Chapter 3.4

Recording sleep and wake

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Introduction

As well as in all medical disorders, taking the patient’s history is very important in sleep medicine, too. Polygraphic studies, however, are indispensable and recording of sleep and wake gets a more and more important role in clinical neurophysiology.

This chapter is meant to give an overview of technical aspects, how to perform recording and to give an estimate of the diagnostic yield of polysomnography. Choices are pointed out instead of rigid rules. The text aims at providing outlines that can serve to choose ways of performing polysomnography.

To make such choices one should realize what may be encountered in sleep medicine. Thus, insight into the classification of sleep and wake disorders is necessary before registration is started (Table 1).

Polygraphy should be taken in the strict sense of the word. That means not only recording of signals related to clinical neurophysiology as EEG and EMG but also parameters from other fields, for example pulmonary physiology.

There are several possibilities for recording sleep. The most extensive but also very expensive and time consuming way is polysomnography in the laboratory, in fact the ‘gold standard’. Another possibility is polysomnography at home using portable recorders. Both methods give insight in many parameters of sleep.

Polysomnography at home can easily be extended to daytime recording and provides data not only on sleep but on wakefulness, naps etc. as well. Finally, there is limited polygraphy with one to four channels of recording of various parameters, often respiration or movements.

Standardized methods to measure wakefulness are the Multiple Sleep Latency (MSLT) and the Maintenance of Wakefulness (MWT) tests.

As there are many combinations of what can be recorded (see Table 2), the concept of ‘modules’ is introduced here. A module is a way of recording signals related to sleep and wake defined by the method used, for example EEG, EMG, EOG, ECG, thermistor recording of respiration, etc.

It is the aim of this chapter to describe possibilities and give advise how to perform recording of sleep and wake. Still, one can make his own ‘mix of modules’ to get the ideal recording for that particular patient and during given circumstances. Each module will be described in technical details (Section 2) and most used combination of modules (Section 3). Rules for assessment and the relative
TABLE 1

INTERNATIONAL CLASSIFICATION OF SLEEP DISORDERS (SUMMARIZED)

1. Dyssomnias
   (A) Intrinsic sleep disorders
   Examples: psychophysiological insomnia; narcolepsy; sleep apnea syndrome; periodic movement of the limbs disorder
   (B) Extrinsic sleep disorders
   Examples: inadequate sleep hygiene; agent-dependent sleep disorders
   (C) Circadian-rhythm sleep disorders
   Examples: shift work sleep disorder; jet lag

2. Parasomnias
   Examples: sleep walking; sleep bruxism; primary snoring

3. Sleep disorders associated with other medical disorders
   Examples: sleep disorders associated with anxiety disorders; dementia; parkinsonism; COPD

4. Various disorders

value of the various ways of recording disorders will be given in Sections 4 and 5.

Technical aspects

For insight into a disorder in sleep and wake and its intensity it is necessary to record: (1) sleep, (2) respiration, and (3) other factors.

Sleep and sleep depth

EEG

Recording is done with normal scalp electrodes very well fixed to provide many hours of recording without artifacts. The recording can be limited to two (in some cases even one) channels. According to the classical guidelines given by Rechtschaffen and Kales, EEG is recorded from the channels C3-A2 and C4-A1. Good results can be obtained with other derivations, for example, Fpz-Cz and Pz-Oz. As many sleep-related EEG phenomena are located over central regions, recording from at least these areas is necessary.

It is recommended to use paper velocity of 10 mm/s; a time constant of at least 0.3 s, preferably at 1.2 s; low-pass filter of 70 Hz and amplification of 70 μV/cm. Even with these settings difficulties may arise. On standard EEG paper or computer screen such recordings are displayed in epochs of 30 s. This allows easy scoring in the Rechtschaffen and Kales system which has 30 s as standard epoch, but for example for the evaluation of apneas that may last up to two min this time-base is too short. Thus, there should be a possibility to change paper velocity or enlarge the time-base of the computer display.

EOG

Movements of both eyes together are recorded or

| TABLE 2 |
| RECORDED IN SLEEP AND WAKE |

<table>
<thead>
<tr>
<th></th>
<th>Laboratory</th>
<th>At home</th>
<th>MSLT/ MWT³</th>
<th>Limited polygraphy</th>
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<tbody>
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³ MSLT, Multiple Sleep Latency Test; MWT, Maintenance of Wakefulness Test. Parentheses indicate additional, not standard.

ᵇ Necessary for sleep scoring according to Rechtschaffen and Kales.
alternatively, movements of each eye. Surface electrodes are fixed at the outer corners of the eyes. Filter settings should allow analysis of slow and rapid eye movements (recommended time constant: 1.2 s; low-pass filter: 30 Hz, amplification 200 \( \mu V/cm \)).

**Muscle tone**
Surface electrodes are used for this recording as well, mostly from the mental or submental muscles (recommended settings: time constant: 0.03 s, low-pass filter 70–120 Hz, amplification 30 \( \mu V/cm \)).

**Respiration**

**Respiratory movements (= effort)**

**Measurement of excursions of breast and abdomen.** It is possible to limit the measurements to movements of the abdominal wall only. Methods are induction-plethysmography, elastic bands and measurement of thoracic impedance.

**EMG of respiratory muscles.** Qualitative EMG from respiratory muscles is possible, using surface electrodes. Only in very adipose people this method is not feasible. EMG of the intercostal muscles can be recorded in the second and third intercostal space next to the sternum. The EMG from the diaphragm can be recorded in the eighth to tenth intercostal space in the first axillary line (recommended settings similar to those for the evaluation of muscle tone).

**Esophageal pressure.** Changes in pleural pressure are related to inspiratory movements. They can be measured directly from changes in esophageal pressure measured by a balloon or catheter-tipped manometer. Changes in pressure in a respiratory rhythm are a qualitative and quantitative parameter for inspiratory movements. Measurement of esophageal pressure is up to now the only reliable method to diagnose the so-called Upper Airway Resistance Syndrome.

**Adequacy of respiration.**

**Airflow.** Airflow can be measured by a thermistor that transduces changes in temperature (between in- and outgoing air) into electrical signals. The thermistor is fixed before nose or mouth or both. The method is semi-quantitative and gives only limited information on the volume of air passed.

**Blood gases.** For measurement of arterial oxygen saturation (\( \text{SaO}_2 \)) the method of choice is pulse-oxymetry either from a finger or from the earlobe. One should realize that it takes a period up to 30 s before hypopnea or apnea is measurable in a lower \( \text{SaO}_2 \).

In patients without pulmonary disorders the pCO\(_2\) at the end of an expiration is representative for the arterial pCO\(_2\). In patients who do have lung disorders end-tidal pCO\(_2\) is only a qualitative measure. Measurement of pCO\(_2\) is the only way to quantify hypoventilation. Unfortunately, end-tidal pCO\(_2\) is practically measurable only by wearing a whole-face mask or by taking samples from a catheter in the nasal pharynx. Both methods are of limited use in sleep studies.

Technically it is possible to quantify hypoventilation with transcutaneous electrodes. Due to the long-time constant of such systems they can be used only in patients with chronic hypoventilation that is more or less stable. Thus, the system is adequate in patients with COPD, but cannot be used in patients with fast changes in pCO\(_2\), for example, in sleep apnea syndrome.

**Other factors**

**EMG activity (often resulting in visually detectable movements)**

This activity is measured over the anterior tibial muscles of both sides, if possible as well over the extensor carpi muscles of both sides. Surface electrodes are fixed over the muscles with an inter-electrode distance of 2–4 cm with settings similar to those used in the detection of muscle tone but with lower amplification. In case only one channel is available, one electrode is put over the right anterior tibial muscle and the other over the left side. Similar techniques can be used in the analysis of abnormal activity in the masseter muscles or in the arms.

**Body position**

In particular for the assessment of snoring and apneas, it is important to know whether the patient
lies on his back or in another position. Gravity sensors (mercury tilt-switch or accelerometer) or video registration can be used.  

**Body temperature**

The method of choice is a rectal probe with a thermal element.
**ECG**

A one-channel derivation is adequate as the important parameters are cardiac frequency and the occurrence of (ventricular) extrasystoles. For the analysis of these parameters a good quality QRS-complex suffices.

**Snoring (sounds)**

Measurements through a miniature microphone or other vibration-sensitive device, for example built into the thermistor, or a microphone fixed on the skin over the larynx.

**Arterial blood pressure**

Measurement through photo-plethysmography.

**Spontaneous erections**

Measurement using elastic bands.

**Esophageal pH**

Measured by a thin catheter electrode.

Recording of all these signals can be done in different ways. Registration on paper is the classical way; more modern is recording on the hard disc of computer and – after assessment – storage on, for example, CD-ROM.

**Combination of modules**

The modules mentioned above can be combined in various ways. This can lead to recording using a wide selection with nearly all modules to recording of only a few parameters and allows for classification in ‘levels of registration’ (see Table 2).

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**Level 1**

**Level 1a. Polysomnography in the sleep laboratory (Fig. 1)**

Recording of at least 9 modules from the list mentioned in Table 2: EEG, EOG, submental EMG, ECG, respiration measured as airflow, effort and SaO₂, recording of body position and movements of legs, eventually arms or body during sleep are obligatory. In this situation there is continuous supervision by trained personnel and interventions during the registration, for example change of body position of the patient or CPAP pressure titration, are possible.

**Level 1b. Polysomnography using portable apparatus at home (Fig. 2)**

The same parameters as mentioned under level 1a can be recorded. EEG, EOG, EMG (chin, legs), ECG, respiration parameters are obligatory. The main difference lies in the fact that there is no supervision by trained personnel and lack of interventions.

The *Multiple Sleep Latency and Maintenance of Wakefulness Tests* were developed to quantify excessive daytime sleepiness. Both tests are performed according to rigid protocols and strict supervision of the patient is obligatory. EEG, chin EMG and EOG are the modules to be used, if possible ECG as well.

**Level 2. Polygraphy**

This level comprises recording equipment that can be used at home and is portable. It records a selection of the above mentioned modules with the exception of EEG. Per definition sleep scoring is
impossible. There is no supervision by trained personnel, no possibilities for intervention.

*Level 2a. Extensive polygraphy*

A minimum of 4 modules, mostly respiration (effort, flow, SaO₂) and ECG are chosen. Sometimes body position, snoring sounds or leg movements are recorded as well. There are several well-known systems of this kind of polygraphy commercially available. Systems with movement-sensitive transducers in the bed combined with recording of respiration parameters belong to this category as well.

*Level 2b. Limited polygraphy*

Recording limited to 1, sometimes 2 or 3 modules. Examples are continuous oximetry during the night and long-term movement detection such as actigraphy. The latter is long-term (up to a week) recording of gross movements. A movement sensitive transducer and a counting device are worn around the wrist mostly in a watch-like fashion. Such equipment gives indirect information on sleep and wake behaviour over long periods.

*Remarks*

(1) Modules should be combined according to the leading principle of maximal information at the lowest cost for patient and laboratory. For an assessment of sleep the modules EEG, EOG and surface chin-EMG and their relation in time are necessary.

(2) Abnormal respiration, movement of legs, snoring sounds etc. are frequent disturbers of sleep. There is good evidence that not the disturbances per se but the accompanying arousals are the cause of the sleep disorder and the ensuing symptoms during daytime. Thus, the method of
recording should give insight in these parameters and into their relation to sleep.

(3) Disturbances, in particular respiration disorders that are latent or only in limited ways present during non-REM sleep, often prove to be clinically relevant during REM-sleep only. Thus the method of recording should give possibility to delineate REM-sleep.

(4) Excessive daytime sleepiness (EDS) is an important parameter in estimating the severity of disturbed sleep. Possibilities to record the EDS are the MSLT and the MWT tests. Both give standardized measurements of sleepiness or the ability to remain awake during daytime. There is no consensus on what test is best. Both tests are time consuming. Questionnaires such as the Epworth Sleepiness Scale are useful and a reasonable alternative. Another possibility is to do ambulant polysomnography at level 1b not only during sleep but during the day as well. All patients that will have interventions like Continuous Positive Airways Pressure (CPAP) therapy or Uvulo Palatal Pharyngeal Plastic surgery (UPPP) in sleep apnea syndrome, or possibly lifelong medical treatment as in narcolepsy or the Periodic Limb Movement Disorder and/or Restless Legs Disorder (PLMD/RLS) should have level 1a recording combined with MSLT or 24 h level 1b recording at least once providing insight into the sleep disturbance itself, its cause and severity expressed in sleep architecture and EDS.

(5) In the present state of technology it is not possible to do reliable automatic analysis of polysomnography according to the Rechtschaffen and Kales rules. Visual assessment by trained personnel in a man/machine interaction is the best method available at the moment. (see also: automatic analysis).

(6) The report should comprise demographic details and all what has been measured and analyzed. Sleep quality should be described into the parameters in use for that (see Section 4).

(7) There are no serious safety issues in polysomnography. The presence of a physician during polysomnography or other sleep tests such as the MSLT or MWT is not necessary.

Assessment

For the visual assessment of sleep according to criteria of Rechtschaffen and Kales details from the EEG, EOG and EMG from chin muscles are used. The assessment is expressed in a number of parameters of which most important are: (see Fig. 1).

Sleep

(a) Time in bed (TIB). The time between going into bed (lights out) and going out of bed. Time out of bed during the night is excluded.

(b) Total Sleep Period (TSP). The time elapsed between begin of sleep (stadium 2 or any other stadium of sleep with the exception of stadium 1) and the end of the last epoch of sleep.

(c) Total Sleep Time (TST). This equals Total Sleep Period (TSP) minus time awake. Movement times (see e) are assessed as time in sleep.

(d) Wake periods after sleep onset (WASO). Time during the sleep period being awake.

(e) Movement time. Large movements of the body with a duration of more than 15 s during sleep.

(f) Duration of the stages (wake, REM, non-REM 1,2,3,4) in min.

(g) Percentage time in the various sleep stages. The duration of the sleep/wake stages as percentage of time in bed, total sleep period or total sleep time.

(h) Sleep efficiency index (SEI). (Total sleep time (TST) divided by time in bed (TIB)) × 100.

(i) Sleep onset latency. Time in min elapsed from lights out to the first epoch of stadium 2 or to the first epoch of stadium 1b for the MSLT.

(j) REM latency. The time from sleep onset to the start of the first episode of REM. Sleep onset latency and REM latency are the main parameters for an MSLT as well.

(k) Arousal. An arousal is defined as an abrupt shift in EEG frequency (with the exception of sleep spindles and delta activity) that occurs during sleep and lasts for 3 s or longer. K-complexes, artifacts and shifts in delta activity are not included in reaching this 3 s criterion. Submental EMG amplitude changes with accompanying EEG arousal are not scored as an arousal. Arousals result in fragmented sleep rather than shortened sleep.

When the patient is awakened by the arousal for a
period of 5 min or longer this epoch is scored as an awakening.

Unfortunately, there is no world-wide consensus on assessment of sleep fragmentation. When other methods are used (for example inclusion of micro-arousals) this should be stated explicitly.

**Respiration**

There is no consensus about criteria for the assessment of ventilation. Some points:

(a) A period of apnea or hypopnea is relevant when it lasts 10 s or longer.

(b) The definition of hypopnea is not clear. Most authors use 50% reduction in airflow measured from a thermistor or the combination of this cut-off point combined with a SaO₂ drop of more than 4%.

(c) The gold standard for hypoventilation is a rise of arterial pCO₂ estimated from its end-tidal value (or transcutaneous measurement, see previous remarks).

(d) Periods of apnea and hypopnea are counted over the period of sleep during the night and calculated to a mean per hour of sleep, the so-called apnea/hypopnea index. Up to now this index above 5/h is considered as pathological. It looks, however that this cut-off point is not justified. From a practical point of view this index is relevant when it exceeds 15 per hour.

(e) The distinction between obstructive and mixed apneas (obstructive and central apneas) is dubious from a clinical point of view.

(f) There is no consensus about the assessment of diminished SaO₂. It looks reasonable to qualify lowering as significant when the SaO₂ drops below 90% or is lower than 4% of values during normal breathing in wake.

(g) The SaO₂ can be quantified in an oxygen desaturation index (OD). This gives the number of drops in SaO₂ per hour. In addition the percen-

**TABLE 3**

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<thead>
<tr>
<th>ASSESSMENT OF PERIODIC LIMB MOVEMENT DISORDER (PLMD)*</th>
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<tr>
<td>Diagnosis of PLMD when</td>
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<td>(1) PLM-arousal Index &gt;5/h of sleep</td>
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<td>(2) Sleep Efficiency Index &lt;85% (of Time in Bed)</td>
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<td>arousals) Index &gt;10</td>
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<td>(2) NREM 3 + 4 sleep &lt;15% of Total Sleep Period</td>
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*PLM, Leg movements that are seen with (semi) periodic intervals (see text and Fig. 3a). Assessment according to R.M. Rijman, pers. commun.

tage of time in which the SaO₂ is lower than for example 90%, 80% or 70%, etc. can be given.

As mentioned under ‘remarks, 2’ there is a tendency to consider ventilatory parameters per se less important than their impact on sleep and wake as expressed in percentage non-REM 3 and 4 sleep, arousals, EDS, etc.

**Leg movements**

The EMG of the anterior tibial muscles is used to quantify periodic movements of the legs in sleep (Periodic Limb Movement Disorder, PLMD). The movements are relevant when they occur during sleep. In the related Restless Legs Syndrome the movements may occur during wake time but they are seen during sleep as well, giving rise to the concept that both disorders show overlap. Further points in the definition of the movements are a duration between 0.5 and 5 s and their periodicity (Fig. 3). The latter means that the movements occur in sequences of at least 4 movements with an interval of between 4 and 90 s. For each movement it should be stated whether it causes an arousal or not. The PLM-arousal index, i.e. the number of movements with an arousal per hour

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Fig. 3. Periodic Movement of the Limbs disorder. (a) (Semi) periodic movements of the legs followed by an arousal during this 1 min of recording. Legend as in Fig. 1a. (b) Level 1b recording at home over a period of approx. 18.5 h. Recording of sleep, leg movements and respiration. Legend as in Fig. 1b. The patient suffers from insomnia. Period Wake after Sleep Onset (WASO) is 1 h and Sleep Efficiency is 78% (of Time in Bed). There is only 9% of NREM 3 + 4 sleep. The sleep disturbances are due to a Periodic Movement of the Limbs disorder (PLM/arousal index: 40/h of sleep). There are no apneas.
of sleep, is seen as pathological if it is 5 or higher. As we think that the present rules for assessment (see Further reading list) are not completely satisfactory, a somewhat modified version is given in Table 3.

**Automatic analysis**

All recordings, whether simple pulse-oxymetry or multi-module investigations as polysomnography in a laboratory, render great amounts of data. Automatic analysis would be helpful in
terms of time, accuracy and costs. Such programs are available. It should, however, be realized that each automatic method harbors the danger of ‘garbage in, garbage out’, meaning that one should be sure that the signals are of high quality and should be easily available as raw data for non-automatic re-analysis. Up to now, an automatic analysis of parameters related to respiration, snoring sounds and (leg) movements is technically feasible. The same holds for the ECG. Large problems, however, are encountered in the automatic analysis of sleep itself. This is due to artifacts and aspects of the prevailing Rechtschaffen and Kales method of scoring of sleep. Admittedly there are methods of automatic analysis according to the Rechtschaffen and Kales rules, but the performance of such systems is at best 80% accord-ance to visually scored sleep in normal subjects. This is not acceptable and means that the visual assessment of sleep following the criteria of Rechtschaffen and Kales is as yet the only useful method.

The main problems are the discontinuity (stages wake, REM and NREM 1–4) and low-time resolution (30 s) inherent to the Rechtschaffen and Kales method. Most important in this respect is that the Rechtschaffen and Kales scoring for a certain sleep stage is based on sleep phenomena that are not concurrent. An automatic system has to ‘decide’ on data that are dispersed over epochs of sometimes many minutes of recording. For example, for the decision to score NREM 2 sleep, sleep spindles, K-complexes, moderate amplitude background activity etc. are to be detected. These phenomena do not occur simultaneously. Hence the automatic analyzer has to remember what was seen during an earlier epoch and has to combine this information with data from the epoch that is analyzed at that moment. Fortunately, other methods that differ significantly from the classical Rechtschaffen and Kales assessment allow fully automatic and continuous assessment of sleep. Most promising are the developments in the delta plot analysis. Very important for research in new methods is the easy exchange of sleep data between laboratories that is available now, for example, in the ‘European Data Format’.

**Diagnostic yield**

The value of a method can be given in various parameters. At each such study in this respect, comparison has to be made with a gold standard. In sleep medicine this ideal is not available, but polysomnography in the sleep laboratory at level 1a approaches this ideal.

As there are serious drawbacks for this ‘gold standard’ examination such as costs, duration and limited availability, one should always try to use more limited ways of registration that are cheaper and that give the same or even better answers for the questions asked by the clinician: Which patient has to have what kind of registrations to get the optimal results?

**Guidelines for the practical use of poly(somno)graphy**

**Level 1a. Polysomnography in the sleep laboratory**

This method with its comprehensive measurement of physiological parameters is indicated for patients in whom the diagnosis is problematic. For example patients suspected of Sleep Apnea Syndrome in which there are confounding clinical details or in which other sleep disorders such as PMLD are possible as well. Furthermore, level 1a examination should be performed in all patients who will get interventions for example CPAP or surgery for Sleep Apnea Syndrome or intensive medical therapy for narcolepsy, PMLD, etc. This supervised form of registration in the sleep laboratory allows interventions. That is the reason why this method of registration is indicated for titration of CPAP pressure. Drawbacks are its cost in time and the lack of insight in sleepiness during daytime.

The so-called siesta-sleep registration, i.e. the recording of an afternoon nap, is at the 1a level from a technical point of view but it has a low sensitivity and specificity for disturbances in sleep. Patients with Sleep Apnea Syndrome often have no respiratory disturbances during a siesta-sleep registration but still prove to have the disorder during night sleep and vice versa. Thus, a level 1a registration is still necessary and makes a siesta sleep registration redundant.
Level 1b. Polysomnography at home with a portable system

This way of registration is suitable for the same categories of patients that would otherwise have had polysomnography in the sleep laboratory. There are, however, some differences. Although technical facilities are large at the moment there are still some limitations in parameters that can be recorded by a portable system. Furthermore, the method of registration with a portable system is not supervised and as such not useful for interventions. Registration at home has its own advantages. It can be performed under circumstances that are normal for the patient. He or she sleeps in his/her own bed and falls asleep at his/her own sofa! In case ambulant poly(somno)graphy is extended over periods of 24 h or longer the method gives insight into the waking period during daytime and allows quantification of (excessive) daytime sleepiness or other phenomena that occur during the day. The method is much cheaper and more suitable for follow-up studies than polysomnography in the sleep laboratory.

The MSLT and MWT tests are performed in order to answer limited questions: is there excessive daytime sleepiness or inability to stay awake? They are meant to give quantification of these questions. The tests are performed under supervision of a trained technician but are not intended for intervention. For the questions posed their sensitivity is high and results have face-value, but specificity is low. For example, a pathologic MSLT can be encountered in Narcolepsy, Sleep Apnea Syndrome, PLMD, etc.

Polygraphy (levels 2a and 2b)

In this category belong all forms of limited polygraphy at home using portable equipment. Combinations of various parameters with the exception of EEG are recorded. In particular for screening and follow-up for the Sleep Apnea Syndrome there is a role for this equipment. The sensitivity and specificity, for this disorder, of level 2a equipment is at about 80–95% (when compared with polysomnography at level 1a or 1b). This indicates that there is a place for such equipment. The indication for use in other sleep and wake disorders is limited as the methods give only indirect information on disturbances of sleep itself.

Equipment that is intended for monitoring of one or two parameters during sleep (level 2b) can be used for screening of Sleep Apnea patients. An example is long-time pulse-oxymetry. For this method some validation studies were performed in which comparison was made with polysomnography at level 1a or 1b. Depending on the severity of respiratory disorders during sleep sensitivity and specificity varied between 40% and 100%. The more severe the Sleep Apnea Syndrome, the more exact were the results of pulse oximetry. This conforms to the expectation that in clear abnormalities diagnosis can be made with more simple methods.

Further reading


Carskadon, M.A., Dement, W.C., Miller, M.M., Roth, T., Westbrook, P.R. and Keenan, S. Guidelines for the multiple sleep