Tidal breathing analysis in young children

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Abstract

The shape of flow pattern during tidal expiration is influenced by peripheral airway obstruction. The time from the start of expiration to peak expiratory flow ($t_{PTEF}$) divided by the total expiratory time ($t_E$) is significantly decreased in children with asthma. Experimental studies in the cat have shown that the expiratory flow pattern is the result of mechanical properties of the respiratory system (resistance and compliance) and of post-inspiratory activity of inspiratory muscles. Computerised modelling of these mechanical and muscular properties during tidal breathing allows to derive the resistance and compliance of the respiratory system from the expiratory flow pattern.
Pulmonary function in young children

The increasing incidence of lower respiratory illnesses and wheezing in young children and the diverse aetiology of these complaints are a challenge to the clinician. Diagnosis and treatment of these children are often largely based on medical history and physical examination. Assessment and quantification of airflow obstruction can be helpful in the formulation of proper therapeutic strategies and follow-up of these patients. Several objective methods are available to evaluate pulmonary function in these young children. Lung volume can be measured with body plethysmography or with gas dilution techniques. Resistance and compliance of the respiratory system can be measured both non-invasively (passive deflation or oscillation techniques) and invasively (e.g. with an oesophageal balloon). Partial expiratory flow-volume curves can be obtained in young children using rapid chest compression techniques. All these techniques, however, are hard to apply in daily practice, because they require fully equipped research laboratories, are often only applicable under sedation and are (more or less) invasive.

Figure 1. Representative recordings of tidal breathing flow over time in (A) a normal subject and (B) a patient with moderate airway obstruction. The ratio $t_{PTEF}/t_E$ can be calculated as $a/(a+b) \times 100\%$. The ratio is decreased in patients with airway obstruction.
Tidal breathing analysis - historical perspective

The need for simple, objective methods to measure pulmonary function in young children led to several studies on the evaluation of tidal breathing patterns. In 1905 Ten Have was the first to describe differences in expiratory flow patterns between healthy persons and patients with obstructive lung disease: “The expiratory flow-curve in patients with asthma is particularly different from normal. At first flow increases rapidly, afterwards it decreases rapidly and eventually slowly reaches zero flow” (Figure 1).

Later, in 1956, Bouhuys (in his thesis “Pneumotachography, the Clinical Significance of Respiratory Airflow Recording”) was the first to describe the parameter \( t_{PTEF}/t_E \), which was decreased in patients with asthma. In this ratio, \( t_{PTEF} \) is the time to peak tidal expiratory flow and \( t_E \) is the total expiratory time. It was not until 1981 that Morris and Lane showed renewed interest in the changes in expiratory flow patterns in patients with airway disease. They found significantly decreased values of \( t_{PTEF}/t_E \) in 51 adult patients with obstructive airway disease compared to 24 healthy controls. They also described a significant correlation between the parameter \( t_{PTEF}/t_E \) and FEV\(_1\), the gold standard of airway obstruction.

Analysis of flow pattern in children

In 1980 the parameter \( t_{PTEF}/t_E \) as a measure of airway obstruction was also investigated in young children. The recording of flow patterns is easily performed in young children, using a mouthpiece or facemask and pneumotachograph. These measurements do not require active co-operation or co-ordination and children are allowed to breathe quietly while laying in bed or sitting upright.

In 1996 a study was performed in our centre to evaluate the validity of the ratio \( t_{PTEF}/t_E \) as a measure of airway obstruction in children. In a group of 226 healthy schoolchildren (age 3-11 years) \( t_{PTEF}/t_E \) was measured. The mean value (43.0 ± 7.6%) was significantly higher compared to a group of 64 asthmatic children (30.0 ± 8.2%, p<0.001) (Figure 2). Moreover \( t_{PTEF}/t_E \) in children with asthma increased after bronchodilation and was
significantly correlated to other parameters of airway obstruction including FEV₁, MEF₅₀ and MEF₂₅. These findings demonstrated that \( \frac{tPTEF}{tE} \) is related to airway obstruction not only in adults, but also in children.

Practical application of tidal breathing analysis

Although these findings were very promising, the application of tidal breathing analyses in daily practice was not easy. Although group analysis showed significant differences in mean \( \frac{tPTEF}{tE} \) values between healthy and asthmatic children there was a huge overlap of values in these groups, caused by a wide variation in normal values. That is why a single measurement in the individual patient does not allow to discriminate between healthy children and those with obstructive airway disease (Figure 2). Another disadvantage is the wide intra-subject variability of \( \frac{tPTEF}{tE} \). The development of special software for on-line automatic data processing improved analysis of the tidal breathing pattern in children. Using this software a fast measurement of mean \( \frac{tPTEF}{tE} \) can be obtained from 20 breaths, thereby decreasing the intra-subject variability.

However, using the same software, it was difficult to record the tidal breathing pattern in each individual child for almost 1 minute. In daily practice this method appeared to be possible in infants using a facemask, and in children from the age of 2-3 years using a mouthpiece. In these children \( \frac{tPTEF}{tE} \) can be used as a measure of airway obstruction, especially when studying groups rather than individual children.

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**Figure 2.** \( \frac{tPTEF}{tE} \) values in 226 healthy volunteer children (interrupted bars) and 64 patients with asthma (closed bars).
Physiological background of $t_{PTEF}/t_{E}$

The physiological background of $t_{PTEF}/t_{E}$ was also studied. It was assumed that the expiratory flow follows the laws of elasticity from the end of inspiration. This “lung-emptying curve” is characterised by the time-constant of the respiratory system ($\tau_{rs}$), the product of flow resistance and compliance. At the start of expiration the expiratory flow during tidal breathing is decreased by the post-inspiratory activity of inspiratory muscles (especially the diaphragm). This muscle activity decreases exponentially, characterised by the time-constant of the muscle ($\tau_{\text{muscle}}$). The expiratory flow can be considered the result of the elastic recoil pressure of the lung and the post-inspiratory muscle activity of the diaphragm. In this way the parameter $t_{PTEF}$ follows the equation

$$t_{PTEF} = \frac{1}{1/\tau_{\text{muscle}} - 1/\tau_{rs}} \ln \left( \frac{\tau_{rs}}{\tau_{\text{muscle}}} \right)$$

In studies on cats, simultaneous measurement of flow patterns and muscle activity showed that real-life $t_{PTEF}$-values significantly correlated with the values predicted by the above model.

Based on these observations it then was postulated that $t_{PTEF}/t_{E}$ is not a direct representation of airway obstruction but especially a reflection of breathing control, expressing both the mechanics of airway and lungs ($\tau_{rs}$) and the inspiratory muscle activity ($\tau_{\text{muscle}}$). This explains why the relationship between $t_{PTEF}/t_{E}$ and other parameters of airway obstruction is not always unequivocal.

Tidal breathing analysis, the future

The important disadvantages, described above, explain the diminished interest in the parameter $t_{PTEF}/t_{E}$ in recent literature. However latest studies (unpublished data) have shown that this model can describe and analyse not only the single $t_{PTEF}/t_{E}$ value in the expiratory flow volume curve but the complete expiratory flow pattern. The most important
parameters of this model are still the mechanics of airway and lungs (τrs) and the inspiratory muscle activity (τmuscle). Therefore, very accurate recording of both τrs and τmuscle can be obtained by recording the patient’s flow pattern followed by computerised fitting of these data to the above-described model. Because τrs is the product of resistance and compliance of the respiratory system, this parameter can provide important information to the physician. When this technique is followed by expiration through an external known resistance, both resistance and compliance of the respiratory system can be calculated.

Summary

Tidal breathing analysis has been studied for almost 100 years. After a simple phenomenological description both animal and human studies have evaluated the parameter dPTEF/dE. The availability of a computerised lung model enables accurate description of the mechanics of the respiratory system. Although several disadvantages still exist, this technique has contributed significantly to our understanding of airway mechanics.
References