ORIGINAL ARTICLES

Detection of Apneas in Infants During Sleep: A Study Comparing Thoracic Impedance and Inductive Plethysmography

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To compare the reliability of two techniques (thoracic impedance and inductive plethysmography) commonly used to assess respiratory move-ments in infancy. Whole night polysomnographic studies were performed in 52 infants (30 females, 22 males, median postnatal age 15.1 weeks) with simultaneous recordings of respiratory movements by thoracic impedance (TI) and inductive plethysmography (IP), of oxygen saturation, transcutaneous and endexpiratory CO2, ECG, EEG, EMG, EOG, and actimetry. Each test was divided into 10-minute intervals for statistical evaluation. After manual evaluation of all respiratory events shown, occurrence rates of false positive and false negative apnea detection by each system were compared. Median apnea frequency was 19.1 per hour of total sleep time (predominantly central apnea with a significant drop after the first trimenon). The 99.5% of all apneas were correctly detected by IP, 98.9% by TI (difference not significant). There were considerably more false positive results of IP than of TI recordings (in 7.9 % vs. 4.4% of all 10-minute time periods). Both thoracic impedance and inductive plethysmography are suitable for monitoring of respiratory movement in infancy. We recommend TI for surveillance of high-risk patients, while IP remains a suitable screening method. Simultaneous use of both methods may assist to solve differential diagnostic problems in the pediatric sleep laboratory. (Sleep and Hypnosis 2001;3(2):62-67)

Key words: polysomnography, respiratory movement, thoracic impedance, inductive plethysmography, reliability, sudden infant death

INTRODUCTION

Breathing disorders of different etiologies are frequent problems in neonatal intensive care, but also in hospital and outpatient treatment of small infants. Thus, there is a great need for secure and practicable assessment of infants' respiratory movements and detection of apneas. Current measurement techniques for this purpose include piezo elements, infra red sensors, pneumatic elements, thoracic impedance pneumography, and respiratory inductive plethysmography (1-4). In different stages of infant development, registration of in- and expiratory movements is greatly disturbed by artifacts. Apparently, thoracic impedance (TI) and inductive plethysmography (IP) are the two predominant techniques for measurement of respiratory movements during infancy (5-7). The aim of this study is to test and compare the signal reliability of the two methods. As reference values we used all simultaneous recorded parameters of the polysomnography to objective both methods. From the results, we derived recommendations for respiratory monitoring and detection of apneas during the first year of life.

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METHODS

Results from polysomnographic (PSG) studies in 52 infants were evalu-ated with the aid of statistical frequency analysis. PSG was performed in healthy infants as part of a campaign to prevent Sudden Infant Death (SID), in preterm babies suffering from bronchopulmonary dysplasia (BPD), and in infants without clinical signs of illness but with breathing abnormalities observed by their parents at home, including apparent life threatening events (ALTE). Table 1 summarizes the patients history and indications for polysomnography.

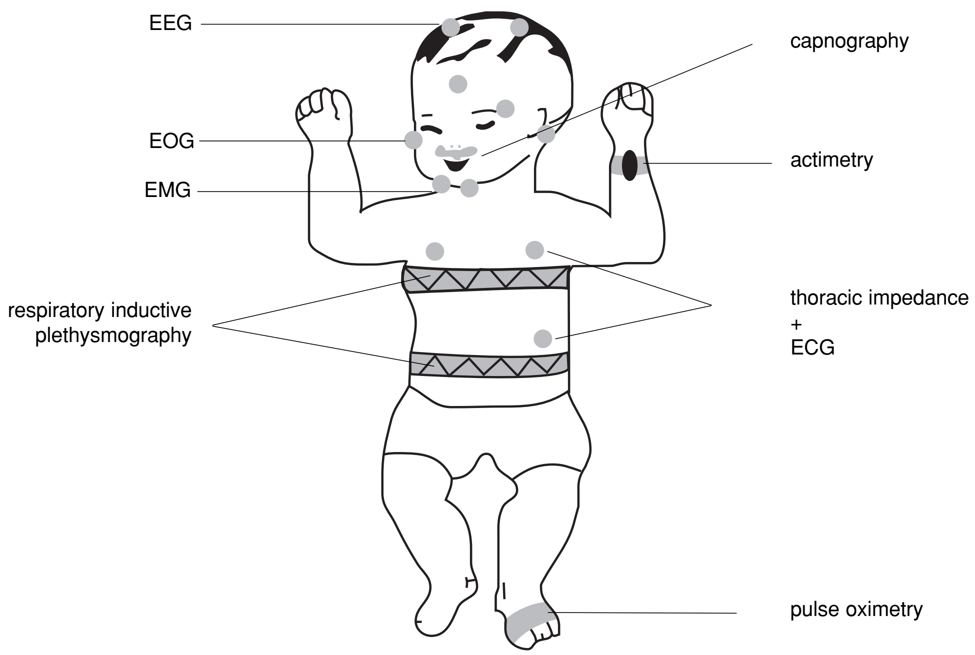
Table 1. Indications for complete PSG with simultaneous recording of respiratory movements by thoracic impedance (TI) and respi-ratory inductive plethysmography (IP)

Indication group	n
SID prevention questionnaire	34 (12 preterms)
Follow-up in known apnea syndrome	9 (5 preterms)
Clinical suspicion of apnea syndrome	4 (1 twin from SID victim)
Apnea due to other diseases	5 *

*(post pneumonia, 1; post asphyxia, 1; BPD, 1; anemia, 1; post laparotomy and long-term artificial ventilation, 1)

a whole-night PSG study was started, usually between 8.00 and 9.00 p.m. The environment of the sleeping laboratory was adjusted to the special needs of pediatric patients. Thoracic impedance was measured with a commercially available cardiorespiratory monitor (Smartmonitor™ 900, Fa. Healthdyne Inc., USA). Respiratory in-ductive plethysmography with simultaneous recordings of thoracic and abdominal movements was performed with the Respitrace™ device, Fa. Ambulatory Monitoring Inc., USA (8-10). Apart from respiratory movement assessment, PSG studies included simultaneous recordings of electroencephalography (EEG: C3/A2, C4/A1), left and right electrooculo-graphy (EOG), submental electromyography (EMG), oxygen saturation (SaO_2) and pulse waveform by pulse oximetry, electrocardiography (ECG), endexpiratory CO_2 by capnography, transcutaneous pCO_2 measurement, and actimetry. All signals were recorded and processed by the polysomnographic system ALICE 3® version 1.20 Apreco©, Fa. Healthdyne Inc., U.S.A.. Figure 1 shows the placement of several polysomngraphic sensors.

Figure 1. Polysomnographic configuration used in this study. Standard monitoring of EEG, EOG, EMG, ECG, oxygen saturation, capnography, and actimetry is combined with simultaneous recording of respiratory movements by inductive plethysmography and thoracic impedance.



All patients were free of respiratory tract infections for at least one week at the time of examination. After placement of measurement electrodes by specially trained pediatric nurses, and individual infant's preparation for the night including feeding,

In order to enable the direct comparison between the two methods to register breathing movements, system configuration was adjusted to allow for parallel input of analogous signals from both respiratory thoracic impedance measurement (TI) and respiratory inductive plethysmography (IP), and thus simultaneous recording of respiratory movements assessed by both methods.

Raw data were divided into 10-minute intervals, and the numbers of respiratory abnormalities per time interval detected by TI and by IP were determined separately. Central apneas were defined as cessation of respiratory movement and air flow for at least three seconds, obstructive apneas as cessation of air flow with persisting breathing movements for at least three seconds, and mixed apneas as a combination of both patterns for at least five seconds.

All polysomnographic recordings were validated manually by one single experienced investigator. Using all PSG data, especially oxygen saturation, EEG, ECG, and actimeter recordings, the nature of the apparent breathing disorders was determined. The reference value results from the sum of all simultaneous detected parameters.

Comparison of manual and computed evaluation allowed to group respiratory events detected by TI as well as IP method into

1.true, objective apnea,
2.false positive apnea, and
3.false negative apnea.

Statistical analysis was performed using SPSS® Base 8.0 (SPSS Inc., USA). We compared the occurrence rates of false positive and negative apnea detection by each technique. Confidence intervals of the relative incidence were estimated according to Clopper and Pearson.

RESULTS

Polysomnographic analysis was performed in 52 infants (22 males, 30 females). Four had a central apnea syndrome, characterized by an elevation of apnea-hypopnoea-index and mean apnea duration, one infant displayed a significantly higher amount of periodic breathing than normal for his age. Direct comparison of thoracic impedance (TI) and inductive plethysmography (IP) showed a clear superiority of IP. In 94,2% of all investigations IP recognized detected apneas better than TI. The total sum of cor-rectly detected apneas was 99.5% for IP and 98.9% for TI, but this difference was not significant. False positive apnea detection, i.e. registration of apneas in spite of regular breathing, occurred less frequently when using TI. In 96.2% of cases, periods were found with more false positive readings by IP than by TI.

Regardless of the errors mentioned above, results in general are convincing. In 2,246 of 2,275 time intervals (98.75%), both methods detect apneas correctly if present. Table 2 and 3 show the false positive and false negativ apneas of both methods during all study time.

Table 2. Rate of false negative apneas detection of both methods

false negative detection of apneas		inductive plethysmography		thoracic impedance	
		incidence	percent, %	incidence	percent, %
valid					
	correct detected	2264	99,5	2248	98,2
	1 error	9	0,4	24	1,6
	2 errors	2	0,1	3	0,2
total		**2275**	**100**	**2275**	**100**

Table 3. Rate of false positive apneas detection of both methods

false negative detection of apneas	inductive plethysmography		thoracic impedance	
	incidence	percent, %	incidence	percent, %
non error	**2095**	**92**	**2174**	**95,6**
1 error	132	5,8	74	3,3
2 errors	33	1,5	22	0,9
3 errors	10	0,4	3	0,1
4 errors	2	0,1		
5 errors	1	0,1	2	0,1
6 errors	2	0,1	-	-
total	**2275**	**100**	**2275**	**100**

DISCUSSION

Respiratory disorders are the leading cause of morbidity in the first year of life. High incidences are known for respiratory distress syndrome in preterm babies, for central apneas in infants and upper and lower airway infections during the whole range of infancy. Breathing disorders are a common symptom in these diseases (11,12). A safe method for registration and evaluation of apneas is thus required for both inpatient and home monitoring of infants and toddlers affected. Because of the risk in acute respiratory diseases as bronchopneumonia or bronchiolitis, a highly sensitive method to monitor respiratory movements is needed. An artifact-free signal registration is necessary for diagnostic purposes, requiring a high specificity, if sleep-related breathing disorders are suspected (i.e. obstructive sleep apnea syndrome).

Assessment, evaluation, and differentiation of breathing regulation disturbances in infancy are highly dependent on signal reliability of the method chosen. The importance of signal interpretation is demonstrated in two examples. The area marked in Figure 2 was labeled as a central apnea by the automatic evaluation program. The apparent cessation of thoracic and abdominal movements recorded by IP was probably caused by a movement artifact. Specific filter settings of the analogue signal typically produce "clipped" curves which are falsely interpreted as apneas (13-15). Figure 3 shows a central apnea defined by cessation of air flow and thoracic and abdominal movements with a concomitant decrease in oxygen saturation down to 92%. The condition was correctly assessed by the system. However, continuos TI signals, probably of cardiac origin, falsely suggested continuing breathing efforts.

Figure 2. Inductive plethysmography recording wrongly suggestive of apnea (probably movement artefact).

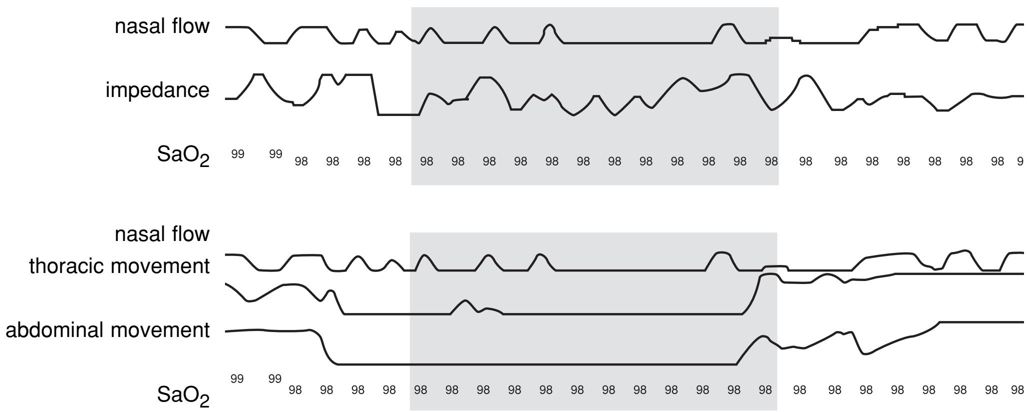
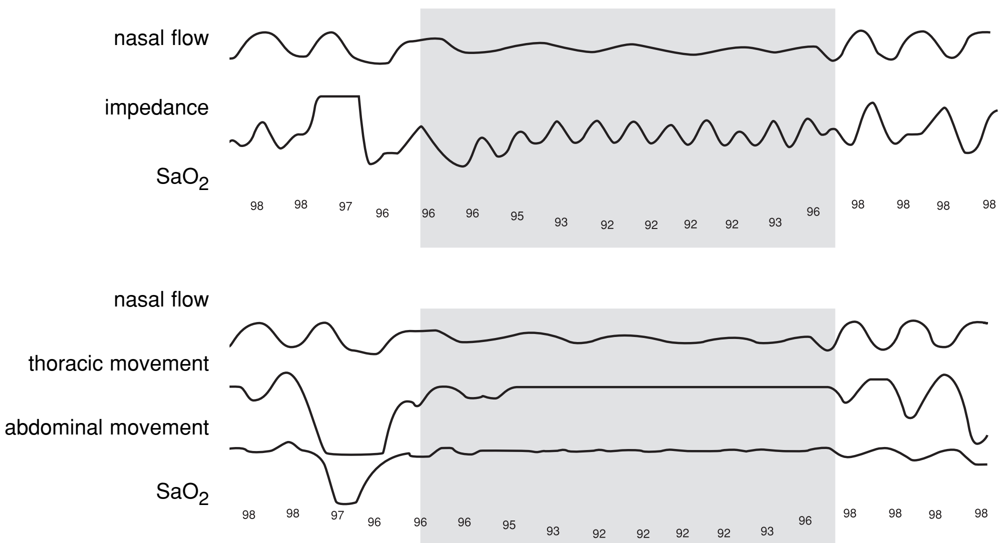


Figure 3. A true central apnea is correctly recorded by IP, while the TI sig-nal shows continuing waves of low amplitude probably caused by cardiac action. Placement of TI electrodes may have been inappropriate.



There is no simple answer to the question as to which is the better method to diagnose apneas in infancy. However, overall results of our study demonstrated a higher sensitivity for sleep apnea detection by IP than by TI. Relative frequency of apnea recognition (including central, obstructive, and mixed apneas) was 99.5% of total study time for IP and 98.9% for TI. The main cause of failure to detect some apneas by TI was a misinterpretation of cardiac artifacts as apparent breathing activity. Jeffrey et al and Wilson et al suggested several methods for filtering and reduction of cardiac artifacts but were unable to completely resolve the problem (7,16). Our findings support earlier results published by Brouilette and co-workers and Adams et al, who found a higher apnea detection rate through the inductive method as compared to impedance measurement (17-19). The first attempt to simultaneously use both techniques for PSG was reported by Brouilette. He studied 29 children with a median postnatal age of 41 months, including seven infants, during a mean time interval of 71 minutes. Sensitivity for appropriate registration of breathing move-ments was 99.6% for IP, and 98.3% for TI. Frequently, errors of the TI method were caused by impaired detection of obstructive apneas.

Several authors reported misinterpretations of obstructive apnea events by TI, an observation not supported by our results. All 228 obstructions registered had been recognized both by TI and IP. However, TI had substan-tial problems in differentiation of paradoxical breathing with inverse motion of ribcage and abdomen, and of "pressing", a common event in infancy resulting in a cessation of air flow. IP is definitely superior in recognition of these conditions, which was confirmed by Adams and co-workers in a study using simultaneous IP and TI recordings in 25 preterm babies (17). The quality of respiratory monitoring is not only determined by correct detection of real events but also by the rate of false alarms. A home monitor may be judged very safe if it reports every apnea, but may be rejected by parents if false alarms are common (20). Respiratory inductive plethysmography has advantages in recognizing true apnea but a significantly higher rate of false positive apnea registrations. In our study, false positive diagnosis of central apnea by IP occurred in 180 time intervals, by TI in 101 intervals. A better result for specificity of IP than for TI was seen in no more than 3.8% of all cases.

Several reasons may be responsible for false positive apnea diagno-sis. Technical errors, i.e. signal disturbances by electromagnetic interference, have to be considered as well as mistakes in handling, i.e. incorrect placement of the Respitrace“ strings. Initial calibration of the IP signal is important to prevent "clipping" of the respiration curves and to allow cor-rect differentiation between apnea and hypopnea (21).

CONCLUSION

Simultaneous recording of respiratory patterns by TI and IP and evaluation of possible breathing disorders in the light of other polysomnographic data enables us to directly compare the accuracy of both methods. Our data suggests a greater sensitivity but lower specificity of IP. There is no general answer to the question as to which method is preferable. The decision for the kind of respiratory movement monitoring depends on indication. For inpatient treatment of sick neonates and infants, TI provides sufficient. This fact is also proven by precise detection of apneas (>98%) with the TI. The impedance method is also widely used for home monitoring. Easy handling and the option of parallel ECG recording are valid reasons for TI. However, the incidence of false positive alarms is still too high, and continuing efforts to develop more efficient measurement techniques are necessary. Although the option to save data improves the possibility of retrospective analysis of events, it does not solve handling problems for parents. Impedance monitoring remains a suitable screening method for pre-ventive polysomnographic diagnostics. Apneas are recognized with 95% accuracy, and technical demands and costs are considerably lower than in respiratory inductive plethysmography. For differential diagnostic purposes in the pediatric sleep laboratory, IP is clearly superior. The simultaneous use of both methods in specialized institutions will achieve a detection rate for real apneas near 100% as well as a substantial reduction of false positive results.

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