The study was aimed at the assessment of the physiological range of $\phi$ and $T_{me}/T_e$ indices in children of up to 24 months of age, as based on noncalibrated respiratory inductive plethysmography performed in the supine position. We also examined the dependence of these indices on children’s age and sex. The study was carried out in 127 healthy children. The results of the study indicate a significant decrease of $\phi$ in children aged 7-24 months in comparison with children of up to 6 months of age ($P<0.001$). Similarly, values of $T_{me}/T_e$ were found significantly higher in the group of older children ($P<0.05$). We did not find any appreciable sex differences in both measured parameters. The results of this study suggest that the $T_{me}/T_e$ index might be more stable, less age-dependent parameter of the Respitrace measurement than the phase angle $\phi$, but further research and analysis to achieve a correct verdict are warranted.

**Keywords:** noncalibrated, respiratory inductive plethysmography, phase angle $\phi$, $T_{me}/T_e$ index

**INTRODUCTION**

Respiratory diseases represent a serious medical problem, especially in children in which these diseases occur relatively often, their course is severe and sequelae may influence respiratory function in adulthood. The literature shows that there is a proportional relationship between airway diseases up to first year of age and various respiratory complications in later age (1-3). Therefore, an early diagnosis of respiratory abnormalities and their treatment is the most measure in prevention later respiratory ailments. Rapid anatomical and
Functional changes of the respiratory system take place during the development of newborns and small children. Not only the airways grow, but pulmonary, interstitial, and smooth muscle tissues evolve and compliance of the thorax changes. The children are predisposed to airway obstructions (4, 5).

The use of pulmonary functions tests in pediatric clinics is limited, because cooperation of a patient is required, which is often impossible in small children. Therefore, during examination of children sedatives are sometimes necessary, which may influence respiration and, consequently, the results of measurement. Hence, new diagnostic methods, other than costly and complicated baby bodyplethysmography, forced oscillatory technique or rapid thoracoabdominal technique, are searched for the use in poorly cooperative children. The noncalibrated respiratory inductive plethysmography (Respitrace) seems to be one such suitable method. It is relatively simple and noninvasive. The principle of respiratory inductive plethysmography is based on the measurement of time-dependent changes of movements in the rib cage and abdominal musculature during breathing. These volume changes are registered as rib cage and abdominal curves, which, among others, allows assessing the synchronisms of the two compartments. Thoracoabdominal asynchrony is expressed as phase angle $\phi$ values and respiratory patterns are evaluated as $T_{me}/T_e$ index. Both were described previously as the best predictors of the extent of airway obstruction (6, 7). Unlike with other functional tests, the sedative treatment during examination of even smaller children up to 5 years of age is not necessary (8, 9).

In this study we attempted to establish the physiological values of phase angle $\phi$ and $T_{me}/T_e$ indices in healthy children of up to 24 month of age, as based on noncalibrated respiratory inductive plethysmography. The other objective of the study was to follow age and sex-dependent changes in the phase angle $\phi$ and $T_{me}/T_e$ indices.

MATERIAL AND METHODS

The study was approved by the Ethics Committee of the Jessenius Faculty of Medicine, Comenius University in Martin, Slovakia. A hundred and twenty seven healthy children of up to 24 months of age (mean age: 11.3 ±0.6SE months and mean weight: 10.8 ±0.4 kg), 81 boys and 46 girls, were included into the trial. Children were divided into 4 age-groups: up to 6 months (n = 41), 7-12 months (n = 34), 13-18 month (n = 28), 19-24 months (n = 24).

The following inclusion criteria were considered: negative family and personal history regarding allergies; normal course of pregnancy, birth, and the postpartum adapting period; none inborn pulmonary or cardiovascular abnormalities; a minimum time of one month between the examination and any acute inflammatory conditions; no medications that might influence respiratory function, and written informed consent of the parents.

All children examined were awake and were in the supine position (10). No sedatives were applied. A minimum time interval between food intake and the beginning of the investigation was 30 min. The only motion restrain the children had were two elastic Respitrace bands around the rib cage and abdominal regions.
A Respitrace (Studley Data Systems 150, U.K.) equipment for respiratory inductive plethysmography was used in this study. The principle of the system is based on the recordings of the time-dependent changes in the extent of movements during breathing using two elastic bands with inductive fibres collocated on the inner side (Respibands transducer, Ambulatory monitoring, USA): the upper (rib cage) is placed below the arms around the rib cage and sternum; and the lower (abdominal) placed around the umbilical region (11-13). The intensity of induction, proportional to thoracic and abdominal circumference changes during breathing is transmitted to analog-digital, two-channel data converter (Lungenfunktions messgerät, Germany). Data are next processed and archived in PC.

The following respiratory inductive parameters were evaluated in children: thoracoabdominal asynchrony (TAA) predictor, expressed as phase angle $\phi$ and $T_{me}/T_e$ indices. The phase angle $\phi$ was calculated from the phase difference between the rib cage and abdominal signals based on the Lissajous loop presentation described in x and y axis. The following mathematical functions for phase angle $\phi$ computation were used: $\sin \phi = m/s$ or $\phi = 180^\circ - u; u = m/s$. The value labeled as „m” represents distance of lissajous loop margins and „s” value represents the extent of lissajous loop in x axis (Fig. 1). Generally, the phase angle value increases when airways obstruction occurs. Another way to evaluate airway obstruction is the $T_{me}/T_e$ index. A total sum of abdominal and rib cage signals constitutes the “respiratory volume” curve and after differentiation “airflow” curve enabled us to calculate $T_{me}/T_e$ index (Fig. 2). This value, which decreases when airways obstruction occurs, represents the ratio of the time from the beginning to the maximum expiratory airflow ($T_{me}$) and total expiratory time ($T_e$).

Minimum 5 consecutive breathing cycles were regarded as acceptable for the appraisal of both parameters. The values of phase angle $\phi$ and $T_{me}/T_e$ indices were calculated in each breathing cycle and then averaged. Data are expressed as means ±SE. Significance of difference was statistically evaluated using a paired t-test. P<0.05 was considered as significant and labeled as follows in the graphs: P<0.05 (*) and P<0.001 (***)

![Fig. 1. Upper rpw - Rib cage and abdominal curves present in various types of respiratory pattern. In addition, phase difference and relationships between the phases are shown. Lower row - Lissajous loop presentation and calculated phase angle $\phi$ values.](image-url)
RESULTS

The values of the phase angle $\varphi$ (Fig. 3) and $T_{me}/T_e$ indices (Fig. 4) were significantly lower in the group of healthy 7-24 months old children than that in
children of up to 6 months of age (P<0.001). However, no significant differences were noted among the age-subgroups within the age of 7-24 months, i.e., 7-12, 13-18, and 19-24 months of age.

The results did not reveal any sex-dependent differences in phase angle $\phi$ and $T_{me}/T_e$ indices between girls and boys (Fig. 5) and (Fig. 6). Finally, the mean values of both parameters established for healthy children are shown in Table 1.

Table 1. Physiological values of phase angle $\phi$ and $T_{me}/T_e$ indices in age-groups of healthy children (means ±SE).

<table>
<thead>
<tr>
<th>Age (months)</th>
<th>Phase angle $\phi$</th>
<th>$T_{me}/T_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6</td>
<td>18.75 ±0.97°</td>
<td>0.44 ±0.008</td>
</tr>
<tr>
<td>7-12</td>
<td>11.61 ±0.56°</td>
<td>0.47 ±0.014</td>
</tr>
<tr>
<td>13-18</td>
<td>11.32 ±0.84°</td>
<td>0.48 ±0.013</td>
</tr>
<tr>
<td>19-24</td>
<td>10.80 ±0.93°</td>
<td>0.48 ±0.012</td>
</tr>
</tbody>
</table>
DISCUSSION

In this study we attempted to introduce respiratory inductive plethysmography as a method for the examination of pulmonary function in small, usually noncooperative, children. Thoracoabdominal asynchrony is considered in clinical practice as a predictor, which changes in proportion to, of airway obstruction (14, 15). Noninvasiveness, lack of the necessity to introduce sedatives or face mask during the examination, makes this method suitable for use in small children of 2-5 years of age (6, 7, 16).

The basic principle of respiratory inductive plethysmography is the measurement of phase relationships between thoracic and abdominal movements during breathing. Ideally, synchronous breathing is characterized by phase angle $\varphi = 0^\circ$ and a closed increasing Lissajous loop shape (17). Many pathological conditions, notably obstructive pulmonary diseases with increased intrapleural pressure, are accompanied by a phase disaliment and thoracoabdominal asynchrony. Augmented pulmonary resistance is linked to thoracoabdominal asynchrony (18, 19), open shape of the Lissajous loop, and an increased value of the phase angle $\varphi$. The paradoxical breathing means the maximally increased airway obstruction, when the phase angle $\varphi$ value is $180^\circ$ and a closed decreasing lissajous loop shape.

Apart from pathological conditions, thoracoabdominal asynchrony accompanies breathing pattern of premature newborns and it is considered as a normal, fleeting feature of REM sleeping in children. Attenuated tone of intercostal muscles triggers inward inspiratory thoracic and outward abdominal movements, which is the main reason for this phenomenon.

The physiological range of phase angle $\varphi$ values in children has by far been studied sporadically in the literature and by the use of other than noncalibrated respiratory inductive plethysmography methods that we employed in the present study. We found a similar range of phase angle $\varphi$ ($18.75 \pm 0.97^\circ$) in children of up to 6 month of age as that reported Allen et al (17). At older age, the value of the parameter decreased progressively, (7-12 months=$11.61 \pm 0.56^\circ$, 13-18 months=$11.32 \pm 0.84^\circ$, 19-24 months=$10.8 \pm 0.93^\circ$), which underscores its age dependence being due likely to changes in compliance of external thoracic structures developing with growth. The thorax becomes more rigid with increased age of children, which is expressed by stabilization of the phase angle $\varphi$ (20). Our results concerning the phase angle $\varphi$ are at variance with those published by Mayer et al (21). The discrepancy may stem from the fact that we examined younger children in the present study.

The other parameter, $T_{me}/T_e$ index, represents the ratio between the time necessary to reach maximum expiratory airflow and the total expiratory time (8). According to Martinez (9) and Morris et al (22), a decreased $T_{me}/T_e$ is often associated with lower airway diseases. Furthermore, these authors also showed a
correlation between the magnitude of $T_{me}/T_e$ index decline and a reduction in airflow; consequently, this parameter reflects increased airways resistance (23, 24).

Since the information regarding the physiological range of $T_{me}/T_e$ in healthy children is also scant, we decided to provide these data in the present study. The values obtained (0-6 months=0.44 ±0.008, 7-12 months=0.47 ±0.014, 13-18 months=0.48 ±0.013, 19-24 months=0.48 ±0.012) also seem age-dependent, although, as opposed to the phase angle $\varphi$, the $T_{me}/T_e$ index shows a tendency to increases with children’s age and the statistical power of the increase is rather small.

In conclusion, in this study we determined the physiological range of phase angle $\varphi$ and $T_{me}/T_e$ values in newborns and young children. Both parameters showed age-dependence and were independent of sex. The study also showed the usefulness of noncalibrated respiratory inductive plethysmography for the examination of small children. The $T_{me}/T_e$ index seems to be more a stable parameter, but its introduction into clinical practice requires further investigations.

REFERENCES


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