REVIEW ARTICLE

Monitoring Pediatric Sleep- Special Issues

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Learning objectives:

- Understand the role of the sleep laboratory for diagnosis and management of a spectrum of pediatric sleep disorders.
- Learn about the special equipment and techniques important in studying pediatric patients.
- Understand recent advances and newer techniques in monitoring pediatric sleep.

Keywords: Pediatric sleep study, pediatric polysomnogram, pediatric MSLT, pediatric sleep laboratory

Introduction

The demand for sleep services for young patients has escalated due to the increased recognition of pediatric sleep disorders over the past two decades. This chapter highlights the essentials of *pediatric* sleep monitoring and stresses the special issues that the sleep clinician and the sleep team need to address in order for a successful outcome. While many techniques used in the "adult" sleep centers may suffice for older adolescent patients, differences in design of the sleep center, data acquisition and interpretation techniques become increasingly important the younger the child. Establishing a pediatric sleep laboratory is detailed elsewhere in this book and complements the current chapter.

The Spectrum of Pediatric Sleep Disorders:

The most common problems presenting to our sleep center requiring monitoring of sleep and wakefulness are:

1. Sleep related breathing disorders.
2. Inadequate sleep hygiene and behavioral insomnia of childhood.
3. Circadian rhythm disorders.
4. Parasomnias.
5. Sleep related movement disorders
6. Hypersomnias

Patients with sleep related breathing disorders include those children with symptoms suggestive of obstructive sleep apnea, babies with suspected apnea of prematurity or congenital hypoventilation syndrome, patients with Arnold-Chiari type-2 malformation with inadequate central control of breathing or a child needing ventilator setting titration to ensure adequate therapy during sleep. It is not uncommon in a busy referral hospital to encounter tracheotomized children needing sleep center services to ensure readiness for decannulation.

Other common scenarios include harried parents who struggle with their children's bedtime resistance and nocturnal awakenings, the teenager who is sleepy during school and failing grades, the inattentive child with "growing pains" complaining of restless sleep and the somnambulator who has walked out of the home for the fourth time at night!

The commonest tools currently used in the diagnosis

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and management of these disorders include:

1. Sleep questionnaires and diaries
2. Laboratory and radiographic investigations
3. Actigraphy
4. Polysomnography and positive airway pressure titration studies
5. MSLT
6. Investigational techniques

Sleep Questionnaires and Diaries

The age appropriate sleep ***questionnaire*** is a screening instrument that can be extremely useful in detecting the common sleep problems in children, and in assigning a priority for evaluation and treatment.

There are several *validated* questionnaires. Two of the best known are the *Pediatric Sleep Questionnaire* (PSQ) (1) and the *Children's Sleep Habits Questionnaire* (CSHQ)(2). Both questionnaires are useful to screen for the most common sleep, medical and behavioral problems in children. A ***sleep diary*** on the other hand is a prospective record detailing the sleep-wake routines of the child typically over two weeks. It provides useful information on children with complaints of excessive daytime sleepiness, insomnia, circadian rhythm disorders, and/or inadequate sleep hygiene. It can help monitor progress after interventions and should also complement the actigraphic record (see below).

We routinely mail a detailed pre-visit sleep habits, medical history and behavior screening questionnaire as well as a weeklong sleep diary to our prospective patients prior to their initial appointment. This form of documentation is quite critical considering that both parents may work, children may be at daycare or nap at the baby-sitter, and be put to bed at night by a grandparent. It potentially allows input from all the caretakers and helps the sleep physician to focus on likely problem areas more efficiently in a busy clinic.

Routine laboratory and radiographic evaluation

Certain sleep disorders such as obstructive sleep apnea (OSA) and periodic limb movement disorder (PLMD) or restless leg syndrome (RLS) have been shown to be associated with abnormalities on routine laboratory testing. Screening may pick up polycythemia (3), elevated serum CRP (4), evidence of insulin resistance (5), abnormal lipid profile (6), abnormal thyroid function (7) or low ferritin levels (8). These tests may be adjunctive in planning therapeutic intervention. For example, iron replenishment has been shown to be helpful in PLMD (8) and correction of hypothyroid state or management of insulin resistance is adjunctive in the treatment of OSA.

In children with suspected sleep disordered breathing (SDB), a lateral soft-tissue radiograph of the neck obtained while the child is awake and upright can be useful to identify adenoidal hypertrophy. This however does not predict the presence or severity of obstruction while the child is asleep and supine (9, 10, 11). Since adenoids may re-grow after surgery, a lateral neck film may be useful in guiding therapy in cases where SDB recurs. In centers with multidisciplinary expertise, orthodontists, otolaryngologists and maxillo-facial surgeons use cephalometric techniques for detailed anatomical assessment in severe cases of cranio-facial malformation (12, 13).

Actigraphy

An ***actigraph*** is a small portable device that senses physical motion and electronically stores the information. Photosensors may also be incorporated and can keep track of ambient light. The data is downloaded into specialized software and can provide detailed information of rest-activity patterns as a surrogate for sleep-wake cycles. This instrument thus fulfils a unique role in the armamentarium of the sleep clinician since sleep logs and direct observations provide only limited and at times inaccurate information (14, 15).

While actigraphy is not reliable for the diagnosis of SDB or PLMD (14, 15, 16, 17, 18), it is useful for examining night-to-night variability in patients with insomnia and for assessment of the effect of therapeutic interventions in circadian rhythm and insomnia disorders (19, 20). Results of actigraphic recordings correlate well with measurements of melatonin and of core body temperature rhythms (20, 21).

We have found actigraphy particularly useful in the diagnostic work-up of delayed sleep phase syndrome (especially common in teenagers) where lack of parental observations of sleep wake routines may limit the information a sleep diary can provide (fig 1). It is also

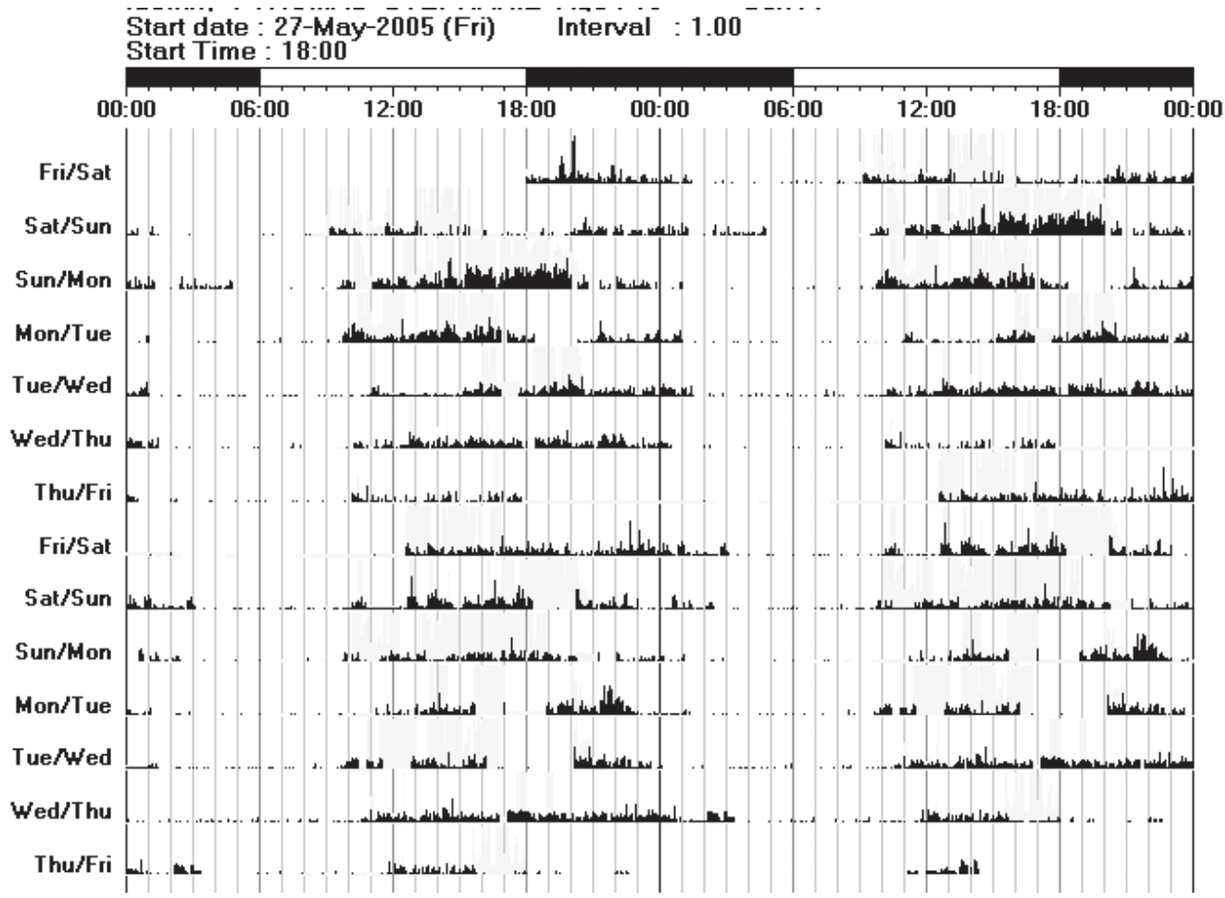

Fig 1: Actigraphic record of an adolescent complaining of daytime sleepiness and relatively normal functioning in the evening hours. The patient was asked to wear the device on the wrist for a period of 14 days during school summer break starting at 6 pm on Friday, May 27, 2005. The light sensor shows the relative ambient light intensity (yellow) and motion is depicted in black. The clock time is denoted on the top. This graphic illustrates delayed sleep onset and rise times with additional delays recorded on weekends. Social pressures like resumption of school may mask the weekday phase delay however the inherent pattern typically resurfaces over weekends. We routinely ask that the device be worn over 2-week periods to capture this variation, which may otherwise be missed in shorter recordings. This patient was diagnosed with delayed sleep phase disorder.

quite indispensable in situations where multiple care providers and erratic sleep wake schedules confound the clinical history.

Note of caution: The usefulness of actigraphy needs to be balanced against the cost of the instrument, and the cognitive and behavioral ability of the child to wear it since improper care (e.g. immersion in water) will ruin this relatively expensive gadget.

Nocturnal polysomnography

Overnight polysomnogram (PSG*)* is a useful tool in the diagnosis of several sleep respiratory and non-respiratory related disorders the mainstay for diagnosis of SDB and PLMD. The reader will notice that one major difference between laboratories catering to children and adults is the use of redundant sensors in the "hook-up". Multiple EEG derivations and more than one type of sensor for air-flow measurement serve to ensure that meaningful data will ultimately become available even in the most challenging patient. For more discussion on scoring respiratory events see chapter on pediatric obstructive sleep apnea in this book.

A. SLEEP STATE

Sleep state is monitored with *Electroencephalogram* (EEG), surface *electromyogram* (chin) and *electro-oculogram sensors*

(EOG).

Sleep stage scoring has been standardized using a limited referential EEG montage (22, 23).

While this is generally considered adequate in children, the staging in infants younger than 6 months of age or in premature infants differs (24). To accurately score and interpret the record, the pediatric sleep laboratory team needs to be familiar with defined EEG changes that occur as the premature brain develops (25).

The standard 10-20 system of electrode placement is utilized as in adults. We routinely use an EEG montage that includes paired frontal-polar (Fp1-Fp2), temporal (T3-T4), central (C3-C4) and occipital leads (O1-O2) referenced to the mastoids (A1-A2). This extended montage not only minimizes interventions required to reposition electrodes during the sleep study, but also provides a means of screening for seizures that may masquerade as parasomnias (fig 2).

Scoring *EEG arousals* in children is controversial. As defined by the American Sleep Disorders Association (ASDA) scoring arousals in children is based on an extension of adult criteria. Thus, a minimum of 3 seconds EEG frequency change is required (26). Some studies have attempted to use modified criteria for scoring arousals in children using durations as short as 1 second. Wong et al. showed poor inter-scorer agreement for scoring arousals < 3 seconds and proposed that the best criteria to use in children are those of the ASDA (27). Similar results were found by our group, whereby the 3-second criterion optimally differentiated between OSA, primary snoring, and controls (28).

B. RESPIRATORY EFFORT

Esophageal pressure (Pes) monitoring is considered the most accurate method to differentiate between obstructive and central events, and therefore in defining upper airway resistance syndrome, whose hallmark is the respiratory event related arousal (RERA). It has been shown that increases in Pes (increasing negativity) often occurs 3 to 5 breaths before the EEG arousal (29). Identifying these changes is useful in the diagnosis of

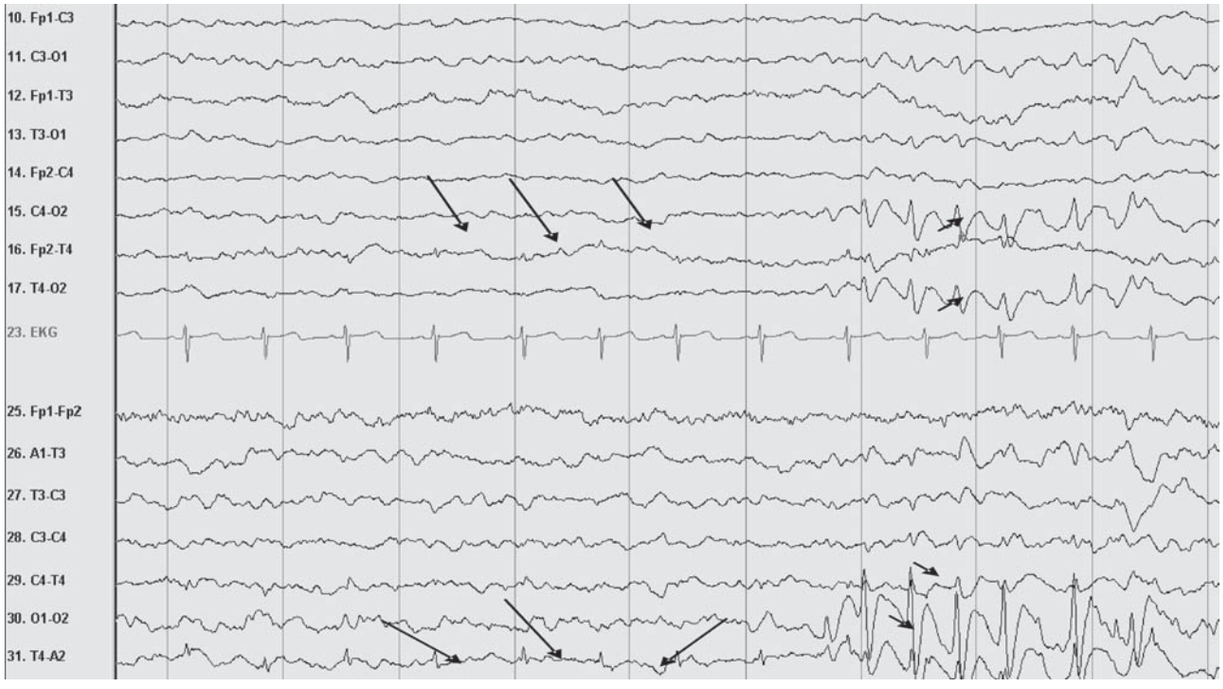

Fig 2: Several EEG leads are routinely used in our pediatric sleep center. This allows detailed analysis of EEG by re-referencing the leads after the acquisition has been done using routine referential montage. Occasionally seizure disorders may masquerade as parasomnias. In this instance, the bipolar longitudinal and transverse array revealed abnormal spike and wave discharges starting abruptly in the occipito-temporal areas (short arrows). These are distinct from the ECG artifact (long arrows) contaminating some of the channels. ECG artifacts are always in phase with the ECG signals (red) and have their general morphology. The vertical gray grid-line markers are at intervals of 1 second. This child was subsequently referred to a neurologist for more extensive evaluation.

upper airway resistance syndrome (UARS) (30).

Because esophageal probes are stressful to the child during placement and usually not well tolerated, a variety of other non-invasive methods are instead used to monitor respiratory effort, and include respiratory inductance plethysmography and nasal pressure measurements.

Respiratory Inductance Plethysmography *(RIP)* is a technique that can be used to measure timing and relative volume of respiration. It is non invasive and once calibrated does not require the use of a face mask or mouth piece. This technique involves the subject wearing two inductance bands, one around the ribcage and the other around the abdomen. Special software will analyze the relative displacements and phase angle of these 2 sensors and calculate an equivalent to the tidal volume (31).

Nasal pressure transducers have been suggested to be equivalent to invasive determination of inspiratory pressure using a supraglottic or an esophageal catheter in assessing flow limitation (32). Further validation of this technique in children and its potential limitations have now been assessed (33-35).

The ***intercostal EMG (IC EMG)*** is monitored by applying disk electrodes to the patient at the level of the lower intercostal spaces, where they can monitor EMG activity both from the diaphragm and intercostal muscles (32).

The IC EMG is useful if the effort belts are not functioning properly, and therefore provides an additional method of documenting ongoing respiratory effort to help classify respiratory events.

C. GAS EXCHANGE

Arterial oxygen saturation by *pulse-oximetry (SpO2), end-tidal CO2 (ETCO2)* monitoring by mass spectrometry or infrared capnography, and *trans-cutaneous CO2 (TcCO2*) are regularly used in our center to measure gas exchange.

Measurement of ventilation is especially helpful in the pediatric patient with neuromuscular disorders, congenital hypoventilation syndromes, non-obstructive alveolar hypoventilation and OSA. In fact, it is well documented that pediatric OSA, unlike the adult counterpart, may present with obstructive alveolar hypoventilation as the predominant abnormality (36). ETCO2 is not reliable in continuous or bi-level positive airway pressure (CPAP, Bi-level PAP) titration secondary to the dilutional effects due to the increased airflow. In such situations, TcCO2 trends augment the information obtained from oximetry alone (37).

D. AIRFLOW MEASUREMENT

Airflow can be measured by one of several methods. ***Pneumotachography*** is the gold standard for quantifying airflow. However, the requirement of a snugly fitting mask makes it uncomfortable and may be not tolerated by the patient. It is rarely used outside the research setting.

Oronasal thermistors can provide semi-quantitative information about the presence or absence of airflow based on temperature differences between the inhaled and exhaled air. The thermistor alone may be unreliable in detecting hypopneas leading to underestimation of the severity of SDB (33) (fig3).

Nasal pressure transducer detects variations in airflow in the nasal cannula resulting from changes in inspiratory and expiratory airflow and may be a sensitive method for detecting airflow limitation (33, 34). Budhiraja and colleagues suggested that the use of nasal pressure and thermistor is more sensitive than thermistor alone in detecting airflow limitation in children (33). The problem with the use of nasal pressure cannula alone in infants and children relates to the longer time spent with uninterpretable airflow signal than when using a thermistor as well. Difficulties in maintaining the cannula in the proper position, obstruction of the cannula by secretions and loss of signal from mouth breathing account for prolonged loss in the airflow signal despite the presence of a trained technician (35).

We routinely use an oro-nasal thermistor, nasal pressure transducer, and ETCO2 to monitor airflow. This approach ensures that an interpretable airflow signal will be available.

E. SNORING CHANNEL

Snoring is the hallmark for OSA. However, not all children with snoring have OSA.

Further, because of limitations inherent in parental observation and the fact that many snorers do not have snoring every night, an objective measure of snoring is

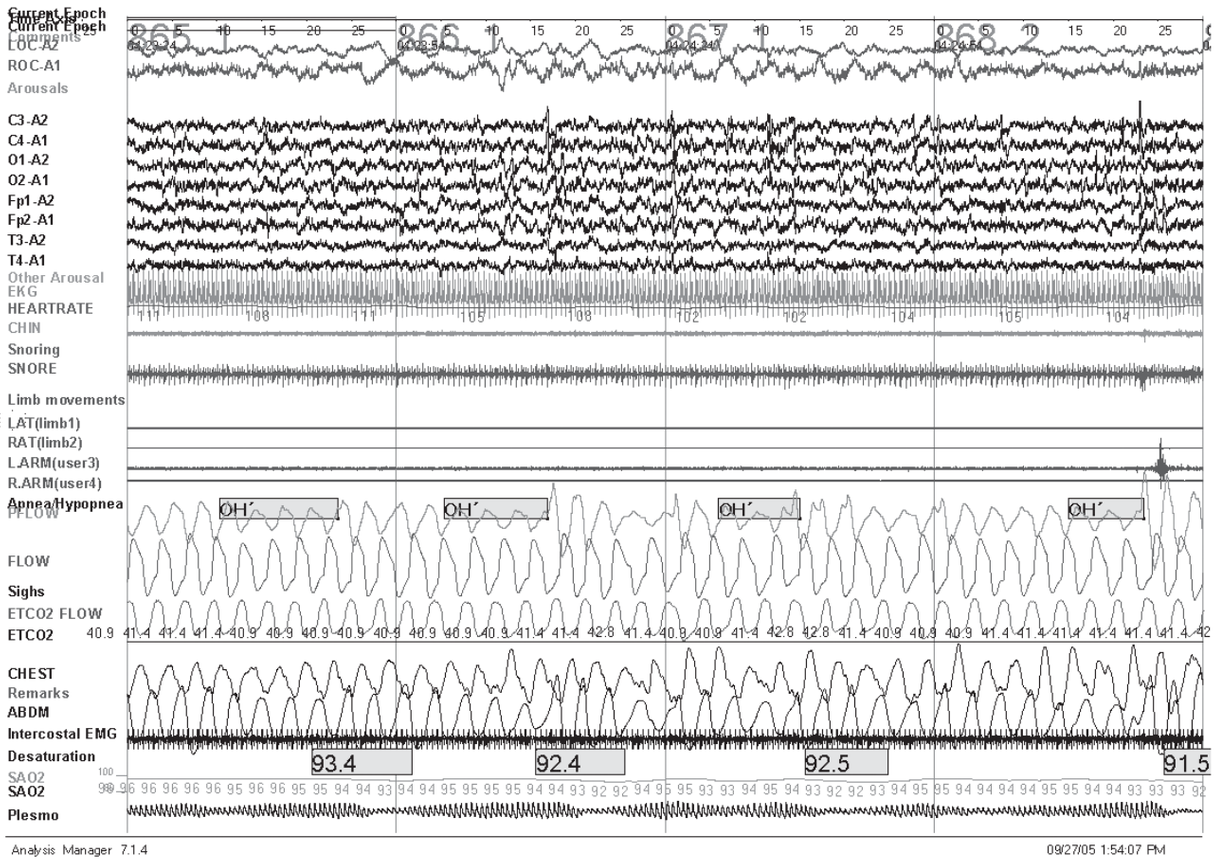

Fig 3: Polysomnographic recording of 4 epochs each of 30 seconds duration in stages 1 and 2 of sleep. The thermistor (FLOW) and end-tidal (ETCO2 FLOW) channels show regular and even tracings with no evidence of hypopneas. However, the more sensitive nasal pressure cannula signal (PFLOW; shown in red) clearly demonstrates repetitive flattening of the waveform indicative of airflow resistance (marked as OH). Obstructive sleep-disordered breathing is additionally reflected in the paradoxical out-of-phase tracings of the effort belts (CHEST, ABDM) and results in cyclical desaturations of 3% in the pulse oximetry (SAO2). It is not uncommon to miss subtle airflow limitation if the thermistor signal is the only flow channel available.

useful. Screening *High-frequency inspiratory sounds* (HFIS*)* as a new research tool has been tested in children with adenotonsillar hypertrophy and SDB. Children who make more HFIS exhibit higher obstructive apnea-hypopnea indices, suggesting that HFIS may be a marker of disturbed breathing during sleep in children with adenotonsillar hypertrophy (38).

F. CARDIAC RHYTHM

At least one channel of the polysomnogram is dedicated to record the cardiac activity. Heart rate and rhythm are measured using a standard ECG lead placement. The cardiac activity is closely monitored in order to assess arrhythmias or significant decelerations associated with the respiratory events.

G. MUSCLE ACTIVITY AND MOVEMENTS

Surface EMG is applied in lower extremities (anterior tibialis is the standard placement in our sleep center) and if PLMD is strongly suspected surface EMG is also applied in upper extremities (extensor digitorum) (39).

To diagnose PLMD, polysomnography must demonstrate repetitive, highly stereotyped limb movements (PLMD) with an index exceeding 5 per hour of sleep (40). Sleep disturbance and daytime somnolence has been reported in children and adolescents with moderate and severe PLMD (18, 41).

H. AUDIO-VIDEOTAPING

An important change associated with new technologies comes with the new recording systems that have, as a

standard feature, synchronized real-time video. This can provide adjunctive assessment on work of breathing, parasomnias including bruxism, night terrors or periodic movement disorders. It also may provide useful information in a child with rhythmic movements or nocturnal seizures (25). Co-sleeping and other parental interventions can be assessed. In infants, in whom distinction between eyes open *vs*. closed is essential for stage scoring (24), the video with zoom-in capability is beneficial.

I. BODY POSITION

Using a *body position sensor* and direct observation (video recording) provides a complete report of body position throughout the night of the study. There is no data to support significant relationship between sleep stages and sleep positions in any age category (42). In adults, sleep apnea is worse when the patient is in the supine position. In children, Fernandes do Prado and colleagues showed that pediatric patients with OSA had a lower obstructive apnea-hypopnea index (AHI) in the supine position (43). Similarly, Cuhadaroglu and collaborators found that AHI in the supine position was better in children with adenoidal hypertrophy but worse in children with adenotonsillar hypertrophy (44).

Multiple Sleep Latency Test

The *multiple sleep latency test (MSLT)* is used to assess daytime sleepiness. Eye movements, brain electrical activity, and muscle tone changes are recorded during 20 to 30 minute naps, spaced 2 hours apart. This test provides quantitative information about the degree of sleepiness (45) and sleep propensity (46) during the daytime. The time interval between "lights out" and sleep onset is defined as *sleep latency;* a *mean sleep latency* is derived from all the naps.

In children, sleep latency is age-dependent and the definition of *pathologic sleepiness* in children must account for this age dependency (47). PSG and MSLT remain the gold standard for making a definitive diagnosis of narcolepsy (48). Narcolepsy may mimic symptoms of OSA (nocturnal snoring and obesity). Importantly, excessive daytime sleepiness in children with OSA is an infrequent complaint but shortened sleep latencies occur in the MSLT (49).

Maintenance of wakefulness test (MWT*)* is another quantitative test to determine daytime sleepiness (45) but is not used in children because it has not been validated.

Investigational techniques:

A. PERIPHERAL ARTERIAL TONOMETRY

Peripheral arterial tonometry (PAT) is a sensitive measure of moment-to-moment changes in the sympathetic activity and reliably identifies arousals in adult subjects. Arousals are associated with increased sympathetic discharge, as evidenced by attenuations in PAT signal (secondary to peripheral vasoconstriction) (50).

We recently examined whether PAT events during sleep are associated with visually recognizable electroencephalographic arousals in children. Arousals in sleeping children were accompanied with sympathetic discharge evidenced by PAT attenuations; however, a significant number of PAT attenuations were not accompanied by visually defined EEG arousals. Furthermore, the significance of autonomic arousals has yet to be explored. At present, PAT signal measurements cannot be recommended as an alternative tool for assessing arousals in children (51).

B. PULSE TRANSIT TIME

The interval between the R-wave of the ECG and the arrival of the photoplethysmographic pulse at the finger is the *pulse transit time* (PTT).

The speed at which this arterial pressure wave travels is directly proportional to blood pressure and to arterial wall stiffness (52). The utility of the PTT as a diagnostic tool in SDB stems from alterations in blood pressure patterns associated with increased respiratory effort and respiratory arousal from sleep. In addition, arousal at the termination of an obstruction event leads to a marked, transient increase in blood pressure, resulting in a decrease in the PTT.

Thus PTT can be used to evaluate arousal from sleep. Katz et al. studied PTT as a measure of arousal and respiratory effort in children, and found that PTT arousals were a more sensitive measure of obstructive events than visible EEG arousals (53). Similar findings emphasizing the applicability of PTT to sleep monitoring in children have been recently reported (54).

Tips for successful pediatric polysomnography:

With the increasing recognition of pediatric sleep disorders, there is an evolving demand for pediatric sleep medicine services, including polysomnography. The procedure of polysomnography can be particularly challenging in young children with limited ability to cooperate, especially when they have developmental disabilities. The facility should have age appropriate and inviting décor and should comfortably accommodate a parent. The size of the bed should be age appropriate (crib for the baby, siderails for the toddler, appropriate bedcover designs for the teenager and the toddler). Personnel need to be patient and skilled in dealing with infants, children and adolescents.

A family-centered approach to PSG emphasizes respect for the family, psychological preparation, adaptation of laboratory routines to the needs of the family, substitution of child-friendly terminology for medical jargon, coping strategies for the child and family during the procedure (55). During sensor hook-up, comfortable positioning of the child, distraction and play, modeling behavior for the parent, and continuous praise and reassurance for the child go a long way in eliciting cooperation and mitigating anxiety.

Practice points

- The demand for sleep laboratories oriented towards pediatric patients is growing rapidly.
- The laboratory needs to be designed in a child-friendly fashion and be staffed by technicians who are comfortable and patient with children including children with special needs.
- Room for an extra bed for the accompanying adult is essential.
- Redundancy in monitoring techniques will optimize the odds of obtaining meaningful data even in the most difficult child.
- Nasal pressure flow transducer and capnography are an essential part of the polysomnogram.
- The sleep clinician caring for children needs to be aware of EEG maturational patterns and peculiarities of staging and scoring techniques for the infant and older child.

Suggested readings

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