**TECHNICAL NOTE**

**Improvement of tidal breathing pattern analysis in children with asthma by on-line automatic data processing**


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ABSTRACT: The time taken to achieve peak tidal expiratory flow as a proportion of total expiratory time (PTEF/E) during tidal breathing (TB) is used as a parameter of airway obstruction in children with asthma. Curve selection bias is one of the most important limitations to the method. This study evaluates three curve selection methods, including a computer program, which on-line selects and analyses TB curves (Masterscreen Paediatric; Jaeger, Germany).

TB analysis was performed in 26 children (aged 4–7 yrs) with asthma, before and after methacholine provocation and after subsequent bronchodilatation. Levels and stability of TB parameters derived from computer-selected, unselected and unbiased eye-selected curves were compared. PTEF/E ratios of the computer-selected curves agreed well with the unbiased eye-selected curves (limits of agreement -4.8 and +5.8%), but were significantly different from the ratios of unselected curves. Computer-derived PTEF/E ratios had the highest level of stability: the reliability coefficient of baseline measurements was 0.96 for computer selection, 0.84 for eye selection and 0.87 for no selection (reliability index = 1 at maximal stability). Tidal volume, respiratory rate, inspiratory and expiratory time were also assessed accurately by the computer program. The mean PTEF/E ratio (computer selection) dropped after methacholine provocation (from 30±9 to 22±9% at provocative dose at which forced expiratory volume in one second had dropped ≥20% from baseline (FEV₁-PD₂₀ level), p<0.001) and was restored after bronchodilatation (30±6%; p=0.001).

We conclude that on-line computer analysis is preferable to no selection and to by-eye selection. The use of the program avoids curve selection bias and enhances the applicability of tidal breathing analysis as a measure of airflow obstruction in young children.

Table 1. – Demographic data and baseline pulmonary function data of 26 children with asthma

| Age (yrs) | 6.5±0.9 |
| Height (cm) | 120±7 |
| Body weight (kg) | 23±4 |
| Sex (M/F) | 19/7 |
| FEV1 (mL) | 1480±270 |
| FEV1 % pred | 107±11 |

Values are presented as mean±SD. M: male; F: female; FEV1: forced expiratory volume in one second; % pred: percentage of predicted value.

Tidal breathing analysis

Tidal breathing analysis was performed three times in all children: before methacholine challenge; during airway obstruction, i.e. immediately after reaching PD20; and after subsequent bronchodilatation. Tidal breathing analysis was performed with the Masterscreen Paediatric system (Jaeger).

Procedure. During tidal breathing analysis, the children were sitting upright in an easy chair, with their head resting against the back of the chair. They were instructed to breathe normally in a well-fitting silicone face mask.

Tidal breathing airflow was recorded by a Lilly pneumotachometer with a flow range of 0–20 L·s⁻¹. The total resistance of the flow sensor was below 50 Pa·L⁻¹·s⁻¹, and the dead space of the pneumotachometer was 90 mL. The pressure drop was measured by a differential pressure transducer (pressure range of ±1 kPa).

Computer analysis. After BTPS correction, the flow was digitally integrated to volume at a rate of 500 Hz. The sampling rate of the tidal breathing analysis program for flow and volume can be set to match the different needs for different patient groups. For fast-breathing babies, a maximum sampling rate of 250 Hz is possible. In slower-breathing children, sampling rates of 160 or 100 Hz can be selected. The sampling rate selected influences the resolution of the times and volumes determined as well as the resolution of the ratios calculated. In this study, the 100 Hz sampling rate was selected, which leads to a resolution of 10 ms in time determination and a typical resolution of 2% (assuming time to peak flow of 500 ms). By averaging several breathing cycles, the inaccuracy caused by this resolution improves.

Peak tidal expiratory flow was determined by searching for the sample with the highest flow value in each breathing cycle. The onset of expiration was defined as the last change of airflow direction before the peak flow, and the end of expiration was defined as the next change in airflow direction after the peak flow.

For each consecutive breathing cycle, the time taken to achieve peak tidal expiratory flow as a proportion of total expiratory time (PTEF/E) and the volume taken to achieve peak tidal expiratory flow as a proportion of total expiratory volume (V_PTEF/V_E) were calculated on-line.

After each expiration, the last series of breathing cycles were evaluated statistically. Supposing that most breathing artifacts (e.g. swallowing, hiccups) are in the outer quartiles of the calculated (PTEF/E and V_PTEF/V_E) range, the program automatically deleted the (PTEF/E and V_PTEF/V_E) values below the 25 percentile and above the 75 percentile for each parameter range. The mean and standard deviation of the remaining 50% interval around the median ratio was calculated. Breathing cycles with both ratios within the middle part were treated as representative. From these representative breathing cycles, mean inspiratory time (I), expiratory time (E), total breathing cycle time (t_total), tidal volume (V_t), respiratory rate (RR) and minute volume (MV) were calculated.

The number of breathing cycles analysed can be selected in the program (minimally 6, maximally 50 cycles). In this study, a sample size of 20 breathing cycles was selected. Thus, the (PTEF/E and V_PTEF/V_E) ratios in this

Methods

Maximal expiratory flow volume (MEFV) measurements

MEFV measurement was performed in all children, with use of a pneumotachometer system (MasterScreen Pneumo; Jaeger, Germany). The best MEFV curve, according to the American Thoracic Society (ATS) criteria, from at least five trials was used [16]. Data were stored and processed in a 486 sx Notebook computer. All values were corrected to body temperature, ambient pressure and saturation with water vapour (BTPS) conditions. For reference values, data of ZAPLETAL et al. were used [17].

Methacholine provocation

Methacholine provocation was performed according to a standardized protocol [18]. Methacholine aerosols were generated by calibrated DeVilbiss 646 nebulizers with closed vents and 3 mL methacholine bromide solution in buffered saline in the vial. The nebulizer was attached to a Rosenthal dosimeter. During a deep inspiration with sufficient airflow, the dosimeter was triggered for 0.6 s. A total of 20 µL of aerosolized solution was delivered via a mouth tube. After performing baseline MEFV measurement, saline was inhaled to rule out nonspecific reactions and, subsequently, methacholine was administered in doubling doses. Methacholine mouth doses of 3, 6, 12, 24, 50, 98, 196, 392 and 784 µg were administered. MEFV measurement was performed 3 min after every dose of methacholine. Provocation was continued until the dose at which FEV1 had dropped 20% or more from baseline (PD20). After this dose, 200–400 µg of salbutamol dose-aerosol was administered via a Volumatic®. After 15 min lung function tests were repeated.
study were the calculated means of the 10 middle values of the last 20 cycles of the recording.

To indicate the stability of the tidal breathing pattern, the calculated $t_{PTEF}/t_{E}$ and $V_{PTEF}/V_{E}$ ratios and the calculated momentary mean values of these ratios are displayed in a breath-by-breath diagram (trend-analysis) (fig. 1c). Independent of the relatively large scatter of the individual $t_{PTEF}/t_{E}$ and $V_{PTEF}/V_{E}$ ratios, the mean trends usually show stable values after a short period of adaptation (generally 20–30 s). In this study, the recording was continued during 20–25 tidal breathing cycles after achievement of these stable mean trends.

After ending the recording, a mean flow-time and a mean flow-volume curve was calculated from the representative breathing cycles by performing a time-based averaging of the flow and volume signals (fig. 2). By this procedure, the influence of noise on the signal was decreased. Representative mean flow-time and flow-volume curves can be displayed on screen or on a printed report. In displaying the final result the mean value, the standard deviation and the minimum and maximum of the $t_{PTEF}/t_{E}$ and $V_{PTEF}/V_{E}$ ratios are shown in a box-plot (fig. 2c).

After completing the recording the results were stored in the database. In the result phase, it is possible to toggle the status of single measured $t_{PTEF}/t_{E}$ values on the breath-by-breath result screen to remove them from or add them to the average value. This possibility was not used in the "computer selection method" in this study.

Selection protocols. In this study, breathing curves for mean parameter calculation were selected in three different ways. The first method was the "computer selection" of 10 curves from the last recorded 20 breathing curves, as described above. The second method was the "no selection" method: all of the last recorded 20 breathing curves were toggled as valid and mean tidal breathing parameters were calculated from these 20 curves. The third method was unbiased "selection by-eye". For this method all curves were toggled as invalid. From the last recorded 20 breathing curves, 10 curves were selected by-eye and toggled as valid by an independent investigator who was unaware of the "computer selection" and "no selection" results. Valid curves were selected according to a well-described selection protocol [12]. Selection criteria were: 1) no doubtful points of zero-flow (e.g., no breathholding during or between the inspiratory and expiratory phase); 2) no doubtful point of expiratory peak flow (no more than one peak); and 3) the curve is not obviously different from the regular tidal breathing pattern (e.g., no deep sighs). When more than 10 of the 20 curves were toggled as valid, mean calculations were based on the last 10 valid curves of the recording. The $t_{PTEF}/t_{E}$ from the by-eye selection of the independent investigator was regarded as "gold standard" for $t_{PTEF}/t_{E}$ level.

Statistical analysis

Data are reported as mean±standard deviation, unless otherwise indicated. For comparison of data, Student's paired t-test was used. Spearman rank correlation coefficients were used to evaluate correlations. Analysis
of agreement was performed as described by Bland and Altman [19]. For statistical evaluation of the stability of the $t_{PTEF}/t_{E}$ ratio, the reliability coefficient (RC) was used. A subject's true $t_{PTEF}/t_{E}$ ratio is estimated by taking the average over $n$ breathing cycles within the subject. The RC of this average calculated $t_{PTEF}/t_{E}$ ratio is defined as:

$$RC = \frac{\sigma_{\text{inter}}^2}{\sigma_{\text{inter}}^2 + \sigma_{\text{intra}}^2/n}$$

in which $\sigma_{\text{inter}}^2$ is the between-subject variance of true $t_{PTEF}/t_{E}$ ratios, $\sigma_{\text{intra}}^2$ is the within-subject variance of single $t_{PTEF}/t_{E}$ ratios within one subject, and $n$ is the number of breathing cycles used to calculate the average $t_{PTEF}/t_{E}$ ratio within a subject. RC (also called intra-class correlation coefficient) reflects the within-subject stability of a calculated average $t_{PTEF}/t_{E}$ ratio (the nearer RC to 1, the more stable the average ratio).

**Results**

*Computer selection versus selection by-eye*

Mean $t_{PTEF}/t_{E}$ of all 78 measurements (three times in 26 children) using the computer selection was 26.5±8.7%. This was not significantly different from the mean $t_{PTEF}/t_{E}$ level when breathing curves were selected by-eye (26.0±8.2%; $p=0.12$). Mean values of the other tidal breathing parameters using the two different selection methods are summarized in table 2. There were no significant differences between computer and eye selection, except for a small difference in $t_{E}$.

The mean difference between the $t_{PTEF}/t_{E}$ ratio obtained by computer selection and selection by-eye was 0.5%. The standard deviation of the differences was 2.7%.

<table>
<thead>
<tr>
<th>Method of selection</th>
<th>Computer</th>
<th>By-eye</th>
<th>No selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{PTEF}/t_{E}$ %</td>
<td>26.5±8.7</td>
<td>26.0±8.2</td>
<td>27.1±8.1</td>
</tr>
<tr>
<td>$V_{PTEF}/V_{E}$ %</td>
<td>28.4±7.9</td>
<td>28.0±7.5</td>
<td>28.9±7.2</td>
</tr>
<tr>
<td>$V_T$ L</td>
<td>0.28±0.09</td>
<td>0.28±0.08</td>
<td>0.28±0.08</td>
</tr>
<tr>
<td>RR breaths·min⁻¹</td>
<td>22.7±5.4</td>
<td>23.5±5.3</td>
<td>22.4±5.0</td>
</tr>
<tr>
<td>MV L</td>
<td>6.2±1.7</td>
<td>6.3±1.8</td>
<td>6.0±1.6</td>
</tr>
<tr>
<td>$t_I$ s</td>
<td>1.23±0.31</td>
<td>1.19±0.28</td>
<td>1.22±0.28</td>
</tr>
<tr>
<td>$t_E$ s</td>
<td>1.54±0.41</td>
<td>1.50±0.39</td>
<td>1.59±0.41</td>
</tr>
</tbody>
</table>

Values are presented as mean±SD. Results were compared by paired t-test, and level of significance is presented in parenthesis. $t_{PTEF}/t_{E}$: time to achieve peak tidal expiratory flow as proportion of total expiratory time; $V_{PTEF}/V_{E}$: volume taken to achieve peak tidal expiratory flow as a proportion of total expiratory volume; $V_T$: tidal volume; RR: respiratory rate; MV: minute volume; $t_I$: inspiratory time; $t_E$: expiratory time; NS: nonsignificant.
Unselected curves versus selection by-eye

Mean \( t \text{PTEF}/\text{E} \) of all 78 measurements, when calculated from 20 unselected breathing curves was 27.1±8.1%. This was significantly higher compared to the eye selection value (p<0.001; table 2). The mean values of \( \text{PTEF}/\text{E} \), \( \text{FEV}1 \), and \( \text{FEV}2 \) were also significantly higher compared to the eye selection values. \( \text{RR} \) and \( \text{MV} \) were still significantly lower. No significant difference was found in \( \text{VT} \) (table 2).

Ninety five percent of the no selection \( \text{PTEF}/\text{E} \) values were within -3.9 and +6.1% of the eye selection values. Limits of agreement between the eye and no selection parameters are summarized in table 3.

Computer selection versus unselected curves

Except for \( \text{PTEF}/\text{E} \), \( \text{RR} \) and \( \text{t1} \), tidal breathing parameters derived from the computer selection method differed significantly from the nonselection method parameters. \( \text{tPTEF}/\text{E} \) and \( \text{tE} \) were significantly lower in the computer selection (p<0.05 and p<0.001, respectively). \( \text{VT} \) and \( \text{MV} \) were significantly higher compared to the no selection method (p<0.05 and p<0.001, respectively) (table 2).

Influence of airway obstruction

Mean \( t \text{PTEF}/\text{E} \) in 26 children using computer selection before methacholine provocation was 29.8±8.8%. After provocation at \( \text{FEV}1\text{-PD}_{20} \) level (mean \( \text{FEV}1 \) 1.09±0.230 mL, 79±13% of predicted) \( t \text{PTEF}/\text{E} \) fell to 21.9±9.2% (p<0.001). In 21 children (81%) \( t \text{PTEF}/\text{E} \) decreased after methacholine, in five children (19%) \( t \text{PTEF}/\text{E} \) increased. After administration of salbutamol, lung function returned to normal values (\( \text{FEV}1 \) 1.54±0.270 mL, 112±14% of predicted, not significantly different from baseline values). Mean computer selected \( t \text{PTEF}/\text{E} \) value was 27.9±5.8%, which was not significantly different from baseline value. In 21 children (81%) \( t \text{PTEF}/\text{E} \) increased after salbutamol, in five children (19%) \( t \text{PTEF}/\text{E} \) decreased.

Mean \( t \text{PTEF}/\text{E} \) values from selections by-eye equally fell after methacholine and were restored to baseline values after administration of salbutamol (table 4).

The fall and rise of the nonselected mean \( t \text{PTEF}/\text{E} \) values after methacholine and subsequent salbutamol administration were significant, but p-values were lower compared to the changes in computer- and eye-selected measurements.

In all three different methods of breathing curve selection, \( \text{VT} \), \( \text{RR} \), \( \text{MV} \), \( \text{t1} \) and \( \text{tE} \) did not change significantly after methacholine or salbutamol administration.

Influence of the selection method on the stability of \( t \text{PTEF}/\text{E} \)

Using the no selection method, the calculated average \( t \text{PTEF}/\text{E} \) ratios of 20 breathing cycles correlated significantly with the standard deviation of these mean ratios with Spearman rank correlations of 0.64 (baseline), 0.65 (after methacholine) and 0.40 (after salbutamol). To

Table 3. – Limits of agreement of tidal breathing parameters using three different selection methods

<table>
<thead>
<tr>
<th></th>
<th>Computer versus by-eye</th>
<th>No selection versus by-eye</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t \text{PTEF}/\text{E} ) %</td>
<td>-4.8 ± 5.8</td>
<td>-3.9 ± 6.1</td>
</tr>
<tr>
<td>( \text{PTEF}/\text{E} ) %</td>
<td>-5.6 ± 6.0</td>
<td>-4.6 ± 6.4</td>
</tr>
<tr>
<td>( \text{VT} ) L</td>
<td>-0.03 ± 0.04</td>
<td>-0.03 ± 0.03</td>
</tr>
<tr>
<td>( \text{RR breaths-min}^{-1} )</td>
<td>-5.4 ± 4.6</td>
<td>-4.2 ± 2.0</td>
</tr>
<tr>
<td>( \text{MV L} )</td>
<td>-1.34 ± 1.25</td>
<td>-1.28 ± 0.69</td>
</tr>
<tr>
<td>( \text{t1 s} )</td>
<td>-0.34 ± 0.37</td>
<td>-0.20 ± 0.26</td>
</tr>
<tr>
<td>( \text{tE s} )</td>
<td>-0.16 ± 0.20</td>
<td>-0.15 ± 0.34</td>
</tr>
</tbody>
</table>

For definitions see legend to table 2.
In the by-eye selection method, $\sigma^2_{\text{inter}}$ of $\log \frac{\text{PTEF}}{V_T}$ was 0.078 at baseline, 0.173 after methacholine and 0.030 after salbutamol; $\sigma^2_{\text{intra}}$ was 0.151, 0.098 and 0.133, respectively. Consequently, RC of the mean log $\frac{\text{PTEF}}{V_T}$ ratios of the by-eye selection in this study was 0.84 at baseline, 0.95 after methacholine, and 0.69 after salbutamol (fig. 5).

The computer selects breathing cycles by cutting off the five upper and five lower values of the parameter range of 20 breathing cycles. This process influences both $\sigma^2_{\text{inter}}$ and $\sigma^2_{\text{intra}}$ as well as $n$. The RC of the mean log $\frac{\text{PTEF}}{V_T}$ ratios resulting from the standard computer selection was 0.96 at baseline, 0.98 after methacholine and 0.94 after salbutamol. Figure 5 displays the RC values of mean log $\frac{\text{PTEF}}{V_T}$ ratios, not only when 0 (no selection method) or 5 upper and lower values (standard computer selection) are cut off, but also when other numbers of outer values would be cut off.

Discussion

The present study addressed the question of whether the method of tidal breathing analysis can be improved by on-line automatic data processing. Three different methods of breathing curve selection were compared and the influence of airflow obstruction was studied. Several aspects of computer-based analysis are discussed.

Computer selection versus selection by-eye

This study showed a high level of agreement between $\frac{\text{PTEF}}{V_T}$ ratios calculated from "regular" breathing curves selected by-eye by an unbiased investigator and those selected by the computer program. There were no significant differences between mean $\frac{\text{PTEF}}{V_T}$ values of both selection methods and the limits of agreement were acceptably narrow. All other tidal breathing parameters showed comparable high levels of agreement between both methods of curve selection. In this study in unsedated young children with asthma, the computer program was equally as successful in selection of valid breathing curves for parameter calculation as the unbiased by-eye selection method in deleting "irregular" breathing cycles. Analysis of the stability (as reflected by the RC) of the resulting mean $\frac{\text{PTEF}}{V_T}$ values of both methods revealed a higher stability of the computer-selected ratios compared to the by-eye-selected ratios (fig. 5). The avoidance of selection bias in the clinical setting and the high level of stability of the $\frac{\text{PTEF}}{V_T}$ ratio made the computer selection method preferable to the by-eye selection method.

Unselected curves versus selection by-eye

All tidal breathing parameters showed the same levels of agreement between no selection and eye selection as between computer selection and eye selection (table 3). However, mean values of all tidal breathing parameters (except for $V_T$) from the no selection method were significantly different from the values of the unbiased eye selection values (table 2). The reliability coefficients of
the $PTEF/E$ ratios derived from the no selection method and the by-eye selection method were comparable, indicating a comparable level of stability. However, the systematic differences in $PTEF/E$ levels between these two methods and the lower stability of the ratios compared to the computer selected ratios make the computer selection method more attractive.

All tidal breathing parameters (except for $V_{PEF}/V_E$, $RR$ and $I/I$) of the no selection method were significantly different from the computer selection method.

**$PTEF/E$ as a parameter of airflow obstruction**

$PTEF/E$ was a parameter of airflow obstruction in this study. The mean value of the ratio significantly decreased during methacholine-induced airflow obstruction and returned to baseline after administration of salbutamol. This pattern was in line with other studies in young children. Currera et al. [6] showed that $PTEF/E$ was lower in school-age children with asthma compared to normals. Carlsten and Lordrup-Carlsten [14] and van der Ent et al. [12] showed a rise of $PTEF/E$ in children with asthma after administration of salbutamol.

In this study, 5 of 26 children showed an "adverse" change of $PTEF/E$ after bronchoprovocation, and an equal number showed an increase of $PTEF/E$ after bronchodilatation. This is in line with other studies [12, 14], and stresses that $PTEF/E$ is more useful as a parameter of airflow obstruction in epidemiological research than in individual patients.

This study showed that unbiased selection by-eye and computer selection confirmed the fall and rise of $PTEF/E$ levels during methacholine provocation and subsequent administration of salbutamol with equal levels of significance (table 4). The differences in $PTEF/E$ of the non-selection method had lower levels of significance. This was another reason to prefer the computer selection method above nonselection.

$V_t$, $MV$, $RR$, $I/I$, and $E/E$ did not change during airflow obstruction and subsequent bronchodilatation.

**Several aspects of computer-based analysis**

There is increasing interest in the measurement of $PTEF/E$ as a measure of airway obstruction in infants and young children. This simple and noninvasive test could become a powerful tool in epidemiological studies concerning the determinants of early respiratory morbidity [2, 3]. One of the major problems in tidal breathing analysis is the variability of the tidal breathing pattern. The intra-individual coefficient of variation of the ratio $PTEF/E$ ranges from 18.1–26.1% in healthy neonates [5, 9] to 21.8% [6] and 26.5% [12] in school-age children. This large variability of breath-to-breath patterns puts several special requirements on the analysis software of the recording instruments.

Firstly, the number of breaths averaged to give an overall mean parameter for each patient has to be large enough to reach a stable value. When the calculated ratio is not stable, the discriminative value of $PTEF/E$ as a measure of airway obstruction will be low. Recently, Stocks et al. [13] showed that probably at least 10–15 breathing curves have to be averaged to reach an acceptable level of repeatability. Tidal breathing computer programs which average less than 10–15 breathing curves may result in a high proportion of infants and children being misclassified as having airway obstruction, or as being at risk for respiratory disease in later life [2, 3].

This study shows how the stability of a mean $PTEF/E$ ratio was related to the number of unselected breathing cycles which was averaged (fig. 4). In patients with airflow obstruction (after methacholine) the RC approached the maximum after averaging about 10 sequential breathing cycles. In patients with little (baseline) or no (after salbutamol) airflow obstruction, the tidal breathing pattern was more variable (highest $\sigma^2_{intra}$). This results in lower levels of stability, indicated by lower RC values. Averaging of 15–20 (baseline), or more (after salbutamol), unselected breathing curves is necessary to reach a stable value in these patients.

The tidal breathing analysis program described here can average up to 250 breaths during one test. In sleeping infants, a relatively unlimited number of breathing cycles can be recorded. Unsedated young children do not tolerate endless recordings. In the present study, it was possible to record at least 20 breathing curves after stabilization of the breathing pattern in unsedated children aged 4–7 yrs. This is in line with former results [12].

Because of the limitation of maximal sample size, other possibilities of increasing the stability of the $PTEF/E$ ratio were investigated. The RC values both of the no selection method and the by-eye selection method remained under 0.90 in children without or with only slight airflow obstruction (fig. 5). The stability of the computer-selected ratio was optimal in all degrees of airflow obstruction. The stability of the computer selection method exceeded the stability of the other two methods because of low $\sigma^2_{intra}$ values.

The computer selection method used the centre 50% of $PTEF/E$ values around the median. Figure 5 shows the RC values if other cut-off points had been used. The stability of the ratio would have been equal if, for instance, 6 instead of 10 of the outer values had been deleted. This adaptation in the computer program should be considered when these observations are repeated in other groups of patients.

Secondly, tidal breathing analysis computer programs have to exclude curve selection bias. Selection bias is probably inevitable when the investigator selects the curves from the recordings by eye. Several authors report that they selected "regular" curves [5, 6, 10]. Others selected a period of the recording by excluding "technical alterations" of the regular breathing pattern, such as sighs, hiccups and swallowing [2, 3, 12, 13]. Although the use of a well-described selection protocol can lead to good interobserver correlation [12], selection bias can influence the applicability of tidal breathing analysis by new investigators, especially when it is combined with a small number of averaged curves. In the present study, the selection of curves was completely computerized; this ruled out selection bias by the investigator.

The third advantage is that the on-line data processing by the program easily indicates when the tidal breathing pattern is stabilized after starting the recording.
STOCKS et al. [13] showed that the first sample of tidal breathing curves after application of the face mask has lower tPTEF/E values compared to samples during later recordings. Different samples during prolonged recording showed quite stable tPTEF/E values. The computer program displays the momentary mean tPTEF/E and V*PTEF/E values during recording of tidal breathing. It is easy to see when these momentary mean values do not change any more during continuation of the recording. In the present study, the adaptation period was generally 20–30 s. We only used tPTEF/E values which were sampled after this period.

An additional advantage of the computer program is that the time of the recording can be kept to the minimum. The recording can be started immediately after the adaptation period, and the investigator does not spend time in hesitating about whether individual breathing curves are “valid” or “invalid”. Minimizing the procedure time increases patient compliance and improves the applicability of the method in large scale epidemiological research.

In conclusion, automatic analysis of tidal breathing flow patterns enhances the applicability as a measure of airflow obstruction. An appropriate computer program can avoid curve selection bias, can produce a stable average of an appreciable number of single curves and allows recording after stabilization of tidal breathing. This study showed that the on-line computer analysis is preferable to the no selection and to the by-eye selection methods.

After resolving these methodological problems, more studies on the value and physiological background of tPTEF/E have to be performed. The present study shows that in groups of patients tPTEF/E correlates with airway obstruction.

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References