Nocturnal hypoxemia and hypercapnia in children with neuromuscular disorders

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Material and methods

Lung function and respiratory muscle tests

The study was performed at the end of the morning or in the beginning of the afternoon and started with the determination of breathing pattern. The patient remained in the sitting position and breathed room air for almost 2 minutes to achieve a steady state for end tidal carbon dioxide. Breathing pattern was determined from flow tracing, measured by a pneumotachograph (Fleisch # 3, Lausanne, Switzerland) which was attached to a mouthpiece. Tidal volume (V_T) was expressed in ml/kg and minute ventilation (V_E) in L/min and the ratio of breathing rate to V_T (f_R/V_T) was calculated.

After a period of rest, capillary arterial blood gases with pH were first determined [1]. Then functional residual capacity was measured by the helium dilution technique (FRCHe). Thereafter, the patient was asked to perform at least 3 physician-accepted forced vital capacity (FVC) curves and the curve with the highest FVC was used for the analysis [2, 3]. Maximal static inspiratory (Pimax) and expiratory (Pemax) pressures were measured from FRC and total lung capacity, respectively. Patients were asked to perform at least 3 measurements until two reproducible maximal values were obtained. The best value was retained for analysis and the mean value that could be maintained for one second was calculated [4].

In order to determine the strength of the inspiratory muscles, the patient was asked to perform at least 10 to 20 short, sharp maximal sniffs and the maximum sniff nasal inspiratory pressure (SNIP) was recorded [5].

Afterwards, an oesogastric catheter was inserted pernasally after careful local anesthesia (lidocaine 2%, Astra Zeneca, Rueil-Malmaison, France). This 2.1 mm external diameter catheter mounted pressure transducer system has two integral transducers mounted 5 (for the gastric pressure, Pgas) and 35 cm (for the oesophageal pressure, Pes) from the distal tip (Gaeltec, Dunvegan, Isle of Skye, UK). This catheter was advanced gently until the distal tip was in the stomach and the proximal pressure transducer in the middle portion of the oesophagus. Appropriate placement of the Pes transducer was assessed with the usual method [6]. Pdi was obtained by subtracting on line the Pes signal from the Pgas signal.

During quiet breathing, paradoxal breathing was assessed by calculating the ratio of the Pgas swing to the Pdi swing (ΔPgas/ΔPdi), which is an index that reflects the relative contribution of the diaphragm to tidal breathing [7]. A negative ΔPgas/ΔPdi signifies paradoxical movement of the diaphragm.

The patient's inspiratory effort during quiet breathing was assessed by measuring Pes and Pdi swings, and the oesophageal (PTPes) and diaphragmatic (PTPdi) pressure-time products. The PTPes product by breath (PTPes/breath) was obtained by measuring the area under Pes signal between the onset of inspiratory effort and the end of inspiration, and was referred to the chest wall static recoil pressure-time relationship according to a methodology adapted from Sassoon and colleagues [8]. The PTPdi/breath was obtained by measuring the area under the Pdi signal from the onset of its positive deflection to the end of inspiratory flow. Both PTPes and PTPdi were also expressed per minute (PTPes/min and PTPdi/min) by multiplying the pressure-time products per breaths by the breathing frequency, values in healthy adults being around 100 $cmH_2O.s.min^{-1}$ [9].

Finally, dynamic lung compliance ($C_L$dyn) was measured during quiet breathing as previously described [10]. Inspiratory airway-lung resistance ($R_L$insp) was calculated according to the formula based on the technique of Mead and Whittenberger [11]: $R_L insp = [(Pes_0 - Pes - (V/C_L dyn)]/V'$ where Pes_0 is the Pes value at the start of inspiratory flow, V is the instantaneous volume of breath integrated from airflow, $C_L$dyn is the dynamic lung compliance calculated for the same breath, and V' is the instantaneous airflow. Mean values over the inspiration were used as estimates of $R_L$insp.

The strength of the inspiratory muscles was measured again by asking the patient to perform the sniff maneuver but this time, maximal Sniff Pes and Sniff Pdi were measured. The strength of the expiratory muscles was measured by asking the patient to perform a maximal cough. The peak Pgas value of at least 5 maximal coughs was measured (Pgas cough) [12].

The diaphragmatic tension time index (TTdi), which estimates the endurance of the diaphragm, was calculated during quiet breathing as TTdi = (Pdi/Sniff Pdi) x Ti/Ttot, where Pdi is the mean Pdi during spontaneous breathing, Sniff Pdi the maximal Pdi during a sniff, and Ttot total breath time [13]. The oesophageal tension time index (TTes), which estimates the overall endurance of the inspiratory muscles, was calculated as TTes = (Pes/Sniff Pes) x Ti/Ttot where Pes is the mean Pes during spontaneous breathing and Sniff Pes the maximal Pes during a sniff [13].

Overnight pulse oximetry and transcutaneous carbon dioxide recording

An overnight pulse oximetry (SpO_2) and transcutaneous carbon dioxide ($PtcCO_2$) recording was performed in room air by the combined SenTec Digital Monitor using the V-SignTM Sensor (SenTec AG, Therwil, Switzerland) which has been validated in our laboratory [14]. The following data were extracted from the SenTec Digital Monitor: mean and minimal SpO_2, number of desaturations ≥ 4%/hour of recording, percentage of total nighttime spent with a SpO_2 < 90%, mean and maximum $PtcCO_2$, and percentage of total nighttime spent with $PtcCO_2$ > 50 mmHg. Nocturnal hypoxemia was defined by a minimal SpO_2 <90% for at least 2% of sleep time [15] and nocturnal hypercapnia was defined by a maximal $PtcCO_2$ value >50 mmHg for at least 2% of sleep time [16].

Polysomnography

Polysomnography (PSG) was performed in room air [17]. Obstructive apnea was defined as a drop in thermal sensor amplitude by ≥ 90% of baseline for at least 2 respiratory cycles, with continued or increased inspiratory effort during reduced airflow. Central apnea was defined as a drop in thermal sensor amplitude by ≥ 90% of baseline in absence of inspiratory effort, either with a duration ≥ 20 sec or at least 2 missed breaths and associated with arousal, awakening or ≥ 3% desaturation. Mixed apnea was defined as a drop in thermal sensor amplitude by ≥ 90% of baseline for at least 2 respiratory cycles with the absent inspiratory effort initially, then resumption of effort during latter part of event. Hypopnea was defined as a drop in nasal air pressure transducer amplitude by ≥ 50% for a duration ≥ 2 missed breaths, associated with arousal, awakening or ≥ 3% desaturation [18, 19]. Apnea-hypopnea index (AHI) was calculated as the sum of apnea and hypopnea events per hour of total sleep.

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