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Basic technical requirement for paediatric sleep PSG

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Introduction

With the significant and long term detrimental effects of paediatric obstructive sleep disordered breathing gaining increasing recognition, sleep polysomnography (PSG) is becoming a common investigation. The American Thoracic Society (ATS) recommended an attended overnight full polysomnography (PSG) for general monitoring, diagnostic evaluation and management of sleep-related breathing disorders.[1] A standard full PSG simultaneously records various physiologic variables during sleep[2] including electroencephalogram (EEG), electrocardiogram (ECG), oro-nasal flow sensor, respiratory effort, oxygen saturation (SpO_2), snoring microphone, body position, leg movements and video recording. Ancillary equipment can be added if there are other indications. Individual sleep laboratory usually has its own protocol and uses various polysomnographic parameters to evaluate patients' cardiopulmonary function during sleep.

Polysomnography recording standard

Digital sleep monitoring system is used in the recording of PSG. The recommended standard speed is 10 mm/second. Each epoch length is 300 mm wide or 30 seconds. A minimal deflection of 10 mm for a 50 microvolt signal is recommended. Moreover, each montage should have its own filters and sensitivity settings. The notch filter (50 Hz or 60 Hz) eliminates the artifact generated from the main power supply although the epileptiform spikes will be heavily dampened or lost. Thus it is better avoided unless there is significant problem with the 50-60 Hz interference. The impedance should be kept at less than 5 k ohms in all recording parameters to minimise serial signal loss.

Sleep parameters

Electroencephalogram (EEG), electrooculogram (EOG) and electromyographic (EMG) are used to score sleep stages and arousals. EEG electrodes are placed according to the International 10-20 Electrodes Placement System. The monopolar derivation channels C3/A2, C4/A1, O1/A2 and O2/A1 are the commonest montages to record and monitor sleep stages.[3] Scoring of sleep stages should always be based on C4/A1 or C3/A2 EEG tracing, and O1/A2 or O2/A1 EEG tracing is for identifying of sleep onset and arousals. Gold-plated cup electrodes are used in EEG, EOG and EMG. During EEG hook-up procedure, technician should use skin scrub to remove dirt and oily substance from the scalp. The electrodes are filled with conductive paste and applied to the scalp using small pieces of conductive paste gauze to hold the electrodes in place, and seal them from the air. Skin preparation is very important because this helps to reduce the impedance and ensure satisfactory EEG signal quality. Electrodes can be removed easily by warm water at the end of the study.

The EOG records eye movements from at least two channels. Electrodes are placed near right and left lateral canthi. If one electrode is placed 1 cm above the right canthus, then the other electrode should be placed 1 cm lateral and 1 cm below the left canthus. In paediatric cases, the placement of EOG electrodes can be adjusted in proportion to the size of their faces. Due to the corneo-retinal potential difference, the out-of-phase pattern will be shown in the EOG tracings during eye movement.

Chin electromyogram (EMG) records submental and masseter muscles activity. Muscle tone is at the lowest during rapid eye movement (REM) sleep. Hence, chin EMG suppression can help in differentiating REM sleep from other sleep stages.

There are specific filters and recommended sensitivity settings for EEG, EOG and chin EMG. The low frequency filter (LFF) is usually set at 0. 3 Hz and the high frequency filter (HFF) at 35 Hz for EEG and EOG. They have the same filter settings because both signals lie between 0.5 Hz to 35 Hz. On the other hand, the chin EMG signal is in between 20 Hz to 200 Hz, thus the LFF is usually set at 10 Hz and 90 Hz for HFF. The sensitivity setting of EEG is 50 uV/cm for adult and 100 uV/cm for child because the amplitude of EEG signal in children is higher than adult.

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Electrocardiogram (ECG)

ECG is used to monitor heart rate and rhythm in PSG. A three-lead standard placement is employed. It is useful in assessing consequences of the breathing disturbance.[4]

Snoring microphone

A microphone sensor is attached on the skin surface over the trachea. This records the breathing sounds and snoring. It can measure the intensity of snoring and provides a semi-quantitative signal.

Respiratory parameters

Both airflow and respiratory effort should be assessed by quantitative, semi-quantitative and/or qualitative methods.[4] Respiratory parameters monitor patient's ventilation, help to distinguish the different types of sleep apnoea and to evaluate the consequences of sleep-disordered breathing.[4] The filter settings for respiratory parameters are 0.1 Hz for LFF and 10 Hz. for HFF and the sensitivity is set as 50 uV/cm.

Airflow

Oro-nasal flow could be measured by pneumo-tachograph. This is the 'gold standard' for measuring airflow. By using a flow sensor which connects to the oro-nasal mask or tracheostomy tube it provides a direct and quantitative method to measure airflow and tidal volume.[4] However it is an inconvenient method and is usually used in research settings.[5]

Nasal pressure flow measurement is a non-invasive, sensitive alternative in routine clinical setting.[6] It provides a semi-quantitative nasal airflow signals. The nasal cannulae are connected to a pressure transducer. The nasal pressure flow signal derives from the change in the flow pressure at the nares. This method is accurate and more sensitive in detecting flow limitation when using a DC amplifier with no LFF and HFF set at 30 Hz.[6] However, this does not pick up the oral flow signal. Hence, it should be used together with oral thermistor. Moreover, the nasal cannula has to be placed properly and maintained patent to ensure good signal quality.

Oro-nasal thermistor or thermocouple is commonly used as airflow sensor in sleep laboratories. These sensors are easy to use and apply. The airflow signal comes from the temperature differences between inspiration and expiration. It is a qualitative method to measure airflow and identify apnoea. However, the airflow signal from thermistor or thermocouple does not directly correlate to the change in tidal volume; hence these devices are unable to measure the oro-nasal flow accurately, especially to detect hypopnoea [4-6]. Measuring the oral and nasal flow separately and show in two different channels in the PSG recording is preferable. Absence of nasal flow and exclusive oral breathing are abnormal.[4]

Respiratory effort

Measurement of respiratory effort can be carried out in a variety of ways. The asynchronous movement of chest and abdomen suggests paradoxical breathing in obstructive apnoea or hypoventilation though this is normally seen in infant's active sleep.[4] Respiratory inductive plethysmography (RIP), piezo-electric crystal belt and diaphragmatic EMG are employed to monitor respiratory effort during sleep.

In RIP, elasticised chest and abdominal bands are used. The principle of RIP is to measure and summate the changes in thoracic and abdominal cross-sectional area. The changes in the cross section area provide a semi-quantitative method to measure airflow and tidal volume after calibration.[4] This measurement method is sensitive in detecting obstructive apnoea and partial airway obstruction.[4,5] However, the RIP signal can be inaccurate when the position of the bands shifts from the original position.[4,5] The attending technician must pay special attention to this.[4]

For Piezo-electric crystal belt, it produces voltage in response to chest and abdominal expansion. This is a semi-quantitative measurement in monitoring respiratory effort.[5]

The diaphragmatic EMG measures the neural activation of respiratory muscles directly during expansion of the chest wall. To monitor diaphragmatic EMG, two electrodes are placed on the skin under the right or left side of the diaphragm. The problem of monitoring diaphragmatic EMG is the difficulty in getting rid of ECG artifact from the tracing.

Gas exchange

Simultaneous measurement of oxygen and carbon

dioxide levels in blood is very important in monitoring breathing disturbance. ATS[4] suggested that measurement of CO_2 level should be included, especially in paediatric patients and neuromuscular cases. CO_2 level is an indicator of alveolar hypo-ventilation syndrome in children.[4]

Pulse oximeter is widely used in sleep laboratories because it provides noninvasive and continuous measurement of SpO_2.[4] Sensor probe usually is attached to earlobe or digit and measures the peripheral oxygenation. Pulse oximeter should have an analog output of pulse waveform signal which can be interfaced to PSG machine. Plethysmographic waveform is very useful to distinguish true desaturation because diminished amplitude of pulse waveform is an indicator of low signal strength and false desaturation.[4]

End-tidal CO_2 ($ETCO_2$) is commonly employed in paediatric PSG recording. Patient puts on the nasal cannulae connected to $ETCO_2$ monitor. The monitor measures the CO_2 level during inhalation and exhalation. The $ETCO_2$ value is reliable if the cannula is patent and in appropriate position. The plateau $ETCO_2$ value may demonstrate a reliable and good signal for arterial CO_2 reading.[4] Furthermore, the tracing of $ETCO_2$ value is also the signal of nasal flow.

Transcutaneous oxygen tension monitoring (PtO_2) is not routinely used in overnight PSG recording because of the slow response time in detecting transient changes in oxygenation.[4] The PtO_2 value may not be reliable in older or obese patients. Moreover, the location of heated sensor probe has to be changed every 3-4 hours to prevent skin burn, thus patient's natural sleep will be disrupted.

The principle and method of measuring transcutaneous CO_2 ($TcCO_2$) is similar to transcutaneous oxygen tension monitoring. $TcCO_2$ values will not reflect transient changes in $PaCO_2$ and actual arterial CO_2 level.[4] Reposition of heated probe sensor every 3-4 hours is also needed.

Limbs movements

Leg EMG is included in PSG recording. Leg movement sensors or electrodes are placed over the right and left anterior tibialis region.[4] This montage monitors excessive leg movements or leg jerks.

Body position

The body position sensor is attached to the thoracic sensor belt to detect and monitor body position changes. The severity of obstructive apnoea is associated with body position, for instance, more obstructive apnoea occur in supine position.

Audio-video recording

Digital display audio-visual system can be interfaced to PSG machine, therefore the video playing is in synchrony with PSG acquisition. The audio-video recording system is helpful in correlating the findings of PSG recording (e.g. snoring, paradoxical breathing or seizure) and patient's abnormal sleep behaviour (e.g. sleepwalking).

Other parameters in PSG recording

Oesophageal pressure is the 'gold standard' for respiratory effort measurement. Quantitative and reliable signal is obtained by assessing the pleural pressure.[5] Water filled method is used in this department. A French 5 or 6 infant feeding is inserted to mid-oesophageal level and connected to a pressure transducer to obtain the tracing. Adults may use balloon catheter or pressure sensor probe. Calibration must be performed. The drawback of this is its invasive nature.

Oesophageal pH is another parameter that can be studied in PSG. The insertion of pH probe is again an invasive procedure. Calibration of pH probe and pH meter is needed before insertion.

Criteria for an acceptable PSG

ATS[4] recommended that a single overnight sleep study is sufficient to rule out sleep disorder breathing (SDB) in children. However, the total sleep time (TST) of the overnight sleep study should be more than 5 hours, and sleep efficiency greater than 85%. Also, the child should have REM sleep >15% of TST.[7] If the first study does not reflect the child's typical sleep and respiratory patterns, repeated sleep study is needed [4]. Scoring of sleep stages are summarised in Table 1 and Table 2.

Table 1. EEG characteristics of sleep[8]

Alpha: Sequence of waves with a frequency of 8-13 Hz.

Theta: With a frequency of 4-8 Hz

Vertex sharp transient: Negative deflection upward, and then follow up a positive deflection downward with 0.5 sec. Highest amplitude could greater than 200 mv, and at least 75 mv.

Sleep spindles: With a frequency of 12-14 Hz, and the duration of the waveform should at least 0.5 sec.

K complexes: A well-delineated negative sharp wave which is immediately followed by a positive component. The waveform duration is at least 0.5 sec without amplitude limited.

Delta: With a frequency of less than 2 Hz, and have amplitude greater than 75 mv from peak to peak.

Table 2. Sleep stages[8]

Stage wake: EEG tracing with alpha activity more than half epoch and shows rapid eye movements or eye blinking in EOG tracing. Chin EMG level is high.

Stage 1: A relatively low voltage, mixed frequency EEG and theta activity. Vertex sharp transient may occur. Slow rolling eye movements show in EOG tracing. EMG level is usually below than awake.

Stage 2: Presence of sleep spindles and K complexes, without any eye movements.

Stage 3: At least 20% but not more than 50% of the epoch consists of delta wave.

Stage 4: More than 50% of the epoch consists of delta wave. Mostly EOG tracing will pick up EEG waveform.

Stage REM: Appearance of low voltage, mixed frequency EEG and with rapid eye movements (REMs) on EOG tracing. 'Sawtooth waves' appear along with burst of REMs. Muscle tone reaches the lowest level when compared with other sleep stages.

Conclusion

Various methods and parameters are available to monitor cardio-pulmonary function of patients during sleep. Each measuring method has its pros and cons, hence choosing suitable recording parameters are important. The international criteria and standards of performing PSG should be followed to ensure the quality of recording and allow comparison between laboratories.

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