

Use of a pocket-sized turbine spirometer in monitoring exercise-induced bronchospasm and bronchodilator responses in children

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For field studies of asthma, portable hand-held pulmonary function testing devices are required. Other than for peak flow measurements, little has been done to validate their use in children. Fifty children aged 5–15 years having asthma symptoms were examined using an exercise challenge (8 min free running outdoors) and a bronchodilation test (salbutamol inhalation at a dose of 0.15 mg/kg). Pulmonary function was measured with a turbine spirometer, with a Wright peak flow meter (WPEF) and with a flow–volume spirometer (FVS). A fall of 15% or more in peak expiratory flow associated with wheezing or cough was considered diagnostic for bronchial hyper-responsiveness to exercise (BHRE). A rise of 15% or more from baseline in peak expiratory flow after salbutamol inhalation was considered as a positive bronchodilator response (BDR). BHRE was present in 16 children (32%). Using the limit of a 15% or greater fall in FEV₁, turbine spirometry identified 12 as BHRE-positive and no additional cases, giving a sensitivity of 75% and a specificity of 100%. The turbine spirometer showed lower FEV₁ values than the FVS, the difference increasing with airway obstruction. BDR was positive in eight children (16%). Using the limit of a 10% or greater rise in FEV₁, turbine spirometry was positive in six cases. FEV₁ measured by turbine spirometry could not be used interchangeably with conventional FVS. However, the turbine spirometer offers the possibility to measure FEV₁ repeatedly in field conditions, such as during exercise challenges outdoors.

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Histamine and methacholine challenges are currently the most widely used tests for assessing the degree of bronchial reactivity. Exercise challenge consisting of free running outdoors is an alternative approach, simulating real-life conditions. Even young children can complete the test without major difficulties. The free running test has been recently standardized, and it has performed well in epidemiological asthma prevalence studies in children (1–3), although it also has been found to be quite an insensitive method (4). The bronchodilation test is used to demonstrate the reversibility of

bronchial obstruction. In both exercise challenge and bronchodilation tests, a change of 9–15% in forced expiratory volume in one second (FEV₁) has usually been considered as diagnostic (5–7). In peak expiratory flow (PEF), the respective criterion has been a 10–15% change (6,8).

The measurement of PEF is the most frequently used method for monitoring ventilatory function in young children during exercise challenges and bronchodilation tests. On the other hand, most authors regard FEV₁ as the most reliable single parameter reflecting ventilatory capacity in asthma; it is sensitive to changes in both large

and small airways, and it is assumed to be less effort-dependent than PEF (9). However, young children are usually unable to blow repeatedly to a flow-volume spirometer (FVS), and there are also practical difficulties in performing these measurements in outdoor conditions.

Pocket-sized spirometers allowing the measurement of FEV₁ offer many advantages over conventional flow-volume spirometers in everyday medicine; they are portable and easy to use, and therefore suitable for challenge tests and measurements outdoors. The main problem with these devices is that the flow-volume curve cannot be seen and so the reliability of the measurement is difficult to assess. This is of particular concern in children, whose blowing technique may be inadequate. In the turbine spirometer, the compact electronic sensor consists of a turbine flow-volume transducer attached to a hand-held control unit. The control unit integrates the impulses, calculates the values, and digitally displays the tracings, including the common parameters FEV₁ and PEF. In adults, the repeatability of FEV₁ using the turbine spirometer, as well as the correlation between turbine and flow-volume spirometers, has been good (10–12).

The aim of the present study was to determine whether the pocket-sized turbine spirometer could be used to measure exercise-induced bronchospasm and bronchodilator responses in children. If it proves to be reliable, the turbine spirometer provides an alternative for PEF measurements in outdoor settings. We evaluated the reliability of the turbine spirometer by comparing the baseline, post-exercise and post-bronchodilator FEV₁ values with those obtained from FVS.

Methods

Subjects

Fifty children (27 girls and 23 boys) aged 4.9–15 years (mean 10.7 years, SD 2.4) were enrolled in the study. The patients had suffered from respiratory symptoms suggestive of asthma (parental-reported wheezing and/or prolonged nocturnal cough) during the preceding 6 months. They had been referred to the Allergy Unit of Kuopio University Children's Hospital by general practitioners, and they were examined between 8 July 1997 and 16 February 1998. During the examination period, the outdoor temperature varied from +21.6 to –29.5°C, with a mean value of +2.9°C. All children were examined by one of the authors (S.K.).

Pulmonary function testing

In all children, turbine spirometry (TS) (Micro Plus; Micromedical Ltd, Rochester, UK) and flow-volume spirometry (FVS) (Medikro 905; Kuopio, Finland) were performed to measure forced expiratory volume in one second (FEV₁). In addition, PEF was studied by using a Wright's peak flow meter (WPEF) (Harlow, UK). The volume calibration of the spirometers was checked using a 3000 ml calibration pump (Sensor Medics, Yorba Linda, California, USA). TS and WPEF were measured in a random order prior to and 5, 10, 15 and 20 min after exercise, and 15 min after bronchodilator inhalation. FVS was performed only prior to and 10 min after exercise, and 15 min after bronchodilator inhalation. All measurements were repeated at least three times. The measurements in which the variation was less than 5% for FEV₁ and less than 20 l/min for PEF were accepted (13). The highest acceptable FEV₁ and PEF values were used in the analyses. The baseline, post-exercise and post-bronchodilator values were used to calculate the changes (in percentage).

Exercise challenge and bronchodilation test

The exercise challenge consisted of free running outdoors for 8 min to a heart rate > 170/min (about 85% of predicted maximum) (14). During the challenge the heart rate was monitored by a pulse meter (Polar Sport Tester, Polar Elektro Ltd, Kempele, Finland) at 1 min intervals. The children's lungs were auscultated prior to and two to three times after running. Symptoms and signs if present were registered. The outdoor air temperature reported by the Meteorological Institute Kuopio Department was recorded.

Twenty minutes after exercise, all children received inhaled salbutamol at a dose of 0.15 mg/kg (maximum 7.5 mg). Salbutamol inhalation was administered by ultrasonic nebulizer (Omron, Mannheim, Germany).

Bronchial hyper-responsiveness to exercise (BHRE) was defined as a fall of 15% or more in WPEF from the baseline with concomitant wheezing or cough symptoms after the free running test (FRT) (8).

The bronchodilator response (BDR) was positive if there was a rise of 15% or more in WPEF from the baseline measurements.

Statistical analysis

The data were analyzed using SPSS version 7.5 (SPSS Inc. Chicago, Illinois, USA). The

Kolmogorov–Smirnov test was used to check that the continuous variables were normally distributed.

The falls and rises in FEV₁ and WPEF were expressed as percentages from the baseline values. The differences between TS and FVS were calculated for FEV₁ (FEV₁ difference). These differences were plotted against the mean values of the corresponding parameters. The means of FEV₁ difference values were calculated to assess the limits of agreement (mean $\pm$ 2 SD) (15).

The two-tailed Student's *t* test was used to analyze differences in continuous variables between the patient groups. The effects of covariates were analyzed using univariate analysis of variance. The χ^2 test was used to analyze differences between the groups for non-continuous variables. If the expected value was 5 or less in at least one cell of the counting table, Fisher's exact test was used. Cohen's kappa values were calculated to evaluate the agreement between the results obtained by WPEF and TS. A kappa value of 0.8–1.0 indicates excellent agreement, 0.6–0.8 good agreement and 0.4–0.6 modest agreement.

Ethics

The study was approved by the Research Ethics Committee of Kuopio University Hospital. Informed oral consent was obtained from the parents of the children.

Results

At baseline, measurements of FEV₁ by FVS varied from 1.13 to 3.96 l and by TS from 1.16 to 3.64 l. WPEF values varied from 140 to 455 l/min. Both FEV₁ and PEF values were at least 78% of the predicted values, with a mean of 96% of the height-related reference values (95% CI 93–99%) (16,17).

BHRE was present in 16 (32%) of the 50 children, when a 15% or greater fall in WPEF and concomitant wheezing and/or cough were considered as a diagnostic finding. Wheezing, confirmed by auscultation, was present in 16 children; 15 of them showed a diagnostic decrease in WPEF. Correspondingly, 16 children suffered from cough symptoms, but only eight of them had a diagnostic fall in WPEF. The diagnostic fall in WPEF was present in 14 (88%) of the 16 BHRE-positive cases at 5 min, in nine cases (56%) at 10 min, in 11 cases (69%) at 15 min, but only in six cases (38%) at 20 min.

The mean TS FEV₁ fall at 5 min was 19.9% (95% CI 15.2–24.6%) in the 16 BHRE-positive cases, and

2.4% (95% CI 1.0–3.7%) in the 34 BHRE-negative cases ($p < 0.001$). TS identified 12 BHRE-positive cases when a fall in TS FEV₁ of 15% or more was considered as the diagnostic limit (Fig. 1). Thus, TS had a sensitivity of 75% and a specificity of 100%. The positive predictive value was 100% and the negative predictive value was 89%. The diagnostic fall in TS FEV₁ was present in all the 12 cases at 5 min, in eight cases (67%) at 10 min, in nine cases (75%) at 15 min, and only in seven cases (58%) at 20 min. The eight BHRE-negative children with cough symptom remained also negative in TS FEV₁ measurements. The kappa value was 0.80 between WPEF and TS.

BDR was positive in eight cases (16%) based on a 15% WPEF rise from the baseline values. Five (63%) of the BDR-positive cases were also BHRE-positive (Fig. 2). The mean rise in TS FEV₁ was 13.7% (95% CI 4.7–22.7%) in the eight BDR-positive cases and 1.8% (95% CI 0.1–3.5%) in the 42 BDR-negative cases ($p < 0.001$). Using the limit of a 10% rise, TS identified six positive BDRs; four of them had a diagnostic rise in WPEF. Using the 15% limit, TS found only three BDR-positive cases.

Before exercise, the mean difference for FEV₁ measured by TS and FVS was 0.08 l (95% CI 0.04–0.11 l) (3.6%), and the -2 SD limit of agreement was -0.33 l (14.5%) (Fig. 3). After

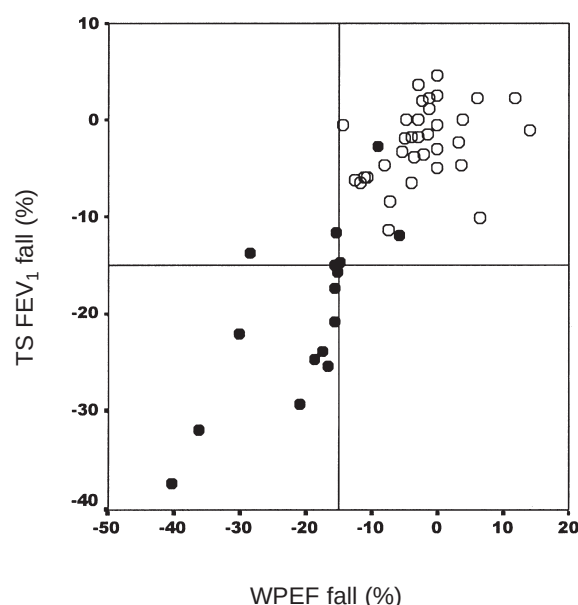


Fig. 1. Wright's peak flowmetry (WPEF) and turbine spirometry (TS) FEV₁ decreases in exercise challenge at 5 min. Decreases in TS FEV₁ and in peak expiratory flow (PEF) were calculated as percentages from the baseline values. Circles (●, positive; ○, negative) indicate the cases with bronchial hyper-responsiveness to exercise (BHRE), i.e. a 15% or greater fall in PEF any time (5, 10, 15 or 20 min measurements), associated with wheezing or cough symptoms.

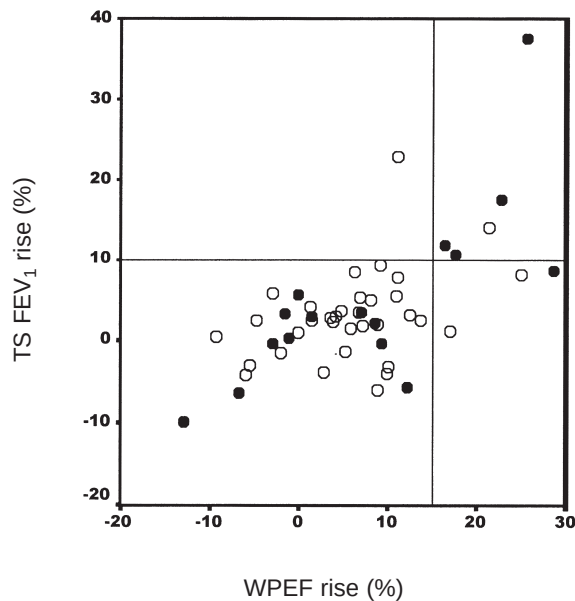


Fig. 2. Wright's peak flowmetry (WPEF) and turbine spirometry (TS) FEV_1 increases at 15 min after bronchodilator inhalation. Increases in TS FEV_1 and in peak expiratory flow (PEF) were calculated as percentages from the baseline values. A rise of 15% or more in PEF was considered as a positive bronchodilator response (BDR). Circles (●, positive; ○, negative) indicate the cases with bronchial hyper-responsiveness to exercise (BHRE). For definition of BHRE, see the text.

exercise, the mean difference for FEV_1 was 0.14 l (95% CI 0.10–0.17 l) (6.0%) and the respective -2 SD limit was -0.40 l (18.4%). This means that, after exercise, TS may show up to 0.4 l lower values than FVS. After bronchodilator inhalation, the mean difference for FEV_1 measured by TS and FVS was 0.10 l (95% CI 0.07–0.14 l), and the -2 SD limit for agreement was -0.36 l (15.4%). After running, FEV_1 falls were greater in TS than in FVS (mean difference 3.6%, 95% CI 2.0–5.3%, $p \leq 0.001$). In addition, FEV_1 difference was significantly greater in BHRE-positive than in BHRE-negative cases (Table 1).

Fifteen children underwent FRT when the air temperature was -5°C or lower, and four (27%) of them had a positive BHRE. When the air temperature was -20°C or lower, one of three children had a positive response. The confounding factor of air temperature was analyzed by univariate analysis of variance. The effect was significant for the 5 min WPEF values ($p < 0.05$).

Discussion

The exercise challenge by free running outdoors is attractive because a physiological stimulus to bronchoconstriction is likely to be more representative of everyday asthma balance than

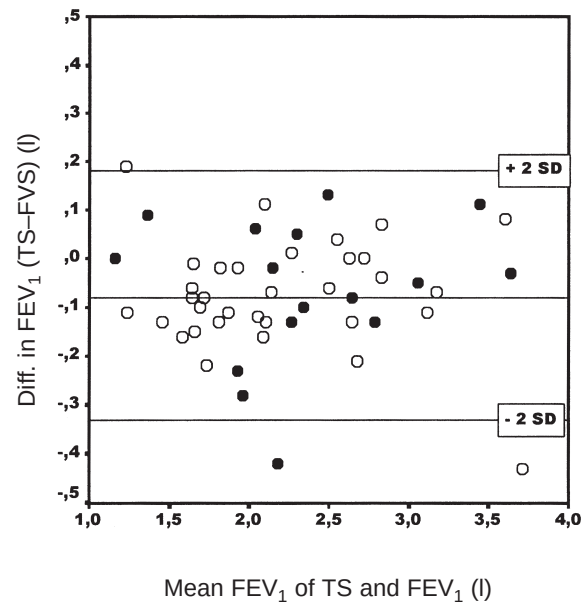


Fig. 3. Comparison of FEV_1 values obtained from the turbine spirometer (TS) and flow-volume spirometer (FVS). The differences between the methods have been plotted against the mean FEV_1 measured with the TS and FVS. Only the measurements before exercise were included. TS shows a mean value 0.08 l (4%) lower than FVS (mean difference). Limits of agreement: $+2$ SD = 0.18 l and -2 SD = -0.33 l. Circles (●, positive; ○, negative) indicate the cases with bronchial hyper-responsiveness to exercise (BHRE). For definition of BHRE, see the text.

pharmacological stimuli. Exercise challenge has proved to be more specific but less sensitive than histamine or methacholine challenges for the diagnosis of asthma in children (18,19). The free running test is simple to conduct, and even young children are able to complete the test without major difficulties. Hyperventilation of cold air is as sensitive a trigger for bronchial obstruction as histamine or methacholine inhalations (20). However, a young child may not adapt to the devices essential for provoking hyperventilation or inhaling cold or dry air in laboratory conditions. In the present study, we tried to combine these two stimuli, hyperventilation and cold air, by conducting the free running test outdoors.

Based on the European Respiratory Society recommendations, the 16 children with a 15% or greater fall in WPEF were regarded as BHRE-positive (8). However, PEF has greater intra-subject variability than FEV_1 , and it is not as sensitive as FEV_1 for small airway changes (21). So, PEF tends to underestimate the degree of pulmonary impairment in children. FEV_1 is commonly considered as the most reliable single parameter for overall ventilatory capacity, and it is therefore the parameter most frequently used in different challenge tests (22). For FEV_1 , a fall of

Table 1. The mean differences in FEV₁ values between turbine and flow-volume spirometry

	Whole study group (n = 50)	BHRE-positive cases (n = 16)	BHRE-negative cases (n = 34)	p value
FEV ₁ difference (l) before exercise	-0.08	-0.06	-0.08	0.676
FEV ₁ difference (l) after exercise	-0.14	-0.20	-0.11	0.040

15% is recommended as diagnostic for exercise-induced asthma in field conditions (22). Using this limit, FEV₁ was positive by TS in 12 children in the present study, having a sensitivity of 75% and specificity of 100%. A lower FEV₁ limit of 10% has been recommended for laboratory conditions (22). Using this limit, TS identified seven cases more, reaching a better sensitivity than WPEF. Haby et al. compared FEV₁ responses with clinical and other lung function data during exercise challenges in field conditions and considered the limit of 13% as optimal (3).

Paul and Schultz have suggested that FEV₁ may be overestimated when measured by TS (23). By contrast, we found that FEV₁ values were lower in TS than in FVS measurements. In both studies, the difference between the two spirometers increased in relation to airway obstruction, and the fall in FEV₁ after exercise was greater in TS than in FVS. These observations suggest that the diagnostic limits should be higher for TS than for FVS, especially for changes inducing bronchial obstruction. We used a high limit, 15%, for exercise-induced FEV₁ response. The change of the limit from 15% to 10% increased, as expected, the sensitivity of the test, but with no loss of specificity. This observation suggests that a limit lower than 15% should also be used for FEV₁ also when measured by TS in field conditions.

When the results were evaluated by the method described by Bland and Altman (14), we found that the 2 SD limits of agreement between TS FEV₁ and FVS FEV₁ varied from -18% to +8%. This shows a rather wide variation, and in fact is greater than usually accepted in conventional spirometry. Thus, TS can not be used interchangeably with FVS, but repeated TS measurements are suitable for short-term follow-up measurements, as are required during exercise challenges. In over 90% of the reactive cases, a significant fall in PEF and FEV₁ was seen as early as at 5 min after running. When PEF was followed, less than half were still positive at 10 min, and only occasional cases later. In FEV₁ measurements, in contrast, over half of the decreased values stayed as low until 20 min. A delayed response after 5 min was seen in only two cases. Later than 15 min there were no new positive responses. We conclude that, in exercise

challenges, the ventilatory functions should be measured for the first time within 5 min after exercise, and the measurements later than 15 min are useless. Only portable devices such as the WPEF and TS allow measurements outdoors shortly after running.

When performing challenge tests outdoors, the air temperature is an important confounding factor, which is difficult to take into account in the interpretation of the results. Our observations suggest that the air temperature plays some role in the results of FRTs and we may have missed few cases not studied in winter. In addition, in Finland, the cold air in winter is always very dry. Likewise, Eliasson et al. found that hyperventilation of dry air produced more bronchoconstriction than did the hyperventilation of cold humidified air (18).

In the present study, the bronchodilation test was seldom positive and identified only occasional new cases over exercise challenge. The test was insensitive regardless of whether PEF or FEV₁ was measured. This is predictable as the baseline ventilatory function was within normal limits in all individuals. Both exercise and bronchodilation tests were positive in 10% of all cases, reflecting the proportion of children with extensive bronchial lability. On the other hand, there were children with significant responses in the bronchodilation test only. Thus, the test should be included in the diagnosis of asthma despite of normal baseline lung function and negative exercise challenges.

In conclusion, TS shows distinctly lower FEV₁ values than FVS, and the difference increases with airway obstruction. TS cannot therefore be used interchangeably with conventional spirometers. However, in the exercise challenge and bronchodilation test TS had good sensitivity and specificity. We conclude that TS for the measurement of FEV₁ may be used in children in short-term follow-up studies, such as exercise challenges and bronchodilation tests.

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