Detection of Central and Obstructive Sleep Apnea in Children using Pulse Transit Time

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Abstract

Aim of this study was to validate the use of pulse transit time (PTT) as a method to monitor sleep apnea in children. PTT was estimated as the interval between the ECG R-wave and the point at which the pulse wave at the finger reached 50% amplitude.

First, we assessed changes in the PTT during breathing against known resistances in 15 awake children; resistance was applied with a modified nose and mouth two-way non rebreathing face mask, having the inhalation valve port fitted with drilled plastic cylinders of various diameters.

Second, we analyzed 20 events of obstructive apnea and 90 events of central apnea during sleep in 10 children.

Our data showed a good correlation between the inspiratory effort and the PTT oscillations amplitude. In addition PTT oscillations amplitude tuned out to successfully discriminate central from obstructive apnea.

1. Introduction

Monitoring of respiratory effort during sleep plays an important role in polysomnographic studies, since increased upper airway resistance causes sleep fragmentation and daytime symptoms [1-3].

Respiratory effort is usually assessed by measuring changes in endoesophageal pressure (Pes) through an endoesophageal balloon catheter [4]. This technique has several disadvantages: first it causes some discomfort and can lead to fragmentary sleep [5][6]; second, the presence of the esophageal monitor can alter the normal respiratory pattern in children during sleep [7].

Recently a noninvasive method for measuring respiratory effort has been proposed. It is based on the estimation of the pulse transit time (PTT), the time needed for the pulse wave to travel from the aortic valve to the periphery, estimated as the delay between the R-wave in the ECG and the arrival of the pulse wave at the finger as determined by pulse oxymetry [8] (figure 1).

It has been demonstrated that PTT oscillations yield a valid measure of inspiratory effort: a significant correlation of oscillations in endoesophageal pressure - induced by an episode of augmented airways resistance - and PTT oscillations between inspiration and expiration has been found in adults with obstructive sleep apnea syndrome [9].

From a physiological point of view, the PTT discloses acute changes in arterial pressure generated by increased oscillations in pleural pressure due to inspiratory effort induced by obstructive events.

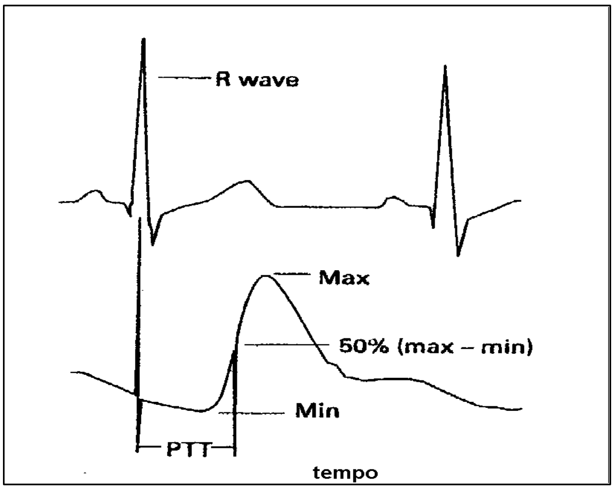

Figure 1. PTT estimation

These observations support PTT as an alternative to esophageal pressure measurement for quantitatively assessing inspiratory efforts in adults [10]. What is now lacking are data on the use of PTT in children. Our aim in this study was to validate the usefulness of PTT as a method for monitoring sleep apnea in children.

2. Methodology

2.1. Experimental protocols

In the first protocol we assessed changes in PTT during breathing against known resistances in 15 awake children (age range 5 to 12 years; mean age 8.3 ± 2.74, 9 boys). The children were selected among patients attending our pediatric service for routine assessment. Participants were tested in the supine position. Each child was fitted with a custom designed nasal and mouth two-way non rebreathing face mask (Series 7910 - Hans Rudolph Inc, Kansas City, Missouri - USA) modified to simulate an inspiratory effort. The inhalation valve port of the mask was adapted to lodge three small plastic cylinders (inner diameter 3, 5 and 8 mm). The openings were gauged to obtain respiratory resistances of 0.064 – 0.010 – and 0.008 mmHg/ml/s for inspiratory flows ranging from 50 to 250 ml/sec. No extra respiratory resistance was applied to the expiratory port. The mask was also equipped with a transducer for measuring negative pressure generated by inspiratory efforts (Figure 2).

After a 3-min trial to stabilize breathing at zero resistance (baseline), the three progressive resistance levels were applied to the inspiratory port, allowing 3 minutes for each trial and a 2-min recovery period with zero resistance between each trial. Subjects were asked to breathe normally through the nose, to relax and to remain still during measurement. Before starting the protocol, all the children received a short training session. To make sure that sequence had no effect on measurements, resistances were applied in random order.

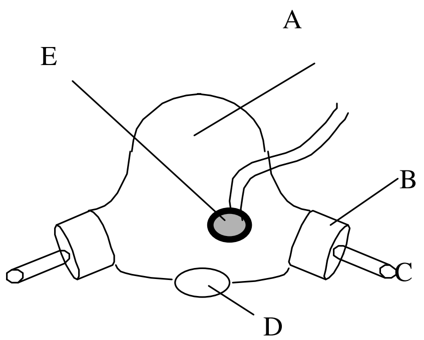

Figure 2. (A) Face mask. (B) The inhalation valve port (B), adapted to lodge small plastic cylinders (C). (D) The expiratory port with no extra respiratory resistance. (E) Transducer for measuring negative pressure generated by inspiratory efforts.

In the second protocol, we analyzed episodes of either central or obstructive apnoeas from 10 children undergoing complete polysomnografic investigation. The episodes were selected by a trained operator by manual scoring of oronasal, thoracic and abdominal traces.

In both protocols, the physiological variables were recorded with a Grass multi-channel instrument (Model Heritage Grass Instruments, Quincy, Mass, USA) and sampled at 250 Hz. Polygraphic data included electrocardiogram (II Lead); arterial blood oxyhemoglobin saturation (SaO_2) and pulse-wave (PW) recorded with a pulse oximeter (NELCOR NPB290) at the finger, mask pressure (only for the first protocol), and abdominal and chest movements (by inductive plethysmography). In the full polysomnographic recordings (second protocol), oronasal flow, abdominal and chest movements, EEG and EOG were also recorded.

2.2. PTT estimation

Data were digitally acquired and transferred to a personal computer. PTT was calculated with a software custom designed in our laboratory. R-waves were detected according to the methods of Pan and Tompkins [11]. Parabolic interpolation of QRS was used to refine the R-wave detection. After the R-wave had been detected the relative minimum and maximum of the PW were identified in the same beat.

PTT was calculated as the interval between the ECG R-wave and the point at which the PW reached 50% amplitude (PW maximum – PW minimum).

We also calculated the amplitude of PTT oscillations (ΔPTT) as suggested by Pitson et al. [12]. The ΔPTT was calculated as the difference between the maximum and minimum PTT values within the same respiratory cycle (Figure 3).

The maximum and minimum PTT were detected manually for every respiratory cycle. For each breathing cycle we also measured the maximal intra-mask pressure drop (Pdrop).

For each subject we analyzed 16 consecutive breaths from the second and third minute of each 3-min breathing trial at baseline and against resistance. We calculated the average ΔPTT and Pdrop over 16 consecutive breaths, for each resistance.

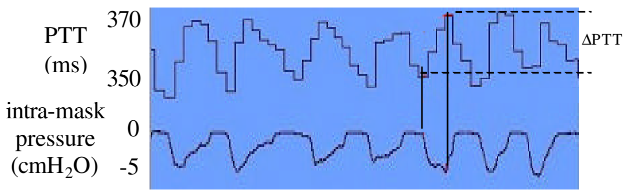

Figure 3. ΔPTT estimation

3. Results

Of the 15 participants selected for the first protocol, 13 children completed the trial and two failed because of poor compliance with the procedure.

The various resistances applied left the mean, maximum and minimum PTT values substantially unchanged. As the applied inspiratory resistance increased, the mean ΔPTT increased significantly (from 11.13 ± 1.41 at zero resistance to 21.02 ± 3.10 at maximum; ANOVA Friedman p <0.05; figure 4).

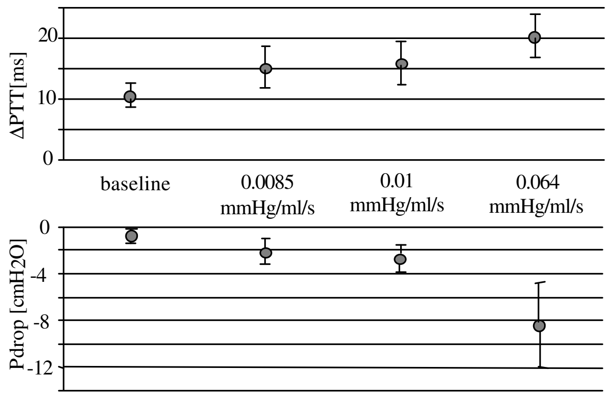

Figure 4. ΔPTT (top) and Pdrop (bottom) averaged all over the population during baseline, and during the application of the inspiratory resistances (0.0085, 0.01, and 0.064mm Hg/ml/sec).

A positive logarithmic correlation was found (R^2 = 0.544) between Pdrop values and ΔPTT values (figure 5).

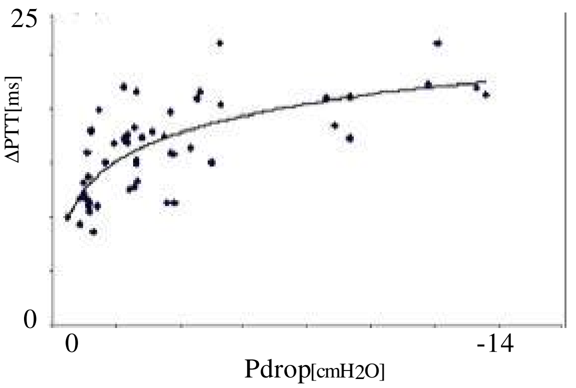

Figure 5. Positive logarithmic correlation (R^2 = 0.544) between Pdrop values and ΔPTT values.

From the polysomnographic data of the 10 children analyzed during sleep, we extracted 20 events of obstructive apnea and 90 events of central apnea. We found that mean PTT values do not significantly changed between central and obtructive apnea, while ΔPTT values during obstrutive apnea was significantly higher than that obtained from central apnea (p<0.001, Mann-Whitney U-test for unpair data; figure 6).

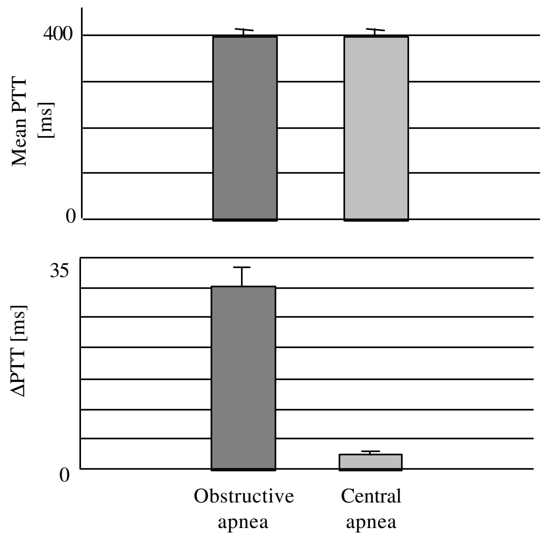

Figure 6. Mean PTT (top) and ΔPTT values obtained during obstructive (dark grey) and central (light grey) episodes, averaged all over the analyzed events (mean±standard deviation).

4. Discussion

The results obtained in this study indicate that PTT is a sensitive descriptor of inspiratory effort in awake children, and thus represents a valid noninvasive alternative to the endoesophageal balloon technique for measuring inspiratory effort. Our data show a good correlation between the induced inspiratory effort and ΔPTT values. Slight pressure falls in the mask (-8.31 ± 3.35 cmH_2O) induced important changes in mean ΔPTT values from baseline (11.13 ± 1.41 vs 21.02 ± 3; p< 0.001). ΔPTT also increased significantly already at a Pdrop of about -1 cm H_2O (Pdrop from -1.10 ± 0.31 to -2.42 ± 0.75 cmH_2O; p <0.001 - ΔPTT from 11.13 ± 1.41 to 15.82 ±2.90; p<0.001). This finding shows that ΔPTT is a sensitive indicator capable of describing even small changes in inspiratory effort.

Another interesting finding is that as the pressure exerted on the respiratory airways increased, ΔPTT increased not linearly but in a logarithmic manner thus tending to saturate. This behavior may have arisen from several cardiovascular factors, mostly unknown, such as elasticity and compliance of the arterial vascular tree. These factors may prevent the pulse-wave transit velocity from increasing or slowing down beyond a certain limit.

We also found that ΔPTT values are capable to discriminate central from obstructive apnea. This latter result is consistent with the different mechanisms involved in central and obstructive apneas: in central apnoeas, no stimulus to the respiratory muscles is generated and no changes in pleural pressure occur.

Conversely, obstructive apneas cause large swings in pleural pressure, producing oscillations in blood pressure detected by PTT. This finding suggests that ΔPTT measurement could have a clinical application also in polysomnographic studies to monitor sleep apnea in children, helping in simplifying portable polysomnographic systems.

For this clinical application an automatic method for assessing ΔPTT has to be developed. In our study we manually calculated the ΔPTT from visual scoring of the signals. Future works will deal with the development and the evolution of an automatic method for ΔPTT assessment in central and obstructive apnea.

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