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Some aspects of pulmonary function tests

Niektóre aspekty badania czynnościowego płuc

Pulmonary function tests are painless methods for measuring lung function. They include: classic spirometry, volume – time curve, flow – volume loop, partial expiratory flow-volume (PEFV), Tidal flow-volume (TFV), peak expiratory flow rate (PEFR), body pletysmography, forced oscillometry, reversibility test, evaluation of bronchial reactivity, and measurement of nitric oxide (NO) concentration in exhaled air [6, 8, 16]. The tests can help to determine the severity of lung diseases, to evaluate a patient's progress while being treated or to get a baseline measurement of lung function before surgery. The tests can also aid the diagnosis of numerous lung diseases as bronchial asthma, chronic obstructive pulmonary disease (COPD), occupational lung diseases, interstitial lung diseases, pollinosis [12, 15].

In this article only chosen spirometric tests will be reviewed.

SPIROMETRY

Spirometry is the most basic and frequently performed test of pulmonary function, measuring the ventilatory function of the airways, i.e., the ability to move air into and out of the lungs. Three different types of spirometers are presented in Figure 1.

Classic spirometry measuring volumes has limited value in comparison with the newer methods. A classic spirogram is presented in Figure 2A. For its registration two types of spirometers are useful, i.e., a water-sealed spirometer (Figure 1 A) and a flow-type spirometer (pneumotachometer connected to a computer) (Figure 1 C). The water-sealed (bellows) spirometers are not used today because of a possibile transference of infection [5, 11].

The explanations of chosen spirometric parameters are presented in Table I. [13].

In 1947, Tiffenau and Pinelli recognized that **volume – time** measurements during forced vital capacity (FVC) manoeuvres are very sensitive in detecting obstructive lung diseases [14]. The volume – time spirogram is presented in Figure 2B. This type

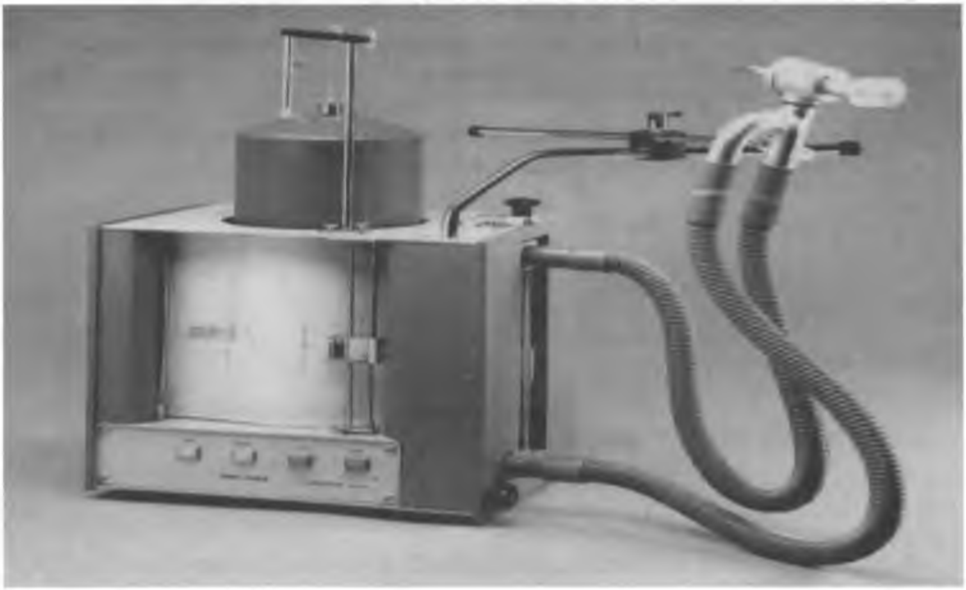


Fig. 1 A.

Fig. 1 B.

Fig. 1 C.

Fig. 1. Three different types of spirometers: A/. Water-sealed spirometer, B/. Bag spirometer, C/. Flow-types (pneumotachometer) spirometers

Table I. Chosen abbreviations used in spirometry interpretation

Abbreviation	Explanation
TLC (Total Lung Capacity)	Total lung volume following a maximal inspiration
TV (Tidal volume)	Volume of air inhaled and exhaled during a silent breathing
RV (Residual Volume)	Volume remaining in the lungs following a maximal expiration
VC (Vital Capacity)	The maximal volume of air exhaled from the point of maximal inspiration
FVC (Forced Vital Capacity)	The maximal volume of air exhaled from the point of maximal inspiration using a maximally forced expiratory effort.
FEV_1 (Forced Expiratory Volume in one second)	Volume of air exhaled during the first second of the FVC.
FEV_1/FVC ratio	Forced expiratory volume in one second expressed as a percentage of the forced vital capacity
FEF_{25-75} (Mean Forced Expiratory Flow during the middle half of the FVC)	Average flow rate over the middle half of the expiration.

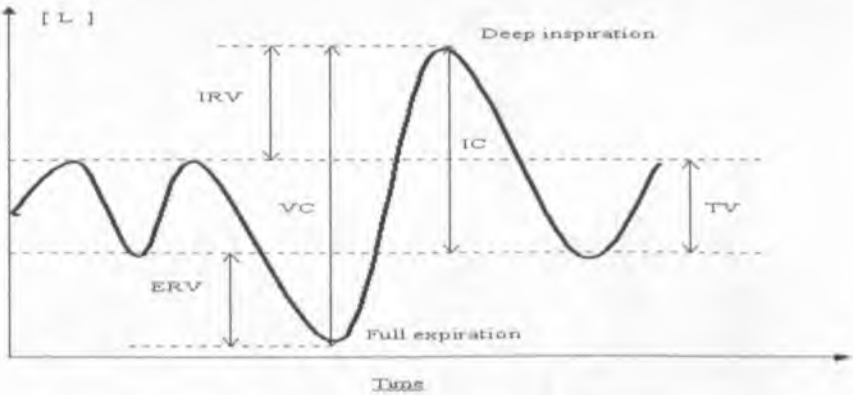


Fig. 2 A. Classic spirogram

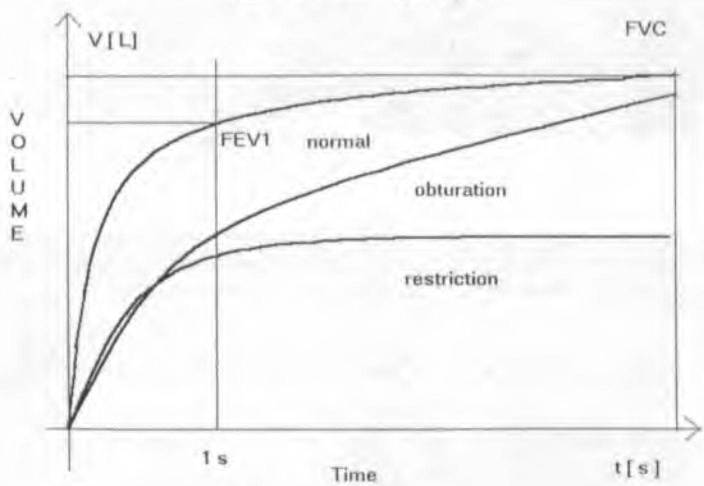


Fig. 1 B. Volume – time curve

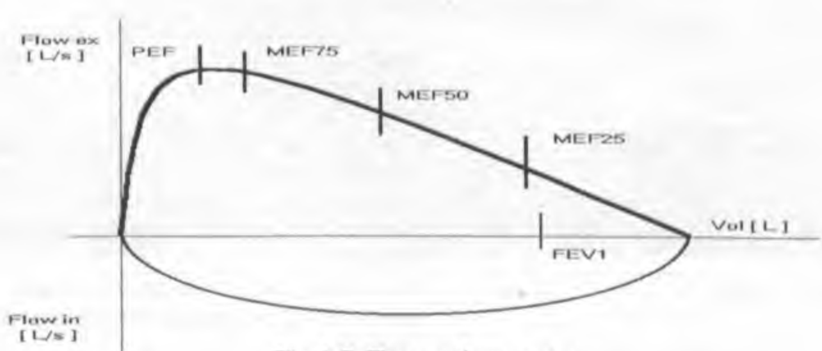


Fig. 1 C. Flow – volume curve

Fig. 2. Three different types of spirograms: A/. Classic spirogram registered using a water-sealed spirometer, B/. Volume time curve registered by a bag spirometr, C/. Flow – volume curve.

of spirogram can be registered using the bellows, bag (Figure 1 B) and flow-type spirometers. The bag spirometers, manufactured since the 1960's by Vitalograph are also difficult to desinfect, but the probability of an infection transfer is low. During the test, the patient only exhales the air into the bag. Using a forced expiratory manoeuvre, which is maximal expiration from Total Lung Capacity (TLC) to Residual Volume (RV) spirometry measures Forced Vital Capacity (FVC) and Forced Expiratory Volume in One Second (FEV_1). The speed of the expiratory airflow is quantified by the FEV_1 and by the relationship of the FEV_1 to the FVC, expressed as the FEV_1/FVC ratio.

Since the mid-1970's, **flow – volume spirograms** have also become common, showing expiratory flow rate as a function of expired volume (Figure 2C). The patient after a few tidal volume breaths performs a forced inspiratory manoeuvre and then a forced expiratory manoeuvre. In adults, the measurement of maximum expiratory flow – volume (MEFV) relationship is one of the most valuable clinical tests in the assessment of pulmonary function. During the forced inspiration it is possible to inhale bacteria or viruses from the pneumotachometer. The newest spirometers of this type use changeable pneumotachometers or filters which exclude infections.

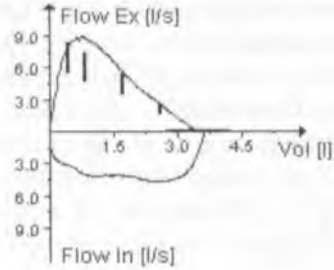
A forced expiration can also be initiated from a partial inspiration to a volume below TLC allowing the recording of partial expiratory flow – volume (PEFV) curve. Such a manoeuvre is easily obtained only in adults and children above the age of 6 years, because of the requirement for co-operation.

There are two methods which allow the forced expiratory flow-volume relationships to be examined in persons unable to perform a voluntary forced expiration: the forced deflation (NEP – negative expiratory pressure) and the rapid thoracoabdominal compression techniques. Both methods use an external pressure source to force the subject to exhale rapidly. In the forced deflation, this is achieved by exposing the airways to a negative pressure source resulting in rapid lung deflation. The NEP technique is restricted to persons with an artificial airway such as an endotracheal tube or a tracheostomy. The rapid thoracoabdominal compression generates a forced expiration by external application of positive pressure to the chest wall and abdomen thereby squeezing the air out of the lungs. This technique can be applied to spontaneously breathing and sedated infants.

Another spirometric technique useful in non-cooperating persons is tidal breathing analysis. The most frequently reported measurements are tidal volume (TV) and tidal flow-volume curve (TFV) [7].

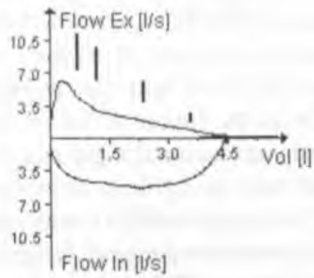
INTERPRETATION OF SPIROMETRY

Obtaining useful information from spirometry print-outs requires both adequate equipment and reproducible performance. The American Thoracic Society (ATS) and European Respiratory Society (ERS) have published guidelines for the standardisation of spirometry equipment and performance of pulmonary function tests. Spirometric equipment should be selected to meet ATS or ERS recommendations, and at



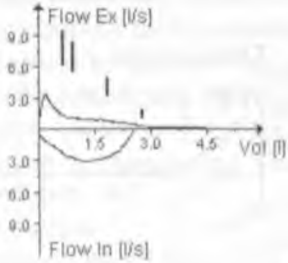
Parametr	Jedn.	Nalez.	Zmierz.	Procent
FEV 1	l	3.05	3.17	104
FVC EX	l	3.50	3.53	101
FVC IN	l	3.50	3.67	104
MEF 25	l/s	2.12	2.39	112
MEF 50	l/s	4.41	5.40	122
MEF 75	l/s	6.08	8.76	144
PEF	l/s	6.88	9.03	131
MEF 25/75	l/s	4.00	4.82	120
FEV1%FVC	%	87.10	89.89	103
PIF	l/s	5.85	4.66	79
MTT	s	0.61	0.52	85
TPEF	s		0.26	
VPEF	l		0.80	
AEX	l*l/s	15.40	16.58	107

Fig. 3 A. Normal flow – volume curve



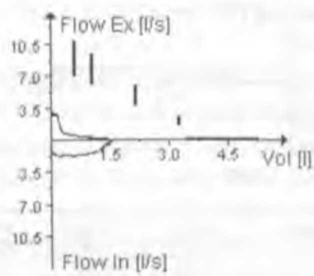
Parametr	Jedn.	Nalez.	Zmierz.	Procent
FEV 1	l	3.90	2.68	68
FVC EX	l	4.80	4.67	97
FVC IN	l	4.80	4.51	93
MEF 25	l/s	2.16	0.98	45
MEF 50	l/s	5.04	1.94	38
MEF 75	l/s	8.00	3.03	37
PEF	l/s	9.21	6.22	67
MEF 25/75	l/s	4.24	1.73	40
FEV1%FVC	%	81.28	57.45	70
PIF	l/s	8.82	5.36	60
MTT	s	0.73	1.14	156
TPEF	s		0.12	
VPEF	l		0.33	
AEX	l*l/s	24.19	10.29	42

Fig. 3 B. Mild obstruction



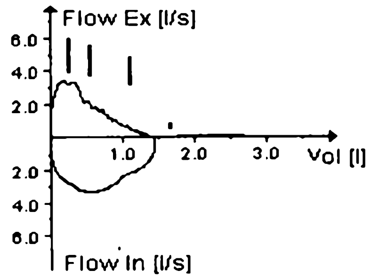
Parametr	Jedn.	Nalez.	Zmierz.	Procent
FEV 1	l	2.89	1.19	40
FVC EX	l	3.74	2.88	76
FVC IN	l	3.74	2.56	68
MEF 25	l/s	1.36	0.60	44
MEF 50	l/s	4.02	0.91	22
MEF 75	l/s	6.89	1.19	17
PEF	l/s	7.73	3.36	43
MEF 25/75	l/s	3.09	0.87	28
FEV1%FVC	%	77.27	41.15	53
PIF	l/s		3.07	
MTT	s	0.87	1.47	168
TPEF	s		0.27	
VPEF	l		0.20	
AEX	l*l/s	15.05	3.05	20

Fig. 3 C. Moderate obstruction



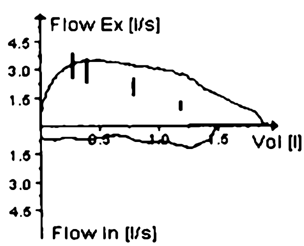
Parametr	Jedn.	Nalez.	Zmierz.	Procent
FEV 1	l	3.63	0.74	20
FVC EX	l	4.39	1.48	33
FVC IN	l	4.39	1.57	35
MEF 25	l/s	2.03	0.22	11
MEF 50	l/s	4.82	0.40	8
MEF 75	l/s	7.62	0.70	9
PEF	l/s	8.82	3.01	34
MEF 25/75	l/s	4.24	0.37	8
FEV1%FVC	%	82.79	50.44	60
PIF	l/s	8.40	1.79	21
MTT	s	0.70	1.41	201
TPEF	s		0.05	
VPEF	l		0.07	
AEX	l*l/s	21.15	1.06	5

Fig. 3 D. Severe obstruction and restriction



Parametr	Jedn.	Nalez.	Zmie'z.	Procent
FEV 1	l	1.77	1.21	68
FVC EX	l	2.25	1.36	60
MEF 50	l/s	3.96	1.62	41
PEF	l/s	4.91	3.44	69
MEF 25/75	l/s		1.41	
FEV1%FVC	%	78.51	88.93	113
TPEF	s		0.08	
VPEF	l		0.17	
AEX	l*l/s	8.91	2.28	25

Fig. 3 E. Restriction



Parametr	Jedn.	Nalez.	Zmierz.	Procent
FEV 1	l	1.28	1.90	147
FVC EX	l	1.60	1.92	120
FVC IN	l	1.60	1.49	93
MEF 25	l/s	1.04	1.84	176
MEF 50	l/s	2.04	3.04	148
MEF 75	l/s	2.90	3.53	121
PEF	l/s	3.15	3.53	111
MEF 25/75	l/s		2.91	
FEV1%FVC	%	80.35	98.64	122
PIF	l/s		1.15	
MTT	s	0.49	0.56	112
TPEF	s		0.37	
VPEF	l		0.48	
AEX	l*l/s	3.26	4.74	145

Fig. 3 F. Variable extra-thoracic obstruction

Fig. 3. Flow – volume curves: A/. Normal, B/. Mild obstruction, C/. Moderate obstruction, D/. Severe obstruction and restriction, E/. Restriction, F/. Variable extrathoracic obstruction

least daily monitoring and calibration must be done to obtain consistent and accurate results [1, 10]. Some of the spirometers sold in our country do not meet these recommendations. Testing should always be conducted at ambient temperatures between 17–40°C. The persons performing spirometry should pay attention to the accuracy of the test. They must demonstrate correct performance of a spirometry test, as well as describing it verbally, to the subject being tested. The following are, the criteria for acceptability and reproducibility [9, 15].

Criteria for acceptability include:

1/. Lack of artifact induced by coughing (Figure 4E), glottic closure (Figure 4C), or equipment problems (primarily leak),

2/. Satisfactory start to the test without hesitation (TPEF < 400ms) (Figure 4A),

3/. Satisfactory exhalation with six seconds of smooth continuous exhalation and/or a plateau in the volume-time curve of at least one second, or a reasonable duration of exhalation with a plateau.

Criteria for reproducibility after obtaining three acceptable spirograms include:

1/. Largest FVC within 0.2 L of next largest FVC,

2/. Largest FEV_1 within 0.2 L of next largest FEV_1,

3/. If the two above criteria have not been met, additional spirograms should be obtained. An acceptable spirogram should not be discarded even if it cannot be reproduced. Up to 8 efforts may be performed in order to meet acceptability and reproducibility criteria. The highest FEV_1 and FVC may be from different efforts. By contrast, FEF_{25-75}, flow – volume, and volume time curves should be reported from the best test curve. This is defined as the acceptable curve with the largest sum of FVC and FEV_1.

Spirometry should be interpreted using the flow – volume and volume – time curves. Normal values of FEV_1 and FVC are based on population studies and vary according to the gender, race, height and age. Computer spirometers express results as percentages of predicted normal values (PV). Values for FEV_1 and FVC that are over 80% of PV are defined as within the normal range. The FEV_1/FVC ratio expressed as a percentage in normal young individuals is at least 80. A ratio under 70% suggests obstruction of airways. However, the FEV_1/FVC ratio declines as a normal sequel of ageing.

A normal flow-volume curve has a rapid peak expiratory flow rate (TPEF < 400ms) with a gradual decline in flow back to zero (Figure 3A).

Obstructive lung diseases change the appearance of the flow-volume curve (Fig. 3 B, C, D). As with a normal loop, there is a rapid peak expiratory flow, but the curve descends more quickly than normal and takes on an concave shape, reflected by a marked decrease in FEF_{25-25}. With more severe disease, the peak becomes sharper and the expiratory flow rate drops precipitously. This results from dynamic airway collapse which occurs as diseased conducting airways are more rapidly compressed during forced expiratory efforts.

Restrictive lung disease does not change the shape of the flow-volume loop, but the overall size of the curve will appear smaller when compared to normals on the

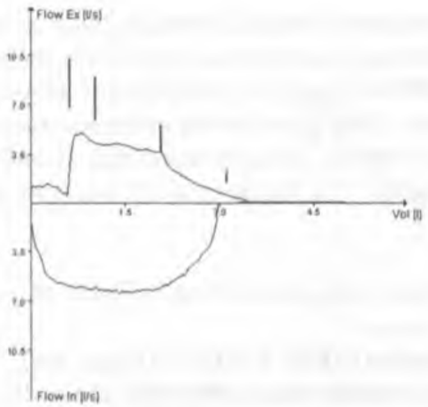


Fig. 4 A. Late onset of expiration

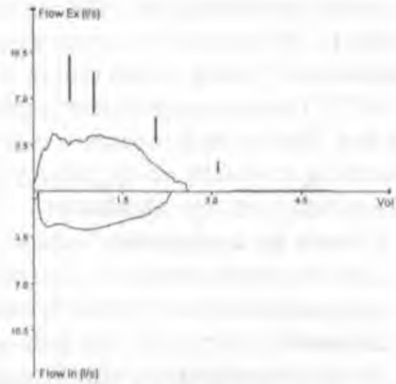


Fig. 4 B. Variable effort

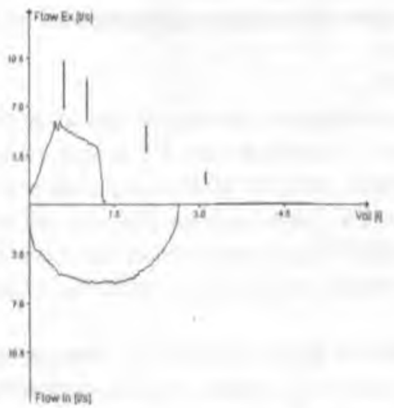


Fig. 4 C. Early glottic closure

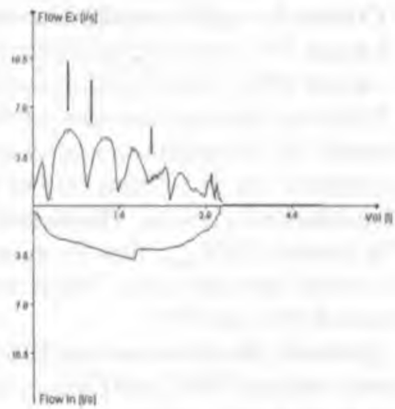


Fig. 4 D. Closing mouthpiece by tongue

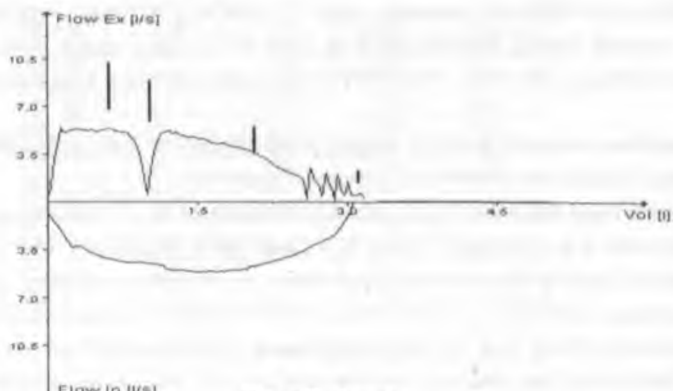
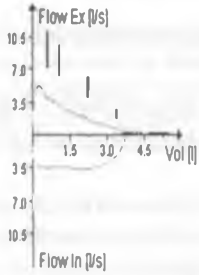


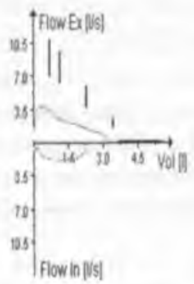
Fig. 4 E. Cough

Fig. 4. Different types of artifacts during Maximal Flow Volume manoeuvre: A. A late onset of expiration, B/. A variable effort during exhalation, C/. An early glottic closure, D/. Closing mouthpiece by tongue, E/. Cough during exhalation



Parametr	Jedn	Nalez	Zmierz1	Zmierz2	Procent
FEV 1	l	3.80	2.52	3.28	129
FVC EX	l	4.58	4.34	4.69	107
FVC IN	l	4.58	3.78	4.34	114
MEF 25	l/s	2.16	0.70	1.21	171
MEF 50	l/s	4.99	1.82	2.87	157
MEF 75	l/s	7.82	3.17	4.74	149
PEF	l/s	9.08	5.27	6.31	119
MEF 25/75	l/s	4.40	1.54	2.55	165
FEV1%FVC	%	83.07	58.09	69.94	120
PIF	l/s	8.64	3.70	4.54	122
MTT	s	0.68	1.19	0.85	71
TPEF	s		0.11	0.11	98
VPEF	l		0.28	0.40	140
AEX	l²/s	22.85	8.56	13.62	159

Fig. 5 A. Reversible obstruction



Parametr	Jedn	Nalez	Zmierz1	Zmierz2	Procent
FEV 1	l	3.68	2.28	2.37	103
FVC EX	l	4.62	3.38	3.64	107
FVC IN	l	4.62	2.39	2.68	112
MEF 25	l/s	1.95	1.24	1.29	103
MEF 50	l/s	4.80	2.02	2.28	112
MEF 75	l/s	7.79	3.09	3.31	107
PEF	l/s	8.88	3.76	4.14	110
MEF 25/75	l/s	3.87	1.93	2.08	108
FEV1%FVC	%	79.67	67.44	65.13	96
PIF	l/s	8.44	1.90	2.21	116
MTT	s	0.78	0.81	0.88	108
TPEF	s		0.17	0.25	147
VPEF	l		0.35	0.39	111
AEX	l²/s	22.19	6.85	7.93	115

Fig. 5 B. Ireversible obstruction

Fig. 5. Reversibility test registered as flow – volume curves: A/. A reversible obstruction, B/. Irreversible obstruction

same scale (Figure 3E). It is important to realize that restrictive lung disease cannot be diagnosed by spirometry alone.

Upper airway obstruction can be suggested by spirometry. Upper airway obstruction includes variable extrathoracic obstruction, variable intrathoracic obstruction and the fixed type of obstruction.

- As a result of extrathoracic obstruction caused by vocal cord paralysis, thyromegaly, tracheomalacia, or neoplasm the inspiratory portion of the flow volume loop can be changed and the expiratory part of the loop appears relatively normal (Figure 3F).
- A variable intrathoracic obstruction (tracheomalacia, neoplasm) mainly affects the expiratory part, giving a flattened appearance to that aspect of the curve.
- A fixed intrathoracic or extrathoracic obstruction affects both inspiration and expiration, giving a flow-volume loop that has an overall box-like shape. It could be caused by tracheal stenosis, foreign body, or neoplasm.

REVERSIBILITY TEST

An improvement in spirometry parameters after bronchodilators is known as the reversibility test. For its performance salbutamol, fenoterol or terbutaline are used. The reversibility test aids differentiation between asthma and chronic obstructive pulmonary disease. Attention should be limited to changes in the FEV_1 because interpreting changes in the FVC or FEF_{25-75} is likely to be complicated by varying lengths of expiration recorded before and after bronchodilators [2]. The ATS recommend that a pre- to post-bronchodilator increase in FEV_1 should be at least 12% of initial FEV_1 and at least 0.2 litres to be called significant [2]. The Global Initiative on Asthma and the NHLBI Lung Health Study regarded a 15% increase in FEV_1 as significant [3, 4]. A failure to achieve the above mentioned increase in FEV_1 post bronchodilator does not completely exclude the possibility of reversible airways disease.

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STRESZCZENIE

Badania czynnościowe układu oddechowego są bezbolesnymi testami oceniającymi różne funkcje płuc. Wśród nich można wymienić: klasyczną spirometrię, krzywą objętość – czas, różne odmiany krzywych przepływ – objętość, pletyzmografię, ocenę reaktywności oskrzeli, stężenie tlenku azotu w powietrzu wydychanym. W tym artykule zostały omówione jedynie niektóre zagadnienia związane z technikami spirometrycznymi. Wraz z rozwojem techniki powstawały nowe sposoby pomiarów spirometrycznych. Używając wodnego spirometru dzwonowego można było wykonać tzw. klasyczną spirometrię oceniającą objętości i pojemności oraz parametry nasilonego wydechu. Tego typu spirometry mogły przenosić infekcje. Nowsze spirometry mieszkowe (np. Vitalograph PFT) mierzyły tylko parametry wydechowe w postaci krzywej objętość – czas i dlatego możliwość przeniesienia zakażenia była minimalna. Najnowsze spirometry pneumotachometryczne połączone z komputerem pozwalają oceniać krzywą przepływ – objętość, a także spirogram klasyczny i krzywą objętość – czas. Wymienne pneumotachometry lub filtry pozwalają zapobiegać zakażeniom w czasie badania. Do oceny zaburzeń przepływu powietrza w drogach oddechowych u osób nie potrafiących współpracować (małe dzieci i osoby nieprzytomne) opracowano nowe techniki badania. Są to: pletyzmografia, pomiar krzywej przepływ objętość przy ujemnym ciśnieniu wydechowym (NEP) oraz wspomaganie wydechu przez zewnętrzny, pneumatyczny ucisk klatki piersiowej i brzucha. Wartość kliniczna dwóch ostatnich metod nie jest jeszcze ustalona.

Aby wynik badania czynnościowego płuc był podstawą do potwierdzenia lub wykluczenia diagnozy, test powinien być wykonany na atestowanym spirometrze przez doświadczoną osobę znającą zasady prawidłowego pomiaru. Badania przeprowadzone niezgodnie z wymogami nie mają żadnej wartości, a nawet mogą prowadzić do błędnych diagnoz i decyzji.

W oparciu o prawidłowo wykonane badanie spirometryczne możemy rozpoznać zaburzenie wentylacji typu obturacyjnego (astma oskrzelowa, przewlekła obturacyjna choroba płuc — POCHP). Do różnicowania astmy i POCHP przydatny jest tzw. test odwracalności oceniający stopień poprawy FEV_1 po przyjęciu leku rozszerzającego oskrzela. Spirometria pozwala także podejrzewać zaburzenia restrykcyjne, oraz zaburzenia przepływu powietrza w krtani i tchawicy.