to estimate sleep parameters with specialized algorithms in computer software programs. With the recent establishment of a Current Procedural Terminology code for wrist actigraphy, this technology is being used increasingly in clinical settings as actigraphy has the advantage of providing objective information on sleep habits in the patient's natural sleep environment. Actigraphy has been well validated for the estimation of nighttime sleep parameters across age groups, but the validity of the estimation of sleep-onset latency and daytime sleeping is limited. Clinical guidelines and research suggest that wrist actigraphy is particularly useful in the documentation of sleep patterns prior to a multiple sleep latency test, in the evaluation of circadian rhythm sleep disorders, to evaluate treatment outcomes, and as an adjunct to home monitoring of sleep-disordered breathing. Actigraphy has also been well studied in the evaluation of sleep in the context of depression and dementia. Although actigraphy should not be viewed as a substitute for clinical interviews, sleep diaries, or overnight polysomnography when indicated, it can provide useful information about sleep in the natural sleep environment and/or when extended monitoring is clinically indicated. ***CHEST 2011; 139(6):1514–1527***

Abbreviations: AASM = American Academy of Sleep Medicine; MSLT = multiple sleep latency test; OSA = obstructive sleep apnea; PSG = polysomnography; SL = sleep latency; SOL = sleep-onset latency; TST = total sleep time; WASO = wake after sleep onset

Clinical Use of Wrist Actigraphy

The first major medical use of actigraphy was for attempting to evaluate psychologic disorders in the pediatric population using purely mechanical sensors first conceived in the 1950s.[1] Over subsequent decades, the development of piezoelectric sensors, lithium batteries, and digital data storage has enhanced accuracy, reliability, and storage capacity, and devices can now record objective, long-term data regarding a patient's daily activity level. This is rapidly developing into a significant asset for sleep medicine clinicians. The field of actigraphy owes much of its increasing usefulness to the advancement of devices (actigraphs) used for measuring body movement with increasing frequency and precision, with current devices able to record and store information for weeks or months, and to the development of automatic scoring algorithms in available software packages for the identification of sleep vs wakefulness. Current devices also have the advantage of small size and light weight, making the devices unobtrusive and convenient for patients. Through the collection of data representing body movement over time, the actigraph paints a picture of daily sleep-wake cycles, which can be useful in the diagnosis and evaluation of several clinical sleep disorders and treatment outcomes.

In 1995, the American Academy of Sleep Medicine (AASM) concluded that actigraphy was useful as a research tool for the study of sleep, but that its clinical usefulness remained uncertain.[2] This statement

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was expanded in 2002 to indicate the potential use of actigraphy to measure sleep in clinical settings; however, the strength of the evidence remained relatively weak.[3] In an updated report in 2007, growing research literature supported the use of actigraphy for clinical application, particularly in the evaluation of circadian rhythm disorders, insomnia, hypersomnia, and obstructive sleep apnea (OSA).[4] This report contributed to the establishment of a category 3 Current Procedural Terminology code (ie, emerging technology) for actigraphy, which was advanced to a category 1 Current Procedural Terminology code in 2009.

There are multiple methods for evaluating patients' sleep complaints, including clinical interviews, sleep diaries, polysomnography (PSG) (laboratory or home based), and actigraphy. The usefulness of actigraphy depends on the specific presenting complaint, and each of the aforementioned assessment methods has both advantages and disadvantages. This article reviews recent studies on the validity of wrist actigraphy in the assessment of sleep patterns, discusses the use of actigraphy relative to other tools available to the sleep medicine clinician, and outlines key considerations in the use of actigraphy in specific sleep disorders patients.

Validation of Wrist Actigraphy vs PSG

In recent years, multiple studies have been published on the validity of wrist actigraphy. Tables 1[5-15] and 2[16-19] summarize 15 studies published since 2004 that compared wrist actigraphy to other established methods of assessing sleep. In total, 10 studies compared actigraphy to PSG in adults of various ages, and two compared actigraphy to videosomnography in infants. Three studies compared wrist actigraphy to daily sleep diaries. Taken together, these studies suggest that wrist actigraphy is useful in the estimation of total sleep time (TST), sleep percentage, and wake after sleep onset (WASO). Findings are less consistent, however, in terms of estimating sleep-onset latency (SOL), particularly among patients with sleep disorders. Studies of adults are shown in Table 1; studies of infants and children are shown in Table 2. Three additional studies with publication dates prior to 2004 are listed in the AASM practice parameters as providing level 1 evidence for the use of actigraphy.[4] We have focused our discussion on the most recent studies, given the changes in devices and software that may decrease the relevance of older studies.

Actigraphy vs Other Methods of Sleep Assessment

When a patient presents with a sleep complaint, clinicians typically begin with a detailed clinical interview. At times, this interview is sufficient to diagnose a sleep disorder, whereas at other times additional assessments are needed. When making the decision regarding which assessments are most appropriate, one must consider the process of differential diagnosis, patient burden, cost, and the importance of understanding sleep in the natural sleep environment vs documenting the characteristics of sleep architecture. Table 3 outlines several considerations one might reflect on in determining the appropriate assessment method(s) to employ.

Sleep diaries represent an important clinical tool and are often used in the behavioral treatment of sleep disorders such as insomnia.[20] Despite their widespread use, sleep diaries have some limitations. Self-documentation of sleep frequency and duration can be prone to systematic biases that have clinical implications. For example, when documenting adherence to a sleep schedule using a sleep diary, Carney et al[21] reported that bedtime was a full hour earlier than the bedtime reflected in the actigraphy data. Other research has shown significant differences in self-reported documentation of nap frequency, nap duration, nighttime awakenings, and sleep latency (SL) compared with actigraphy.[22] Parents of pediatric patients have reported TSTs that are significantly greater (by an average of 1-2 h) than those reflected in actigraphy recordings of their child.[17,23] Self-reported sleep duration in sleep diaries also seems to overestimate time asleep in both young adults[24] and elderly subjects who lack sleep complaints,[25] compared with actigraphy. Although these studies do not imply that sleep diaries are not clinically useful, they do suggest that actigraphy may be useful when patient documentation of sleep habits does not align with other aspects of the clinical presentation.

Strategies to Enhance Wrist Actigraphy Data

As with any home-based monitoring, the patient must be provided with detailed instructions about the device and information on technical support should problems arise. Typically, the duration of recording should be 1 week; however, depending on the specific diagnostic question, recordings of longer or shorter duration are sometimes indicated. The patient should be informed that the device records movement (and light, if relevant) and should be provided with instructions for the removal of the device if it is not fully waterproof. The patient must then return the device so the data recorded can be uploaded onto a computer for scoring and analysis.

The scoring of actigraphy should follow an established protocol. Although there is no consensus in the field on the precise protocol, in general, specific rules should be in place for the review of recordings for artifacts, for determining the major sleep period (typically from "bedtime" to "rise time"), and for the information to be gleaned from the report. As

described previously, clinicians can have confidence in measures of TST, sleep percentage, and amount of time awake at night. Other variables, such as daytime napping and SOL, should be interpreted more cautiously. Often, review of the recording in its entirety can be informative; however, to view night-to-night patterns, a "double plot" can be useful (as in Fig 1). In these plots, each day is repeated adjacent to and below the previous day. This "lines up" the nights of data and can be particularly useful in depicting circadian rhythm sleep disorders.

The use of a concurrent sleep diary during actigraphy recording provides multiple additional benefits: The diary can contribute backup sleep/wake data in the event of actigraph malfunction or noncompliance with its use. The diary can help differentiate awake but relatively motionless periods from true sleep when interpreting the actigraph data and, thus, can potentially improve the accuracy of sleep-onset identification. The diary provides a place where a patient can document his/her reasons for napping, arousals, uncharacteristic behavior, and so forth, which would assist the clinician in finding an underlying cause of the disorder.

The exact information gathered depends, in part, on the device used and the differential diagnostic considerations. For example, some devices may have an "event marker" that patients can press when getting in and out of bed. A diary may, therefore, be needed only to document unusual activities during the day that might impact the recording (eg, device removal for sports, travel across time zones). At a minimum, the patient is typically asked to document the times he/she got into bed for the night and the time he/she last arose in the morning. A sample sleep diary is shown in Figure 2.

Another strategy to enhance the quality of information from actigraphy is the inclusion of a light sensor on the actigraphy device. This can be particularly useful when there are concerns about the reliability of the diary (eg, patient is cognitively impaired or may be malingering), or simply to verify times noted in the sleep diary. Commonly, scorers use a sharp decrease in light levels near bedtime to help define the major sleep period. Because timed exposure to light is sometimes used in the treatment of circadian rhythm sleep disorders, the light sensor on the actigraphy can be used to monitor adherence to light therapy as well. Figure 3 shows an example of an actigraphy recording completed in an inpatient hospital that shows the increase in light levels during nighttime awakenings.

Use of Actigraphy Prior to a Multiple SL Test

Patients with disorders of excessive daytime sleepiness may sometimes be investigated using a multiple SL test (MSLT) to help characterize the severity of daytime sleepiness or to identify the early onset of rapid eye movement sleep during the day (which is characteristic of narcolepsy).[26,27] The MSLT is typically performed in a sleep laboratory where the patient is put to bed multiple times at set intervals throughout the day with the opportunity to sleep. EEG is used to measure the moment of sleep and rapid eye movement onset during each of the sleep opportunities. It is critical, however, that the clinician distinguish between daytime sleepiness resulting from insufficient nighttime sleep before the MSLT and daytime sleepiness of an organic origin (eg, narcolepsy). For this reason, it is necessary to document the patient's sleep habits for a period of time prior to the MSLT. Wrist actigraphy represents a useful tool for objectively documenting sleep habits prior to an MSLT.[27]

Several studies suggest that actigraphy may be superior to other methods for documenting sleep habits prior to an MSLT in clinical settings. In a study of 54 subjects comparing self-reported sleep schedules,[11] sleep log recordings, and actigraphy 2 weeks prior to a MSLT, sleep logs showed an average of approximately 1.5 h more sleep a night than actigraphy. Based on self-report alone, 32% of participants were sleeping <6 h a night. In this study, actigraphy was the only modality to show a significant relationship between average nightly sleep duration and mean SL on the MSLT. The authors suggest that patients were inclined to minimize their nighttime sleep disruption on sleep logs, because the MSLT results often had job status implications. The benefits of actigraphy to establish a patient's sleep schedule prior to an MSLT have been recognized by the AASM[4] and in *The International Classification of Sleep Disorders*, 2nd edition[27] for use in conjunction with, or as a replacement for, sleep diaries. The 2007 practice parameters published by the AASM suggest an optional patient-care strategy to use actigraphy for assessing sleep time in hypersomnia when sleep log data collection is not ideal, specifically suggesting actigraphy for patients with "impaired cognition, literacy or motivation."[4]

Of note, studies typically have not included a comparison of wrist actigraphy with PSG for the assessment of daytime sleep among patients with daytime sleepiness. Although one advantage of actigraphy is the ability to collect information across the 24-h day, the validity of algorithms used to score sleep at night may not be directly translatable into scoring of sleep during the day. Additional research is needed in this area.

Insomnia

Actigraphy can be a useful tool for evaluating insomnia, particularly because insomnia sufferers

Table 1—*Summary of Actigraphy Validation Studies in Adults (Published 2004–2010)*

Study/Year	Total Sample Size, No. (Mean Age, y)	Study Subjects	Comparison Methodology	Device (Manufacturer)	Software/Protocol	Main Findings/Conclusions
Wang et al[5]/2010	39 (61.5)	Non-small cell lung cancer patients	Actigraphy vs sleep diary	MicroMini (Ambulatory Monitoring, Inc)	Action 3.8 (Ambulatory Monitoring, Inc)	87% congruency between actigraphy and sleep diaries. Actigraphy showed significantly more nighttime awakenings.
Sánchez-Ortuño et al[6]/2010	62 (28.4)	Insomnia sufferers (n = 31); control subjects (n = 31)	Actigraphy vs PSG vs sleep diary	Mini-Mitter (Mini-Mitter Co)	Not specified	No significant difference in WASO, TST, or SE for control subjects or insomnia patients. Stronger correlation between actigraphy and sleep diaries than PSG and sleep diaries for SOL.
Natale et al[7]/2009	408 (40.4)	Insomnia sufferers (n = 126); control subjects (n = 282)	Actigraphy in insomniacs vs control subjects	Basic Mini-Motionlogger (Ambulatory Monitoring, Inc)	ACT Millennium (Ambulatory Monitoring, Inc)	Actigraphy showed significant differences in SOL, TST, WASO, SE, and NA > 5 between insomnia sufferers and control subjects. TIB showed no significant difference.
Chae et al[8]/2009	33 (54)	20 subjects with OSA, 13 with ≥ 5 periodic limb movements/h	Actigraphy (with different sensitivity thresholds and protocols for defining SO) vs PSG	Actiwatch-L (Mini-Mitter-Respironics, Inc)	Actiware 5.0 (Mini-Mitter-Respironics, Inc)	5-min immobility protocol most accurate for identifying SO using actigraphy. SL was underestimated when PSG latencies were short and overestimated when PSG latencies were long.
Blackwell et al[9]/2008	68 women (81.9)	Women age ≥ 65 y at risk for osteoporotic fractures (SOF study)	Actigraphy (TAT, ZCM, and PIM modalities) vs PSG	Sleepwatch-O (Ambulatory Monitoring, Inc)	Action W-2 using the Cole-Kripke algorithm	Actigraphy underestimated TST by 68 min for those sleeping ≤ 5 h and overestimated TST by 31 min for subjects with SE < 70%, as compared with PSG. Using the best modality (PIM), sleep parameters TST, WASO, and SE did not differ from PSG by more than 17.9, 6.8 min, and 3.8%, respectively. Lower agreement was found for TAT and ZCM.
Paquet et al[10]/2007	15 (Not mentioned-adults)	Healthy subjects (caffeine vs placebo) undergoing nighttime PSG or recovery sleep PSG after SD	Actigraphy (2 sensitivity modes) vs PSG	Actiwatch-L (Mini-Mitter-Respironics, Inc)	Actiware 5 (Cambridge Neurotechnology)	Significant overestimations of TST and SE in the setting of non-nighttime PSG, which had low SE. Specificity for sleep was 50% overall despite > 90% sensitivity.
Bradshaw et al[11]/2007	54 (30.7)	EDS patients referred for MSLT with PSG	Actigraphy vs PSG vs sleep diary	Unspecified model actigraphic watch (Precision Control Design)	Action W, version 2.4.20 (Ambulatory Monitoring, Inc)	The mean SL found in nights prior to MSLT using actigraphy was significantly correlated with PSG SL during MSLT. SL from sleep diaries significantly overestimated SL and underestimated TST.

(Continued)

Table 1—*Continued*

Study/Year	Total Sample Size, No. (Mean Age, y)	Study Subjects	Comparison Methodology	Device (Manufacturer)	Software/Protocol	Main Findings/Conclusions
García-Díaz et al[12]/2007	62 (Not mentioned-adult)	Suspected OSA	Respiratory polygraphy device with actigraphy vs PSG	Apnoescreen II (Eric Jaeger GmbH & Co)	Not specified	Addition of actigraphy to home-based OSA diagnostic device modestly improved sensitivity for patients with RDI ≥30, but there was no change in patients with RDI of 15–30. Actigraphy overestimated TST and SE.
Sivertsen et al[13]/2006	34 (60.5)	Chronic primary insomnia	Actigraphy vs PSG	Actiwatch Plus (Cambridge Neurotechnology)	Actiwatch Sleep Analysis 2001, version 1.19 (Cambridge Neurotechnology)	Actigraphy had a sensitivity for detecting sleep of 95.2% but a specificity of only 36.3% for detecting wakefulness, for an accuracy of 83.1%. Actigraphy underestimated total wake time and SOL and overestimated TST and SE.
Lichstein et al[14]/2006	57 (Not mentioned-adult)	Primary and comorbid insomnia	Actigraphy vs PSG vs sleep diary	Actiwatch AW64 (Mini-Mitter Co)	Actiware Sleep 3.3 (Mini-Mitter Co)	WASO, TST, and SE were not significantly different among PSG, actigraphy, and sleep diaries. Actigraphy and PSG were not significantly different in SOL and NA. Sleep diaries correlated with PSG in these measures but did not correlate significantly.
Hedner et al[15]/2004	228 (48.8)	Suspected OSA	Actigraphy vs PSG	Watch_PAT100 System (Itamar Medical) with built-in actigraph (Ambulatory Monitoring, Inc)	ASWA in the zzzPAT package (Itamar Medical)	SE, TST, and SL between PSG and actigraphy were not different among patients with mild, moderate, or severe OSA. Actigraphy overestimated SL, especially among those with mild OSA.

EDS = excessive daytime somnolence; MSLT = multiple sleep latency test; NA = number of awakenings; OSA = obstructive sleep apnea; PIM = proportional integration mode; PSG = polysomnography; RDI = respiratory disturbance index; SD = sleep deprivation; SE = sleep efficiency; SL = sleep latency; SO = sleep onset; SOF = study of osteoporotic fractures; SOL = sleep-onset latency; TAT = time above threshold; TIB = time in bed; TST = total sleep time; WASO = wake after sleep onset; ZCM = zero crossing mode.

have a greater propensity for misperceiving their sleep time than individuals without insomnia and overall tend to significantly underestimate sleep time.[28] Studying insomnia using a single-night PSG can conceivably help quantify TST; however, the "first night effect" (ie, the impact of testing in the unfamiliar and restrictive environment of the sleep laboratory) frequently leads to artificially reduced sleep efficiency and time, and there is evidence that this "first night effect" is more pronounced in insomniacs[29] and can take as much as four polysomnographic studies to resolve.[30] Furthermore, insomniacs have considerable night-to-night variability in sleep parameters, which makes actigraphy better suited for an extended data-collection period that would be much too costly and resource intensive for PSG.[31,32]

Actigraphy has been shown to accurately reflect several important sleep parameters for the characterization of insomnia. When comparing multinight PSG with actigraphy, it has been shown that the measurements of WASO, TST, and sleep efficiency do not differ significantly.[6,14] In an article by Sánchez-Ortuño et al,[6] the ability of actigraphy to assess sleep parameters in insomnia was similar to the accuracy in 31 normal sleeping control subjects. In a retrospective study comparing insomnia patients and normal sleepers, Natale et al[7] showed the clinical importance of the sleep parameters of SOL, TST, WASO, sleep efficiency, number of awakenings >5, and mean motor activity by demonstrating that they are significantly worse in insomniacs than in control subjects when studied by actigraphy. The study found that the combination of TST, SOL, and number of awakenings >5 into a single formula was the most effective for distinguishing insomnia patients from normal sleepers, with a positive predictive value of 81% and a negative predictive value of 83%.

As mentioned previously, the reliability of the measurement of SOL by actigraphy as compared with PSG has been controversial, with studies showing it to be underestimated[13,33] or inconsistent.[14] Nonetheless, some studies have shown that SOL measurements correlate with PSG significantly[9,34] and correlated better than PSG with subjective perceptions of sleep.[6]

Interpreting sleep onset from lack of movement sensed by the actigraph can be difficult in sufferers of insomnia, especially among those patients with difficult sleep initiation, where the patient may lay quietly for extended periods of time while awake in bed.[10,35] The reduced sensitivity of actigraphy in detecting the onset of sleep in disturbed sleepers (approximately 0.55)[7] is a major reason why actigraphy is considered a tool to characterize sleep disruptions or follow treatment outcomes in known insomniacs, rather than as a tool to diagnose insomnia.[4]

Finally, the identification of a large discrepancy between actigraphy and self-reported data could suggest the presence of paradoxical insomnia (ie, the patient's self-report is not consistent with objective sleep quality)[27] and that the patient would potentially benefit from psychologic treatment. The actigraphy tracing can be used clinically in these cases to discuss potential differences between the patient's perceived sleep and objectively recorded sleep.

Circadian Rhythm Sleep Disorders

Actigraphy has been recognized as a tool capable of diagnosing circadian rhythm sleep disorders.[4] In one study, the actigraph device was able to detect and characterize significant phase advancement (ie, abnormally early sleep timing) in elderly, compared with younger, subjects.[36] Cases of phase advancement, as well as phase delay (ie, abnormally late sleep timing), were identified in an adult population of 350 subjects showing excellent concordance with established questionnaires about circadian preferences.[37] In this study, actigraphy-calculated bed times and wake times differed by approximately 10 and 20 min, respectively. Actigraphy has demonstrated usefulness in identifying shift-work sleep disorder by documenting shortened sleep times during rest periods classified subjectively as being of poor quality.[38] Blind subjects with free-running clocks were identified and had TST characterization on par with PSG.[39] Jet lag is another condition in which actigraphs have been used to successfully identify a sleep rhythm disorder.[40,41]

The use of actigraphy in circadian rhythm disorders is a practical way of logging sleep/wake data for extended periods of time, which is sometimes necessary to identify the patterns of circadian rhythm disorders. *The International Classification of Sleep Disorders*, 2nd edition[27] requires that at least 7 days of actigraphy be performed with a sleep diary to demonstrate consistency in the pathology. The optimum duration for an actigraph study to diagnose circadian rhythm disorders has not been established, but Berger et al[42] suggest that as many as 3 weeks are necessary to obtain valid patterns of activity and sleep to describe weekly or social rhythms.

Actigraphy can also be used to assess treatment effects in circadian rhythm disorders. A number of studies have demonstrated the successful use of actigraphy to follow the treatment of phase advancement,[43] delay,[44] jet lag,[45,46] and shift work sleep disorder.[47,48]

Sleep-Disordered Breathing

Approximately 9% of women and 24% of men under the age of 60 are thought to have OSA.[49] Given the high prevalence, full PSG is not a convenient or

Table 2—*Summary of Actigraphy Validation Studies in Infants and Children (Published 2004–2010)*

Study/Year	Total Sample Size, No. (Mean Age)	Study Subjects	Comparison Methodology	Device (Manufacturer)	Software/Protocol	Main Findings/Conclusions
Sung et al[16]/2009	10 with 38 overnight studies total (31.2 wk)	Baseline studies across gestational ages	Actigraphy (with different sensitivity thresholds) vs video somnography	Actiwatch AW64 (Mini-Mitter Co)	Actiware Sleep 3.3 (Mini-Mitter Co)	The predictive value of sleep using actigraphy ranged from 91.3% to 96.5% across threshold settings with a sensitivity of 88.2% to 96.8% vs video analysis. Device was not reliable for predicting wakefulness.
Werner et al[17]/2008	50 (5.9 y)	Baseline study	Actigraphy vs sleep diary	Actiwatch Plus AW4 (Cambridge Neurotechnology)	Actiware 5 (Cambridge Neurotechnology)	Satisfactory agreement between actigraphy and sleep diary for sleep start, end, and assumed sleep. Insufficient agreement between actual sleep time and nocturnal awake time.
Sitnick et al[18]/2008	58 (47 mo)	22 subjects with autism, 11 subjects with nonspecific developmental delays, and 25 control subjects	Actigraphy vs video somnography	Actiwatch AW64 (Mini-Mitter Co)	Unspecified Mini-Mitter software	In an epoch-by-epoch analysis, there was 94% agreement, 97% sensitivity, and 24% specificity for sleep compared with video somnography. Sleep-onset time, SOL, sleep end time, TST, number of awakenings, and total sleep duration and number of nocturnal awakenings correlated significantly.
Hyde et al[19]/2007	45 (5.8 y)	Healthy children (age 1–12 y)	Actigraphy vs PSG	Actiwatch AW64 (Mini-Mitter Co)	Actiware Sleep 3.3 (Mini-Mitter Co)	With epoch-by-epoch comparison, agreement rates were high (85.1%–88.6%). Predictive value for sleep (91.6%–94.9%) and sensitivity for sleep (90.1%–97.7%) were high. Predictive value for wake (46.7%–65.6%) and specificity (39.4%–68.9%) were low. No effect of age, AHI, or PSG arousal index.

AHI = apnea-hypopnea index. See Table 1 legend for expansion of other abbreviations.

Table 3—*Main Advantages and Disadvantages of Actigraphy vs Other Sleep Assessment Methods*

Sleep Assessment Method	Main Advantages	Main Disadvantages
Sleep questionnaires	Brief, easily administered in conjunction with clinical interview Low patient burden	Subject to recall biases Limited usefulness in patients who are unable to self-report reliably (eg, young children, dementia patients) Limited validity compared with PSG
Sleep diary	Provides documentation of daily variability Documents habits in the home sleep environment Less recall bias than questionnaires because information is recorded daily	Patient burden higher than questionnaires; requires patient to complete diary each day for maximum validity Influenced by patient's expectations about sleep
Actigraphy	Provides objective information about daily variability and sleep quality Records information in the home sleep environment Not influenced by patient expectations, recall bias, or memory impairments Lower cost than PSG	Limited usefulness in assessment of SOL Higher cost than sleep diaries Patients should complete sleep diaries concurrently to enhance quality of information
Laboratory PSG	"Gold standard" objective assessment of sleep	High participant burden High cost Does not provide information on sleep habits at home Can lead to a "first night effect" phenomenon

See Table 1 legend for expansion of abbreviations.

cost-effective diagnostic modality to keep up with the need for screening large numbers of people, many of whom live far from sleep disorders centers capable of laboratory PSG. The advent of portable devices that record overnight pulse oximetry with the addition of oronasal airflow, respiratory inductance plethysmography, snoring, body position and/or heart rate monitors in the early 1990s[50-53] started the process toward successful home diagnosis of OSA.

To provide an optimal assessment of the severity of breathing disturbances during sleep, such devices should accurately assess TST so that a similar hourly index of respiratory events can be compared with those measured by laboratory PSG. A key concern of respiratory monitoring is that patients with sleep apnea may spend significant time awake in bed; therefore, the respiratory disturbance indices may be lower when the total recording time is used in the denominator of the index calculation. In one study, the use of total time in bed yielded a sensitivity of only 50% for OSA as compared with PSG. The sensitivity improved to 88% when actigraphy TST was used instead of total time in bed, suggesting that some technique to assess TST should be used.[54]

One method of circumventing this limitation of home-based recording is to use an actigraph to estimate TST during the recording; ideally, the actigraph should be integrated into the apnea-monitoring system. TST calculated from actigraph data had only a mean difference from PSG of 2.5 min in a study of 24 OSA patients,[55] although the agreement between the two methods was found to decrease as OSA severity worsened.[15] Hedner et al[15] found good correlation between actigraphy and PSG for TST, sleep efficiency, and SL in OSA subjects, and these findings contributed to the AASM's recommendation for the use of actigraphy to aid in the diagnosis of OSA by providing an estimate of TST during recording.[4] A later study by García-Díaz et al[12] confirmed that sensitivity in the detection of OSA is enhanced by the addition of actigraphy in home ambulatory sleep studies. The improvement in sensitivity, though, was seen only in patients with severe OSA. The authors concluded that home studies were useful in OSA detection and were felt to be an acceptable substitute for laboratory PSG among patients with a high pretest probability of sleep-disordered breathing. Although one could make the case that actigraphy is a more critical addition to home-based OSA screening when the degree of suspicion is lower, the improved sensitivity among patients with severe OSA suggests its routine use is clinically indicated in conjunction with home-based OSA screening.

Actigraphy for the Assessment of Treatment Outcomes

Following the changes in sleep schedule over time allows for actigraphy to help assess and guide the management of circadian rhythm disorders. Actigraphy has also been used to assess sleep in a number of clinical trials of both pharmacologic[56] and behavioral treatments for insomnia.[57,58] It has also been used widely in studies of institutionalized older adults, such

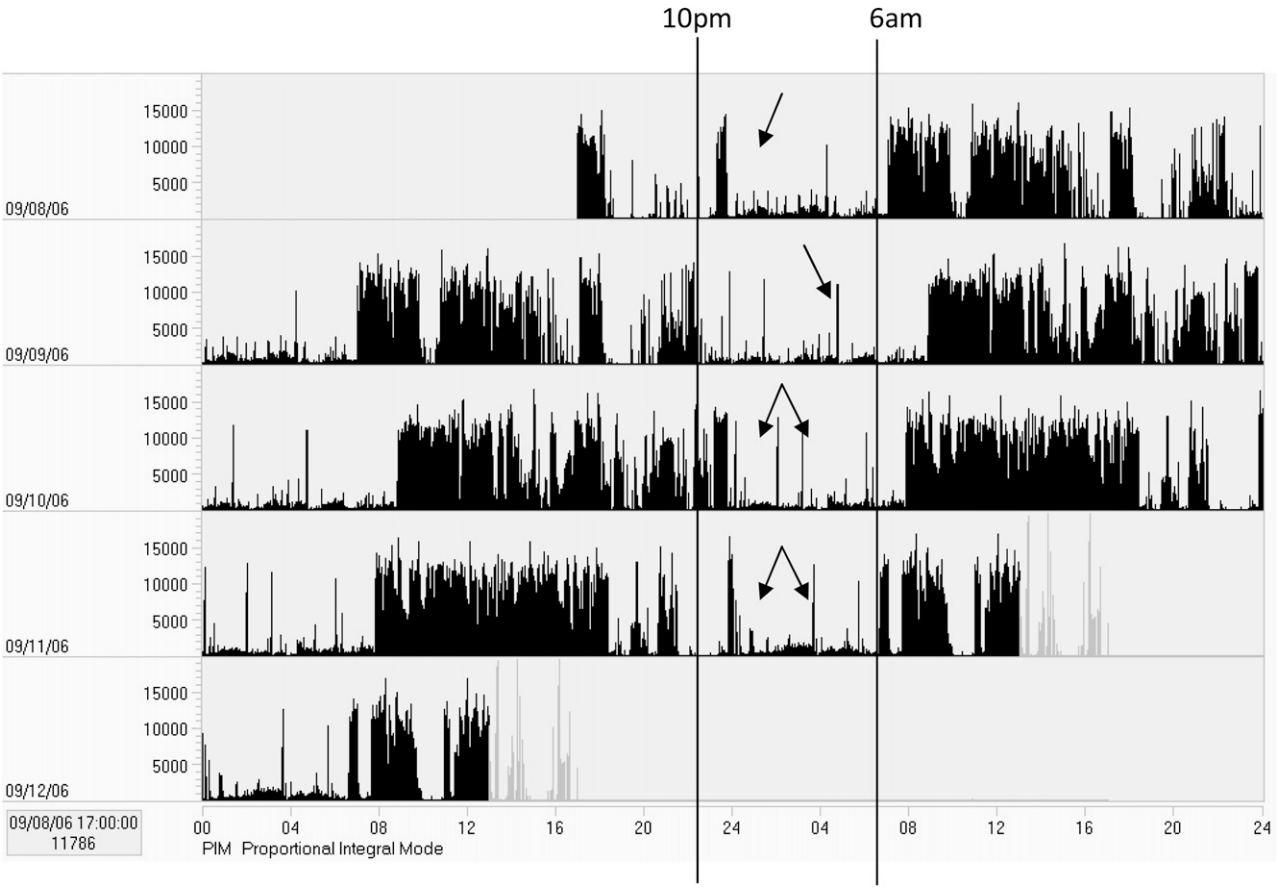


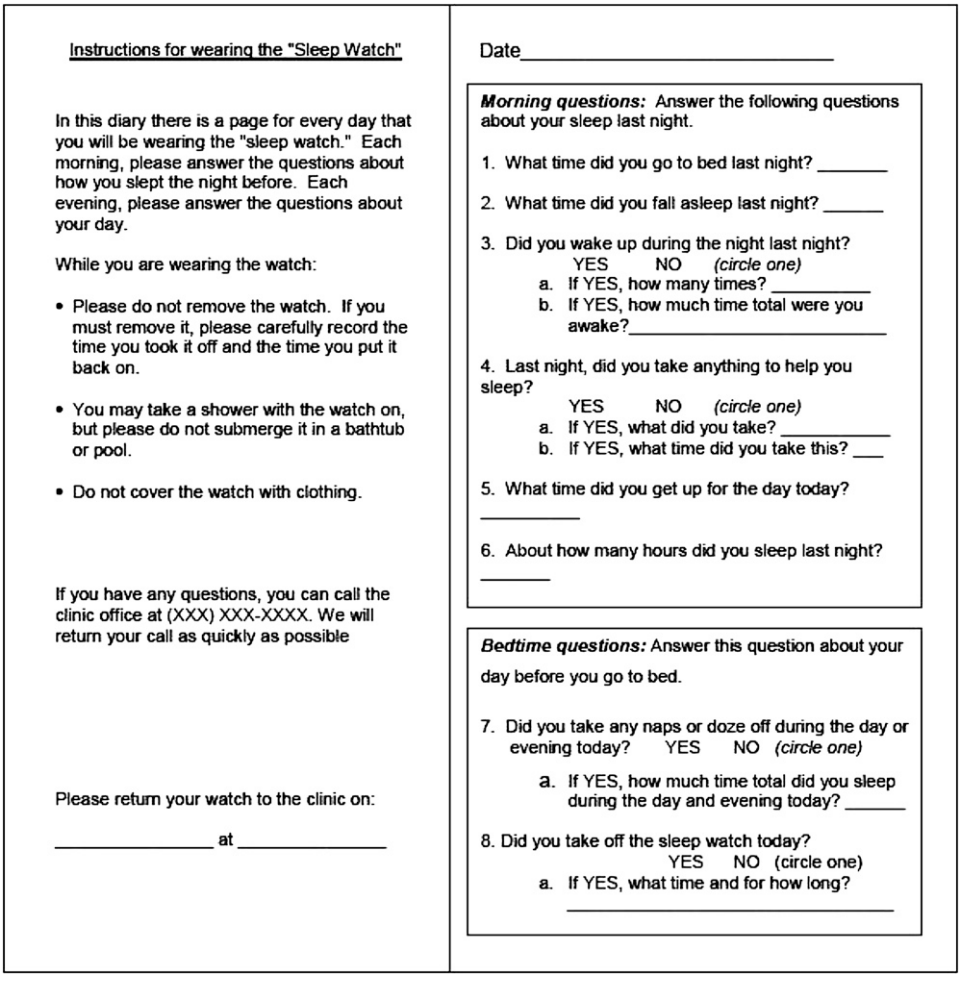
FIGURE 1. Example of a double-plot of actigraphy data. This plot shows nights of data aligned one above the next. This 5-day recording is from a 92-year-old female resident of an assisted-living facility and shows a pattern of abnormally increased activity during the nighttime hours (indicated by arrows).

as those in nursing homes, to assess response to nonpharmacologic treatments.[59,60] The AASM mentions the use of actigraphy for such treatment management as a guideline.[4] Interestingly, simply the awareness that one's sleep schedule is being monitored objectively by a clinician via actigraphy has been shown to improve compliance with a prescribed sleep routine and thereby adds to its usefulness in management follow-up.[21]

Sleep Disturbance in Mood Disorders

Sleep abnormalities have been well documented in the setting of depression and may be a complaint in as many as 90% of these patients.[61] Actigraphy has demonstrated capabilities in characterizing disturbed sleep in the context of depression. Chung and Tso[62] found that actigraphy-derived sleep measures of WASO and TST were independently associated with subjective pain among 91 studied subjects afflicted with major depressive disorder, whereas clinician-rated insomnia and sleep-diary parameters were not significant predictors of pain severity in this study. Variability in sleep duration and fragmentation identified by actigraphy has been significantly correlated with subjects documenting considerable life stressors and especially among those noted to have negative affect.[63] Fragmentation of sleep, demonstrated in wrist actigraphy, has also been shown to correlate with postpartum maternal depressive symptoms.[64,65] Disrupted circadian patterns (based on wrist actigraphy) were also associated with greater depressive and anxious symptoms among cancer patients,[66,67] elderly women,[68] children, and adolescents,[69] based on multiple studies. Of note, one large study of >3,000 older men did not find a relationship between actigraphically estimated sleep and depressive symptoms but did find a relationship between self-reported sleep complaints and depression.[70]

There is some suggestion that actigraphy could be used to follow the progress of depression treatment, given the greater daytime psychomotor retardation demonstrated by subjects with greater depression severity.[49,71] Depressed patients whose depression has improved with therapy have shown greater daytime activity levels,[72] as well as improvement in SL and



Instructions for wearing the "Sleep Watch"

In this diary there is a page for every day that you will be wearing the "sleep watch." Each morning, please answer the questions about how you slept the night before. Each evening, please answer the questions about your day.

While you are wearing the watch:

- Please do not remove the watch. If you must remove it, please carefully record the time you took it off and the time you put it back on.
- You may take a shower with the watch on, but please do not submerge it in a bathtub or pool.
- Do not cover the watch with clothing.

If you have any questions, you can call the clinic office at (XXX) XXX-XXXX. We will return your call as quickly as possible

Please return your watch to the clinic on:

_____ at _____

Date_____

Morning questions: Answer the following questions about your sleep last night.

1. What time did you go to bed last night? _____
2. What time did you fall asleep last night? _____
3. Did you wake up during the night last night?
   YES NO *(circle one)*
   a. If YES, how many times? _____
   b. If YES, how much time total were you awake?_____
4. Last night, did you take anything to help you sleep?
   YES NO *(circle one)*
   a. If YES, what did you take? _____
   b. If YES, what time did you take this? ___
5. What time did you get up for the day today? _____
6. About how many hours did you sleep last night? _____

Bedtime questions: Answer this question about your day before you go to bed.

7. Did you take any naps or doze off during the day or evening today? YES NO *(circle one)*
   a. If YES, how much time total did you sleep during the day and evening today? _____
8. Did you take off the sleep watch today?
   YES NO (circle one)
   a. If YES, what time and for how long?
   _____

FIGURE 2. Sample instructions and daily patient log for use with wrist actigraphy.

sleep percentage estimated by actigraphy.[73,74] Therefore, actigraphy may help document the benefits (or lack thereof) of a specific treatment plan for depression in a given patient. More research is needed regarding how sensitive and specific actigraphy is for the characterization of this change in psychologic state.

Sleep Disturbance in Dementia

Assessing sleep among patients with dementia presents a particular challenge to clinicians. Because sleep disruption is a common behavioral symptom of dementia and contributes to significant challenges for caregivers, it can become an important focus of clinical evaluation and intervention.[75] Actigraphy has several advantages for patients who are incapable of reliably completing questionnaires or sleep diaries because of cognitive limitations, and in cases in which the disruptions associated with laboratory (or even home-based) PSG may be impossible for the patient to tolerate. Nursing home patients are an example of a group with considerable challenges in the attainment of good sleep history or overnight PSG. In nursing home settings, actigraphy has been validated for the study of nighttime sleep[76] and can provide useful information on the patient's sleep habits in the context of the nursing home environment.[77-81]

Key Limitations of Wrist Actigraphy

Although actigraphy is an objective measure of sleep vs wakefulness, it has not been validated for measuring sleep stages. Actigraphy is also prone to overestimating sleep in certain patient groups. A discussion of the limitations of this technology is warranted. When comparing actigraphy's ability to assess sleep parameters to the "gold standard" of PSG, it has shown excellent concordance in the measurement of TST among healthy subjects, with a sensitivity $>90\%$.[9,10,82-85] However, the ability to detect sleep is substantially reduced in patients with disturbed sleep (ie, those who have frequent arousals and reduced TST).[9,10,85]

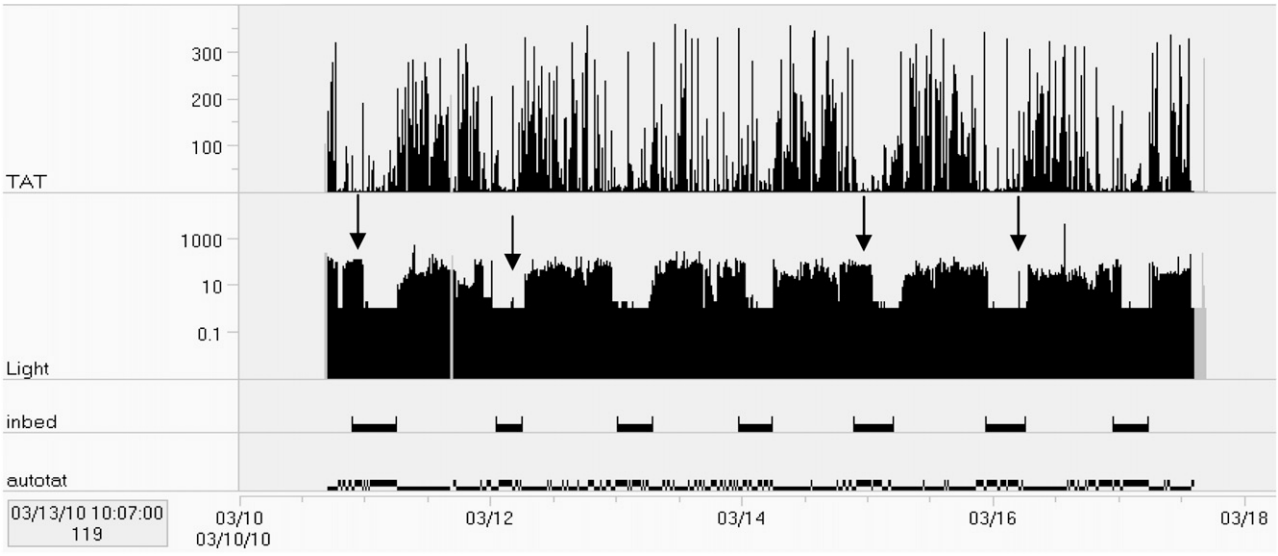


FIGURE 3. Seven-day recording of a 66-year-old woman during hospitalization following ankle injury. Arrows indicate periods when lights were left on after the patient indicated "trying to fall asleep" and occasions when lights were turned on at night. During the day, light levels reached no higher than 450 lux during the 1-week recording period, confirming that the patient did not go outdoors on any occasion.

With actigraphy, because sleep is inferred from lack of movement, subjects who are awake but lie motionless can be classified incorrectly as being asleep, and thus the technique is biased toward overestimating TST, which may lead to incorrectly minimizing the severity of sleep disturbances. This may present a specific challenge for patients with insomnia, and may partially explain the limited validity of wrist actigraphy for estimating SOL. This may also be a concern among individuals who are hospitalized or bed bound, because these individuals may not have as much activity during wakefulness.

Finally, the process of scoring wrist actigraphy data is substantially simplified when a concurrent sleep diary is maintained by the patient. This enables the clinician to determine the key period for analyzing sleep parameters. Typically, the time window between the patient's bedtime and morning rise time is considered the "major sleep period" and used for analysis. In the absence of such documentation, actigraphy can still provide a useful estimate of sleep habits over a 24-h period, but parameters such as TST and WASO may be of more limited use. A sample "actigraphy log" is shown in Figure 2.

Summary and Conclusions

Actigraphy represents a useful diagnostic tool for the sleep medicine practitioner, allowing for assessment of sleep over extended periods of time in the natural sleep environment. Actigraphy appears to provide a valid estimate of TST, sleep percentage, and WASO, but the validity of actigraphy for measuring SOL remains suboptimal. Although actigraphy cannot be viewed as a replacement for other assessment tools such as clinical interviews, sleep diaries, or overnight PSG, it can provide useful information in the evaluation of insomnia and circadian rhythm sleep disorders, in the measurement of sleep habits prior to an MSLT, and as a way to estimate TST in the recording of sleep-related breathing disorders. Key limitations remain the absence of validation studies with many of the commercially available devices and the use of actigraphy in the assessment of daytime sleeping.

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