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Comparison of the Forced Expiration Time Recorded by Two Spirometers with Different Types of Flow Sensors and the Acoustic Duration of Tracheal Noises

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Abstract—The forced expiratory times have been measured in 44 volunteers by means of spirometers equipped with a flow sensor of the Lilly type and a turbine flow sensor, and the acoustic durations of tracheal noises have been compared. The spirometric forced expiratory time has been found to depend on the flow sensor type; thus, its use for diagnosis is problematic.

Keywords: spirometry, flow sensor, forced expiratory time, duration of forced expiratory tracheal noises, estimation bias

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The forced expiratory maneuver is a functional test used to assess respiratory disorders in humans [1]. The change in the forced expiratory (FE) time is recorded both via spirometry and auscultation in patients with pulmonary conditions; however, the use of this parameter in diagnosis is still being discussed [2–4]. Though the relationship between an increase in FE time and bronchial obstruction was found half a century ago [5], the use of FE time was limited in clinic and epidemiologic studies despite the simplicity, low cost, and sensitivity of this pulmonary function test. High variability of both auscultated and spirometry FE times was shown [6]. The standard protocol could reduce the individual variability; however, the auscultated FE time should not be used in diagnosis due to its low specificity [7]. Other authors concluded that the auscultated FE time could be used in diagnosis of the bronchial obstruction in patients older than 60 years if spirometry was unavailable [8].

Recently, the recording of acoustic duration of FE tracheal noises was proposed as a replacement for the subjective evaluation of the auscultation FE time [9]. An increase in the duration of FE tracheal noises was found to be a highly sensitive and specific sign of bronchial obstruction in patients with bronchial asthma [2, 10]. These results have encouraged us to return to the problem of the use of spirometry FE time in diagnosis of bronchial obstruction instead of the acoustic duration of FE tracheal noises.

The modern equipment for the measurements of flow-volumetric respiratory parameters includes various types of pneumotachometers. They are commonly equipped with turbine flow meters; less common and more expensive types are equipped with sensors of pressure gradient (Lilly, Fleisch, and Pitot tubes). Therefore, it is important to understand how the type of a flow sensor affects the FE time.

In this study, we have compared FE times measured using spirometers equipped with a turbine flow sensor or a Lilly type sensor and the acoustic duration of FE tracheal noises in the same group of subjects.

METHODS

We examined 44 volunteers (34 men and 10 women). The group included healthy subjects without any occupational hazards (16 subjects), professional divers (26 subjects), and patients with chronic obstructive pulmonary diseases in remission (2 subjects).

The full characteristics of experimental groups are shown in the Table 1. All subjects gave their informed consent. The experimental protocol was approved by the Ethics Committee of the Medical Association of

Table 1. Anthropometric parameters (Me; LQ; UQ) of the examined volunteers

Parameter	Value ($n = 44$)
Age, years	34; 25; 50
Height, cm	176; 172; 181
Body weight, kg	76; 68; 85

Table 2. The parameters of pulmonary function in the studied subjects measured with spirometers of different type ($n = 44$)

Parameter	Master Screen-Body Jaeger	SuperSpiro MicroMedical	Median bias of estimation, %
VC, L	5.33; 4.63; 6.22	5.20; 4.68; 6.04*	–2.1
FVC, L	5.41; 4.81; 6.25	5.21; 4.59; 6.13*	–3.7
FEV_1, L	4.38; 3.48; 0.85	4.25; 3.41; 4.70*	–2.9
FEV_1/FVC(VC)	76; 73; 82	77; 74; 81	0.1
PEF_{exp}, L/s	9.87; 9.26; 11.25	9.48; 8.43; 10.70*	–3.9
MEF_{25}, L/s	7.83; 6.75; 9.04	7.75; 6.42; 9.22	–1
MEF_{50}, L/s	4.30; 3.58; 4.99	4.36; 3.44; 5.04	1.4
MEF_{75}, L/s	1.48; 1.09; 1.99	1.50; 1.10; 1.94	1.3
$FEF_{25–75}$, L/s	3.49; 2.97; 4.08	3.52; 2.81; 4.29	0.1
T_s, s	8.61; 6.67; 12.20	6.15; 4.1; 8.8*	–28.6

Abbreviations are explained in the methods section. The data are shown as Me; LQ; UQ; * $p < 0.001$.

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The pulmonary function was tested using a Master Screen-Body spirometer (Erich Jaeger, Germany) with a Lilly type flow sensor and a SuperSpiro (Micro-Medical, United Kingdom) spirometer with a turbine flow sensor. The devices were calibrated according to the manufacturers' instructions.

Smoking and physical exercise were avoided prior the examination. Spirometry was performed in the morning no less than 1–1.5 h after meal, in the sitting position. Nasal breathing was prevented by applying a noseclip. Patients were thoroughly instructed by a physician before performing breathing maneuvers. The vital capacity (VC, L) of the lungs, forced vital capacity (FVC, L) of the lungs, forced expiratory volume in the first second (FEV_1, L), Tiffeneau index (FEV_1/VC), Hensler index (FEV_1/FVC), peak expiratory flow (PEF_{exp}, L/s), average forced expiratory flow at 25–75% of FVC ($FEF_{25–75}$, L/s), maximal expiratory flow at 25%, 50%, and 75% of FVC (MEF_{25}, MEF_{50}, and MEF_{75}, L/s), and the spirometry time (T_s) were measured. The criteria of an acceptable breathing maneuver [11] included a back extrapolated volume of less than 5% of FVC or 150 mL; the peak flow reached within 0.1 s; a duration of expiration of no less than 6 s or the volume–time curve reaching its plateau (a change in the volume of less than 25 mL for 1 s). The spirometry was completed if three acceptable breathing maneuvers had been obtained and these maneuvers were reproducible (maximal and the following FVC and FEV_1 values did not differ by more than 150 mL). Among the three successful trials, the one with the greatest sum of FVC and FEV_1 was included in the analysis. The greatest value of the spirometry time T_s was chosen.

The acoustic examination of FE tracheal noises was carried out on the same day according the protocol described in [12], in the sitting position. The acoustic sensor was placed on the right side of the laryngeal area in front of the sternocleidomastoid muscle; a noseclip was applied. The forced expiratory maneuver was performed: a sharp exhalation with the maximal force after a deep inhalation. The breath was hold between inhalation and exhalation for 0.5–1 s. The subjects were preliminary trained to perform the maneuver correctly. The duration of FE tracheal noises (T_a) was measured using equipment described in [13]. Three correct FE maneuvers were recorded; the greatest T_a value was included in further analysis.

The statistical analysis was carried out using the Statistica (Statsoft) software. The results were shown as mean (M) ± standard deviation (SD) for samples with normal distribution and median (Me), upper quartile (UQ) and lower quartile (LQ) for samples with other types of distribution. The difference

between samples was evaluated using the nonparametric Wilcoxon test. To measure correlations between parameters, the Spearman correlation coefficients were calculated. The results were considered significant at $p < 0.05$. The variability of the parameters was evaluated using the coefficient of variation (CV).

RESULTS AND DISCUSSION

The parameters of pulmonary function in the studied subjects are shown in Table 2.

The values of the $FEV_1/FVC(VC)$ ratio and flow velocities MEF_{25}, MEF_{50}, MEF_{75}, and $FEF_{25–75}$ obtained using two different types of spirometers were not significantly different. Significant differences between VC, FVC, FEV_1, PEF_{exp}, T_s ($p < 0.001$) were found. However, the bias of estimation was 0.1–3.9% for the flow parameters VC, FVC, FEV_1, and PEF_{exp}; hence, it was within the measurement error of each spirometer [14]. Such results were anticipated in the case of the correct measurement procedure and spirometer calibration.

At the same time, there was a significant difference in T_s values obtained using two different spirometers (28.6%, Table 2). This difference was more than two times greater than the average variability of measurements in the group, CV = 12.3% (the Master Screen-Body spirometer, Erich Jaeger), and cannot be explained by the variability of the parameter studied.

This bias of T_s estimation could be caused by the different constructions of pressure sensors. The Lilly tube is equipped with a grid creating a constant pressure resistance in the flow range of spirometry. At the same time, a turbine flow meter is characterized by a quasi-static resistance determined by the space free from turbine blades and the dynamic resistance mainly determined by the angle of attack of the rotating blades. A decrease in the flow and rotation speed of the blades in the end of expiration leads to a gradient decline of the resistance from the former value to the latter. Thus the dependence of resistance on the flow is evident. Since the dynamic resistance is greater than quasi-static, the total resistance of a turbine sensor decreases in the end of exhalation. Therefore, the additional pressure created by the sensor decreases, which leads to earlier close of respiratory pathways due to the functional expiratory stenosis following FE [1]. This process apparently leads to a decrease in FE time on a turbine spirometer in comparison with a spirometer of Lilly type. Similar results can be expected in the experiments with a turbine spirometer and a Fleisch type spirometer.

Therefore, the use of T_s is appropriate only if the measurements are performed on spirometers of the same type. Since it is unfeasible in most cases, the diagnostic value of T_s seems questionable.

The acoustic duration of FE tracheal noises T_a was 1.88; 1.49; 2.18 s (Me; LQ; UQ, respectively). We used the method of measurement of the acoustic FE tracheal noises duration [12] in which FE is performed in the free space and does not depend on the type of the flow sensor.

We were interested in the relationship between the acoustic duration and spirometry time of FE. A significant positive correlation ($r = 0.53–0.57$) of these parameters was found; it did not depend on the type of spirometer. This finding supports the conclusion [2] about the connection but not interchangeability of these two parameters.

The T_a/T_s ratios measured using turbine and Fleisch type spirometers were different in healthy volunteers and patients with bronchial asthma; therefore, this parameter was assumed to have a diagnostic value [2]. In our study, the values of this ratio were $24.1 \pm 8.8\%$ and $35.5 \pm 12.8\%$ ($M \pm SD$) as measured by Lilly spirometer and turbine spirometer respectively. As we can see, these values are significantly different ($p < 0.001$) even in the same group of subjects. Hence, the difference in the T_a/T_s ratio in healthy subjects and patients found in [2] could be due to the use of different types of spirometers.

Thus, the spirometry time of forced expiration depends on the type of the flow sensor of the spirometer and cannot be used instead of the acoustic duration of tracheal noises.

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