Flow-volume measurements in children
Flow-volume measurements from childhood to adulthood

4.1

HGM Arets
CK van der Ent

Monaldi Arch Chest Dis 2000; 55: 4, 348-352
Abstract

Flow-volume curves are the most frequently used pulmonary function test during childhood. Even pre school children are sometimes able to perform the maximal effort breathing techniques, required for this pulmonary function test. We report on the most important conditions for reliable measurement of flow-volume curves at all ages. Especially testing atmosphere and equipment, pulmonary function technician requirements, testing procedure, reliability criteria, report making and interpretation are discussed.
Introduction

Pulmonary function testing (PFT) provides an objective method to place a disease into physiologic proportions. The combination of medical history, physical examination and PFT can elicit a clinical diagnosis. In this way PFT does not make, but can confirm a clinical diagnosis, monitor response to therapy and follow progression of disease. The most commonly used test to objectivate lung disease is the flow-volume curve. Results of flow-volume measurements can be presented graphically as flow-volume curves and as corresponding parameters of flows and volumes. More than hundred years after Hutchinson described spirometry, which still is the most basic PFT, the well-known flow-volume curve was described by Hyatt who plotted flow and volume on the y- and x-axes, respectively, of an oscilloscope. This graphic display of results has advantages over the use of spirometry. Simple visual inspection of the flow-volume curve is very useful as a screening method for peripheral airflow obstruction (e.g. asthma), upper airway obstruction (e.g. vascular rings), or restrictive lung disease, although especially restrictive lung disease can not definitely be proven by flow-volume curves. Interpretation of the numeric data of flow-volume measurements, as described in Table 1 takes more time, is less convenient and is less informative compared to interpretation of the graphic flow volume curves of the same patients, as presented in Figure 1. International guidelines for this technique have been developed, in order to guarantee standardised performance and interpretation world-wide.

Table 1. Lung function test results (expressed as percentage of predicted values) in patients with various conditions: a patient with peripheral airway obstruction (A), with central airway obstruction (B), and restrictive lung disease (C).

<table>
<thead>
<tr>
<th></th>
<th>PEF</th>
<th>FEV₁</th>
<th>MEF50</th>
<th>MEF25</th>
<th>FVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>90%</td>
<td>60%</td>
<td>35%</td>
<td>25%</td>
<td>100%</td>
</tr>
<tr>
<td>B</td>
<td>65%</td>
<td>100%</td>
<td>95%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>C</td>
<td>95%</td>
<td>60%</td>
<td>100%</td>
<td>100%</td>
<td>65%</td>
</tr>
</tbody>
</table>

Flow-volume curves of these three patients and a normal subject are shown in Figure 1.
Because of the relative simplicity to perform and to interpret flow-volume curves, this technique has widely entered paediatric practise. Respiratory diseases represent the most common cause of morbidity in childhood. In the Netherlands every paediatrician treats some 500–600 asthmatic children each year, for general practitioners this is about 170 children per year. Nowadays, the flow-volume curve is considered as 'gold standard' measurement for airway obstruction in children and many paediatric patients are tested in adult lung function labs. However, children are not small adults and a lot of child-specific items in the performance and interpretation of flow-volume curves can be overlooked, resulting in errors in diagnosis and treatment. This article reviews the most important differences in flow-volume measurement between children and adults.
Atmosphere

For many children the first visit to a pulmonary function laboratory can be considered as the beginning of a long (if not ever) lasting PFT career and “well begun is half done”. At this stage many things in the lung function lab can cause anxiety or distract the child. That’s why the testing area should be child-friendly and safe. No unpleasant experiences should be related to this area, so to test a child in the same area in which blood is drawn or painful examinations are performed will reduce the amount of co-operation and effort. The first contact with the lung function lab in children aged 5 to 7 years should be no more than a first acquaintance.

Working with children puts several requirements on the investigator. Pulmonary function technicians are often used to stress their adult patients to an utmost performance in a direct way. With children they should take time and pay special attention to welcome the child and to draw its attention from the beginning. They should be able to judge the developmental level of the patient and to explain and instruct the procedure in a catching way. A formal period of instruction and practice can enhance performance. Not every technician is able to work with children. Therefore, it is advisable to have a special lab for children, or to have a limited number of technicians who are specifically trained for children in the adult lab. The importance of a calm, success-oriented environment with an experienced tester cannot be overemphasised.

Most young children have a short span of concentration which can interfere with good results. The technicians’ custom to measure the next patient while the first is waiting for his bronchodilator effect can destroy the child’s motivation to do it’s best. Flow-volume measurements in children take much more time than in adults. For a routine flow-volume measurement with reversibility testing at least 30 minutes should be scheduled. When the management of the laboratory is not willing to take this time, children should not be measured.
Equipment

The lung function equipment should fit to children of several ages. This requires mouthpieces of different sizes to be available, permitting convenient closure of mouth and lips to every child. Improper mouthpieces can result in air leakage and can influence lung function results by changes in upper airway resistance and by trigeminal nerve stimulation. In adults most times a nose-clip is used. However, for flow-volume measurements this is not necessary and it can better be withheld from some children. The equipment should be height adjustable, to prevent flexion or extension of the neck because this can influence maximal expiratory flows. It has been advised to keep the child’s torso and head erect throughout testing in either sitting or standing posture. When measuring in sitting position often a footstool to support the feet is necessary to facilitate maximal expiratory manoeuvres.

Paediatric pulmonary function test equipment should have low inertia, be responsive to small changes in volume and flow. Also it must provide reproducible results. This “technical reproducibility” is a conditio sine qua non. One of, if not the, most important reason to require optimal equipment reproducibility is the fact that in all day clinical practice each patient is his or her own reference for future measurements (e.g. after bronchodilation, challenge or treatment).

Most flow-volume equipment uses commercial software. Software programmes should be explicitly developed for use in children. Apart from the routine requirements for adults (e.g. for flow range, calibration and BTPS corrections) the software should be provided with child specific options. An on-line presentation of flow-volume curves improves co-operation and endurance. Also artefacts (e.g. coughing) can easily be discovered.

The user must have the ability to introduce data on gender, height and weight and should be able to choose the right reference values (see below). Reports of lung function tests must show a flow-volume curve with appropriate scaling of the axes (see below).

When children are measured in a lung function lab, devices for adequate measurement of weight and height have to be available. The growth velocity in children ranges between 5 an 12 cm per year. Important deviations in lung function test results can emerge when recent growth data are not implemented in the measurement. For example, a healthy 12 years old boy who showed a FEV$_1$ of 100% predicted at the age of 11, can show FEV$_1$ of 80% predicted at the age of 12.
125% predicted when the technician fails to take and implement a current measurement of body height.

Children's performance of flow-volume measurements

The performance of a flow-volume curve implies an, especially for young children, relatively complicated manoeuvre, that requires maximal and forced expiratory and/or inspiratory efforts. In most cases of obstructive airway disease especially forced expiration parameters are desired. After a few tidal breaths the child is asked to inspire maximally from functional residual capacity to maximal inspiration, followed by a rapid, forced and complete expiration to residual volume. For detection of upper airway obstruction rapid, forced and complete inspiration follows maximal expiration. Pulmonary function technicians should support these maximal manoeuvres subjectively and control the child’s effort with each testing.

Reliability criteria

For adults reliability criteria have been defined by the ATS and ERS societies. Flow-volume measurements can be interpreted when the curve is technically acceptable and when it is reproducible (Figure 2). Criteria for technical acceptability and reproducibility are summarised in Table 2. Although many authors state that children can perform reliable flow-volume measurements from the age of about 5 years, most children can not reach the above mentioned criteria. Kanengiser and Dozor reported that even most children aged 3 to 5 years of age are able to co-operate and perform forced expiratory manoeuvres, but they failed to test for reliability criteria. Recent data from our own lung function lab showed that more than 90% of children aged 5 - 19 years can perform “technician accepted” flow-volume curves that reach the start-of-test criterion. A flow-volume curve with a rapid rise to peak flow and a sharp peak, nearly always has a back extrapolated volume (Vbe, (see Chapter 4.2, Figure 1)) of less than 5% of FVC as defined by the ATS-ERS (Table 2). However, the end-of-test cri-
terion (exhalation time of more than 6 sec) was reached in only a small minority of patients. We suggested to lower the minimally required exhalation time to 1 second in children below 8 years of age and to 2 sec in older children. A minimum of three technically acceptable manoeuvres should be repeated in order to judge reproducibility of the measurement (Figure 2). We have shown that the ATS-ERS reproducibility criteria (i.e. a difference between

Table 2. Criteria for acceptability and reproducibility of flow-volume curves as defined by ATS-ERS.

<table>
<thead>
<tr>
<th>Curve is acceptable if:</th>
<th>Curve is reproducible if:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Vbe is less than 5% of FVC or less than 0.15 l</td>
<td>- difference between highest and next highest FVC &lt; 200 ml</td>
</tr>
<tr>
<td>- Exhalation time is more than 6 sec</td>
<td>- difference between highest and next highest FEV$_1$ &lt; 200 ml</td>
</tr>
</tbody>
</table>
the highest FVC/FEV₁ and the next highest FVC/FEV₁, less than 200 ml) is not suitable for children. Especially in young children with small lung volumes, this criterion can easily be met despite considerable variability. A difference between highest and next highest FVC or FEV₁ values of less than 5% would be a more appropriate criterion for reproducibility in children¹³. After assessing technical acceptability and reproducibility the best flow-volume curve is defined as the curve with the highest sum of FEV₁ and FVC. This best curve can be used for interpretation (Figure 2).

**Reference values**

In general numeric results of flow-volume measurements are compared with reference values and are expressed as percentage of reference value, also called percentage of predicted. To be able to judge to what extent the reference values are acceptable in a particular situation, information is required about the population from which they are derived, and the circumstances during the measurement. Lung function results largely depend on height, gender and race of the patient. During childhood, especially during puberty, lung growth is not linearly related to height. It is definitely incorrect to extrapolate reference values form adult populations to paediatric values. Figure 3 shows that important differences exist between different reference value data sets. The figure shows that a healthy boy with a height of 130 cm and a FEV₁ value of 1.5 l has a predicted value ranging from 68 - 107 %, depending which reference data set is used. These findings show that it is extremely important to use an adequate reference value data set. Reference value data sets are most often obtained from relatively small groups of children and/or adults who are considered to be free from disease or circumstances, that influence testing (pulmonary disease, smoke (or other irritant) exposure, viral infections, etc.). These value sets are reduced to simple regression equations with standing height as the only independent variable. The reference population should match the patient with regard to sex, age, weight and height, genetic, ethnic and social background, and geographical location¹⁷. Unfortunately such reference values are not available in all countries and one should use the ‘best fitting’ population. In most modern lung function
measurement software a panel of reference value data sets is available.
In lung function laboratories for adults, the risk for the use of wrong refer-
ence values for children is more than imaginary when the lab is visited by
children only incidentally. Measurement of current height and selection of
the most adequate reference value data set should be a standard operating
procedure in every lung flow-volume measurement in children. Ideally
paediatric normal values are included in the software.

![Graph](image)

*Figure 3. Regression curves of 3 different sets of predicted values for FEV$_1$ in boys. A healthy boy with a
height of 130 cm and a FEV$_1$ value of 1.5 L has a predicted value of 68% according to set A (100% = 2.2
L), of 88% according to set B (100% = 1.7 L) or of 107% according to the extrapolated set of values in ado-
lescents in regression line C (100% = 1.4 L).*

**Report making**

Reports of paediatric flow-volume measurements should not be printed at
adult settings. Because, as stated above, the visual inspection of the curves is
the most important part of the interpretation of the test, curves should be
printed in a standardised way. The optimal way is to print the flow-volume
curve as large as possible, with the smallest possible scaling of the flow- and
volume axes in a 2 to 1 ratio (Figure 4). Discrete bronchial obstruction can
be easily overlooked when the flow-volume curve is printed too small, or
when the axis scales are too large (adult sizes in young children). When the
axes are changed in the computer software, the 2 to 1 ratio for flow and volume should be maintained in order to prevent changes in the shape of the curve which can lead to misinterpretations (Figure 4).

In most young children it is very difficult to perform both inspiratory and expiratory flow-volume curves in the same manoeuvre. Because most times the lung function technician will focus on the expiratory manoeuvre, it is advisable to print only the expiratory curves in order to prevent the interpretation of non-informative inspiratory curves.

The numeric data on the paediatric lung function report should be relevant and concise. In young children it is sometimes more relevant to print out $\text{FEV}_{0.5}$ values in stead of $\text{FEV}_1$ values. A main restriction is that, to our knowledge no normal values for $\text{FEV}_{0.5}$ are available. With the increasing use of flow-volume curves in pre school children this should be a main objective of further research. Inspiratory parameters should be left out if the inspiratory manoeuvre was not explicitly performed. Adequate reference value data for the different parameters should be given together with the parameters as percentage of predicted. For lung function parameter ratios

![Flow-volume curves of a healthy child printed with wrong axis-scaling. Discrete abnormalities can be overlooked when scales are too large (A) or misinterpretation can occur as restrictive lung disease (B) or upper airway obstruction (C) when scales are not printed in the standard 2 to 1 ratio for flow and volume.](image)

Figure 4. Flow-volume curves of a healthy child printed with wrong axis-scaling. Discrete abnormalities can be overlooked when scales are too large (A) or misinterpretation can occur as restrictive lung disease (B) or upper airway obstruction (C) when scales are not printed in the standard 2 to 1 ratio for flow and volume.
(e.g. FEV₁/FVC) no percentage of the reference value should be calculated, because a percentage of a percentage is most often not informative.

Use of incentives

During the last years several computerised visual incentives have been developed to stimulate young children to perform maximal forced breathing manoeuvres. For example, children are stimulated to blow out burning candles on the computer screen¹⁸ or to ring the bell by blowing up a balloon in the hands of a clown. Such programmes can be very helpful in the instruction of young children. The use of a programme with burning candles was proven to be helpful in 4 to 6 years old children¹⁸. When visual incentives are used, it is important to realise what is the trigger of the incentive. Incentives can be triggered by PEF, FVC or both. When incentives are triggered by e.g. PEF alone this can have unfavourable effects on other parameters, because children tend to stop their manoeuvre as soon as they have triggered the incentive¹⁹. In general, incentives are useful to instruct the manoeuvre, but they do not improve the results. Therefore, they should not be used in children who can perform forced breathing manoeuvres without these tools.
References

Forced expiratory manoeuvres in children: do they meet ATS and ERS criteria for spirometry?

4.2

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HJL Brackel
CK van der Ent

Eur Respir J 2001; 18: 655-660
Abstract

The aim of this study was to evaluate the applicability of ATS and ERS criteria for spirometry in children.

Methods: We studied maximal expiratory flow volume (MEFV) measurements of 446 school-age-children, experienced in performing MEFV manoeuvres and applied to these manoeuvres acceptability criteria (start-of-test (backward extrapolated volume as a percentage of FVC (Vbe%FVC) or as absolute value (Vbe)) and end-of-test (forced expiratory time (FET)) and reproducibility criteria (absolute and percentual difference between best and second best FVC and FEV1 (dFVCabs, dFVC%, dFEV1abs and dFEV1%)).

Results: The Vbe%FVC criterion was met by 91.5%, the Vbe <0.15L criterion by 94.8% and the Vbe <0.10L by 60.1% of children. Vbe <0.15L appeared to be a more useful parameter than Vbe%FVC. The FET criterion was met by only 15.3% of children. dFVCabs <0.2L and dFEV1abs <0.2L were met by 97.1% and 98.4% and dFVCabs <0.1L and dFEV1abs <0.1L by 79.8% and 84.3% of the children respectively. These criteria appeared to be less useful compared to percentual criteria (dFVC% and dFEV1%).

Conclusions: Even experienced children do not meet all international criteria for spirometry. However, most of their MEFV curves are useful for interpretation. Based on the performance of these children, we propose a re-evaluation of criteria for MEFV measurements in children.
Maximal expiratory flow volume (MEFV) measurements were introduced as a valuable tool in the assessment of respiratory disease in 1947. Since then MEFV measurement has become the cornerstone of pulmonary function testing (PFT) and the most widely used tool in diagnosis and follow up of both adults and children with respiratory illness. However, for young children, the technique of MEFV measurement is often more complicated, because they may lack co-ordination and co-operation. For these children, especially those under the age of 7 years, the instruction and performance of MEFV manoeuvres can be facilitated by the use of computerised visual incentives. In everyday practice MEFV curves are judged to be acceptable when they show a rapid rise to peak flow at the start and a subsequent gradual decrease of flow during the rest of the maximally prolonged expiratory manoeuvre. However, criteria as described by the ATS and ERS for acceptability and reproducibility of MEFV manoeuvres are lacking for (young) children. A summary of these criteria is

Table 1. Criteria for acceptability and reproducibility of MEFV curves as stated by the ATS and ERS.

<table>
<thead>
<tr>
<th>Acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of test criteria:</td>
</tr>
<tr>
<td>* Vbe%FVC &lt; 5% or Vbe &lt; 0.15 L (whichever is greater) (ATS)</td>
</tr>
<tr>
<td>* Vbe%FVC &lt; 5% or Vbe &lt; 0.10 L, (whichever is greater) (ERS)</td>
</tr>
<tr>
<td>End of test criteria:</td>
</tr>
<tr>
<td>* FET &gt; 6 seconds (ATS)</td>
</tr>
<tr>
<td>* Exhaustion of patient or plateau in volume-time curve (no volume change during 1 second) (ATS and ERS)</td>
</tr>
<tr>
<td>No coughing, Valsalva manoeuvre or hesitation (ATS and ERS).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reproducibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>dFVCabs &lt; 200 ml and dFEV₁abs &lt;200 ml (ATS)</td>
</tr>
<tr>
<td>* dFVC% &lt;5% or dFVCabs &lt;100 ml (whichever is greater) and dFEV₁% &lt;5% or dFEV₁% &lt;100 ml (whichever is greater) (ERS)</td>
</tr>
</tbody>
</table>
shown in Table 1. In daily practice, when children perform computer-controlled MEFV manoeuvres, the ATS or ERS criteria will be indicated most times as being not reached.

We investigated whether children with experience in lung function testing meet acceptability and reproducibility criteria for MEFV manoeuvres as defined by the ATS and ERS, during routine PFT. For criteria that were not met by these children, new criteria are proposed.

Patients and methods

All MEFV measurements were performed using a pneumotachometer system with a heated Lilly head (MasterScreen Pneumo and Jaeger Masterlab, Erich Jaeger, Würzburg, Germany). Equipment calibration was performed conform ECSC (European Community for Steel and Coal) guidelines.4 All measurements were BTPS corrected. Measurements were performed with the child sitting straight and wearing a nose clip. Only pre-bronchodilator manoeuvres were evaluated.

Most patients were known with recurrent respiratory symptoms, mostly due to obstructive pulmonary disease such as asthma and cystic fibrosis or recurrent pulmonary infections. A minority of patients were seen preoperatively (e.g. for scoliosis, pectus excavatum) or after chemotherapy.

In the period between January 1997 and January 1999 852 children (436 boys) performed 8388 MEFV tests at the PFT laboratory. We selected all children who were experienced in performing MEFV measurements, i.e. they had previously performed MEFV manoeuvres on at least two earlier occasions. The children were optimally encouraged and performed, after full inspiration, a maximally forced and prolonged expiration. Their MEFV manoeuvres were acceptable, according to our trained and experienced pulmonary function technicians, when the flow-volume curves showed: 1) a rapid rise to peak flow and 2) a full, maximally prolonged expiratory curve, shown by a gradual, asymptotic approach of the curve to the volume axis. If necessary, especially for the first MEFV tests in young children, a computerised visual incentive was used to stimulate this manoeuvre. This consisted of a peakflow triggered series of burning candles on the computerscreen.2 All MEFV curves with a gradual rise to peak flow, with blunt peaks and/or with sudden end expiratory drop of flow to the volume axis...
were not accepted for further evaluation. All children performed at least three technician-accepted curves and for each child the two curves with the highest sum of FVC and FEV\textsubscript{1} during the last PFT were used for final analysis\textsuperscript{5}.

Finally, we could evaluate 446 children (age range 5-19 years) who had performed MEFV manoeuvres on an average of 16.7 occasions. Patient characteristics are given in Table 2.

Table 2. Patient characteristics: mean values (SD, range).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean (SD, range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male/female</td>
<td>234/212</td>
</tr>
<tr>
<td>Age (years)</td>
<td>12.1 (3.5, 5-19)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>43.3 (15.8, 17-83)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>151.2 (17.9, 107-188.5)</td>
</tr>
<tr>
<td>FEV\textsubscript{1} %pred</td>
<td>95.5 (25.0, 26.5-155.0)</td>
</tr>
<tr>
<td>FVC%pred</td>
<td>95.6 (20.1, 28.4-142.6)</td>
</tr>
<tr>
<td>FEV\textsubscript{1} %FVC</td>
<td>83.6 (11.1, 44.5-100)</td>
</tr>
</tbody>
</table>

were not accepted for further evaluation. All children performed at least three technician-accepted curves and for each child the two curves with the highest sum of FVC and FEV\textsubscript{1} during the last PFT were used for final analysis\textsuperscript{5}.

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<td>FEV\textsubscript{1} %FVC</td>
<td>83.6 (11.1, 44.5-100)</td>
</tr>
</tbody>
</table>

Figure 1. Method to determine the backextrapolated volume (Vbe) from a volume-time curve. Vbe should be <5% of the FVC to represent an acceptable start of forced expiration.
We evaluated whether these technician-accepted curves met the ATS and ERS criteria\textsuperscript{3,4} for acceptability and reproducibility (Table 1): backward extrapolated volume (Vbe) as an absolute value and as percentage of FVC (Vbe\%FVC) (Figure 1) for the start of test and the forced expiratory time (FET) for the end of test. The best value of the two curves of each patient was used for evaluation of acceptability criteria. Reproducibility was evaluated by the absolute and percentual difference between forced vital capacities (dFVC\textsubscript{abs} and dFVC\%\textsubscript{abs}) and the absolute and percentual difference between forced expiratory volumes in 1 sec (dFEV\textsubscript{1}\textsubscript{abs} and dFEV\textsubscript{1}\%\textsubscript{abs}) of the two best curves out of a minimum of three curves per individual.

Time to peak flow (tPEF) as start of test criterion, mentioned in earlier standardisation reports\textsuperscript{6} but not accepted in later consensus reports\textsuperscript{3}, was also analysed.

All values of ATS and ERS criteria were also related to age, height, gender and pulmonary function results. In order to be able to propose new criteria we calculated the values that could be achieved by 90\% of the children studied.

**Statistical analysis**

Mean values (SD, range) were calculated for all criteria. Correlations between criterion values and age, height and pulmonary function were studied with Pearson’s correlation coefficients.

Differences between separate groups were analysed using unpaired t-tests. A p-value < 0.05 was considered statistically significant.
Results for the different criteria are given in Tables 3 and 4.

Acceptability criteria: start of test

**Vbe%FVC**
The Vbe%FVC was < 5% in 91.5% of all patients. The mean best Vbe%FVC was 3.3 (+1.7, 0.7-9.5)% (Table 3 and 4). The Vbe%FVC was weakly though significantly related to height, age and pulmonary function (Table 4). 77.2% of children under the age of 8 years was able to reach this criterion (Table 3 and 4).

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**Table 3. Percentages of ‘technician-accepted’ MEFV curves that meet the ATS and/or ERS acceptability and reproducibility criteria.**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>&lt;8yr. (n=36)</th>
<th>8-11yr. (n=175)</th>
<th>12-15yr. (n=146)</th>
<th>&gt;15 yr. (n=89)</th>
<th>Total (n=446)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vbe%FVC &lt; 5%</td>
<td>77.2</td>
<td>80.6</td>
<td>91.7</td>
<td>96.5</td>
<td>91.5</td>
</tr>
<tr>
<td>Vbe &lt; 0.15L</td>
<td>97.5</td>
<td>95.6</td>
<td>94.5</td>
<td>85.4</td>
<td>94.8</td>
</tr>
<tr>
<td>Vbe &lt; 0.10 L</td>
<td>77.8</td>
<td>61.7</td>
<td>59.6</td>
<td>50.6</td>
<td>60.1</td>
</tr>
<tr>
<td>tPEF &lt; 0.1sec</td>
<td>75.3</td>
<td>77.8</td>
<td>89.9</td>
<td>92.0</td>
<td>84.7</td>
</tr>
<tr>
<td>FET &gt; 6sec</td>
<td>8.6</td>
<td>13.3</td>
<td>15.6</td>
<td>36.0</td>
<td>15.3</td>
</tr>
<tr>
<td>dFVC abs &lt; 200ml</td>
<td>100</td>
<td>99.5</td>
<td>94.5</td>
<td>95.5</td>
<td>97.1</td>
</tr>
<tr>
<td>dFVC abs &lt; 100ml</td>
<td>91.7</td>
<td>85.7</td>
<td>74.7</td>
<td>70.8</td>
<td>79.8</td>
</tr>
<tr>
<td>dFVC% &lt; 5%</td>
<td>82.7</td>
<td>89.8</td>
<td>85.6</td>
<td>89.5</td>
<td>87.9</td>
</tr>
<tr>
<td>dFEV1 abs &lt; 200ml</td>
<td>100</td>
<td>99.0</td>
<td>98.2</td>
<td>97.5</td>
<td>98.4</td>
</tr>
<tr>
<td>dFEV1 abs &lt; 100ml</td>
<td>91.7</td>
<td>90.9</td>
<td>78.1</td>
<td>79.8</td>
<td>84.3</td>
</tr>
<tr>
<td>dFEV1% &lt; 5%</td>
<td>91.4</td>
<td>85.7</td>
<td>87.2</td>
<td>88.5</td>
<td>87.2</td>
</tr>
</tbody>
</table>
Table 4. Mean values (SD, range) of ATS and ERS acceptability and reproducibility criteria, gender differences and Pearson's correlation coefficients (R) for age, height and pulmonary function.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Mean(SD, range)</th>
<th>Age</th>
<th>Height</th>
<th>Gender</th>
<th>FEV1%pred</th>
<th>FVC%pred</th>
<th>FEV1%FVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vbe%FVC(%)</td>
<td>3.3 (1.7, 0.7-9.5)</td>
<td>-0.30**</td>
<td>-0.45**</td>
<td>n.s.</td>
<td>0.15*</td>
<td>0.23**</td>
<td>0.14*</td>
</tr>
<tr>
<td>Vbc(l)</td>
<td>0.09 (0.03, 0.04-0.24)</td>
<td>0.14*</td>
<td>0.27**</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>tPEF(sec)</td>
<td>0.07 (0.03, 0.01-0.22)</td>
<td>-0.28**</td>
<td>-0.28**</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.17*</td>
</tr>
<tr>
<td>FET(sec)</td>
<td>4.3 (2.5, 0.5-18.7)</td>
<td>0.30**</td>
<td>0.20**</td>
<td>n.s.</td>
<td>0.50**</td>
<td>0.20</td>
<td>0.72**</td>
</tr>
<tr>
<td>dFVCabs(ml)</td>
<td>58 (50, 0-280)</td>
<td>0.19**</td>
<td>0.30**</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.14*</td>
</tr>
<tr>
<td>dFVC(%)</td>
<td>2.3 (2.1, 0-10.7)</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.29**</td>
<td>0.24**</td>
<td>0.19**</td>
</tr>
<tr>
<td>dFEV1abs(ml)</td>
<td>51 (50, 0-330)</td>
<td>0.20**</td>
<td>0.28**</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>dFEV1%(%)</td>
<td>2.5 (2.7, 0-14.6)</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.31**</td>
<td>0.28**</td>
<td>0.18**</td>
</tr>
</tbody>
</table>

n.s. = not statistically significant; * = P < 0.01; ** = P < 0.001
Vbe
The Vbe was < 0.15 L in 94.8% of the children. The mean best Vbe was 0.09 (0.03, 0.04-0.24) L. The Vbe was significantly related to height and age (Table 4).

tPEF
A tPEF < 0.10 sec was seen in 84.7% of all children. Mean tPEF was 0.07 (0.03, 0.01-0.22) sec. tPEF was significantly inversely related to height and age, with better results in older children (Table 3 and 4).

Acceptability criteria: end of test

FET
During maximal stimulation the maximal forced expiratory time (FET) was < 6 sec in 84.7% of all children. Mean FET was 4.3 (2.5, 0.5-18.7) sec. There was a significant relationship of FET with age and height, but especially with parameters of airway patency (Table 4).

Reproducibility criteria

dFVCabs
The absolute difference between the two highest FVCs (dFVCabs) was < 200 ml in 97.1% of children. The mean dFVCabs was 58 (50, 0-280) ml. dFVCabs was significantly related to age and height, but not to gender (Table 4). All patients in the youngest age group and 95.5% in the oldest age group met this criterion (Table 3).

dFVC%
dFVC% < 5% as a criterion for reproducibility was met by 87.9% (Table 3) of children. Mean dFVC% was 2.3 (2.1, 0-10.7)% . In the older age group a higher proportion of the children reached the criterion, but correlation with both height and age was not statistically significant. There was a weak, although significant correlation between pulmonary function and dFVC% (Table 4).
**dFEV\textsubscript{1}\text{abs}**

Differences between the two highest FEV\textsubscript{1}'s (dFEV\textsubscript{1}\text{abs}) were < 200 ml in 98.4% of all children. All patients in the youngest age group and 97.5% in the oldest age group met this criterion (Table 3). The mean dFEV\textsubscript{1}\text{abs} was 51 (50, 0-330) ml. The dFEV\textsubscript{1}\text{abs} was significantly related to age and height (Table 4).

**dFEV\textsubscript{1}\%**

The percentual differences between the two highest FEV\textsubscript{1}s (dFEV\textsubscript{1}\%) were < 5% in 87.2% of the children (Table 3). The mean dFEV\textsubscript{1}\% was 2.5 (2.7, 0-14.6)% and there was no significant correlation with height or age, but a weak, although significant, correlation with pulmonary function (Table 4).

**Feasibility**

Table 5 gives the values of the different criteria, achievable by 90% of the children. The end of test criterion of FET > 6 sec is the least feasible criterion, especially in the younger age group (Table 3).

| Table 5. Cut-off points for acceptability and reproducibility criteria for values which can be achieved by 90% of the study population. |
|---|---|---|---|---|---|
| Criterion | <8 yr. (n=36) | 8-11 yr. (n=175) | 12-15 yr. (n=146) | >15 yr. (n=89) | Total (n=446) |
| Vbe\%FVC (%) | 6.4 | 5.8 | 4.6 | 4.2 | 5.4 |
| Vbe (L) | 0.11 | 0.12 | 0.12 | 0.16 | 0.13 |
| tPEF (sec) | 0.11 | 0.12 | 0.10 | 0.09 | 0.11 |
| FET (sec) | 1.3 | 2.1 | 1.8 | 2.1 | 1.8 |
| dFVC\textsubscript{abs} (ml) | 83 | 101 | 159 | 150 | 127 |
| dFVC\% (%) | 5.0 | 4.9 | 5.6 | 4.7 | 5.3 |
| dFEV\textsubscript{1}\text{abs} (ml) | 60 | 92 | 128 | 136 | 110 |
| dFEV\textsubscript{1}\% (%) | 4.7 | 6.3 | 6.7 | 5.4 | 6.2 |
Discussion

The majority of the children studied could perform acceptable flow-volume manoeuvres according to the ATS and ERS start-of-test criteria, but only a minority of the children exhaled as long as required by the ATS, notwithstanding the curves were judged to be acceptably performed. When the absolute difference in FVC or in FEV₁, as proposed by the ATS, was taken as a criterion of reproducibility, this was easily met by the majority of children. Despite these findings, most of the criteria showed dependency of age and height, which precludes the applicability of these criteria for children of all ages. In children we consider absolute criteria to be less suitable, especially when they are age dependent and designed for adults. The focus should be on the applicability of relative criteria which are designed to control for changes in the absolute magnitudes of measurements with (pulmonary) growth. Apart from growth, in childhood many other factors may influence the results of pulmonary function testing, such as time and patience of the PFT technician, equipment, use of incentives and disease state. To perform acceptable and reproducible MEFV manoeuvres the child should be able to blow out forcefully, immediately after maximal inhalation, and to continue forced expiration until no further air can be expired. The instruction and control of technique, combined with sufficient patience requires a well-trained pulmonary function technician, able to cope with and to encourage children and able to judge the expiratory process. Several groups reported successful MEFV measurements in young children. Kanengiser and Dozor reported that many 3-5 year old children are able to co-operate and perform rudimentary forced expiratory manoeuvres that are reproducible, but reliability could not be assumed and hardly any MEFV curve met the ATS criteria for acceptability. Le Soeuf and colleagues found that children can perform adequate forced expiratory manoeuvres from the age of 4-5 years.

The present study investigates the applicability of the currently officially accepted reliability criteria, as defined by the ATS and the ERS working groups.
Start of test criteria

In young children the initial efforts to produce a sharp peak flow are often not very rapid in onset. The present study shows that with guidance of a well-trained technician the majority of experienced children can reach the current start-of-test criteria.

In earlier reports on spirometry criteria, tPEF was described as a start of test parameter. If applied, a good start of the forced expiratory manoeuvre (i.e. tPEF < 0.10 sec) was seen in 84.7% of children. For PEF meters the use of dwell and rise time for PEF as recently described by Miller et al. needs further study and has not been used in MEFV manoeuvres in children. Their results showed that especially males and asthmatics have shorter “start times” compared to women and non-asthmatics. In the present study the percentage of children who reached a peak flow within 0.1 second was rather low compared to the current ATS and ERS start of test criteria and therefore would exclude MEFV measurements in a considerable number of children. Therefore, our study supports the former recommendation not to use tPEF as a criterion of acceptability.

Our study indicates that the subjective criterion of a ‘rapid rise to peak flow’, often estimated by eye by pulmonary function technicians, is sufficient to select acceptable curves. Optimally, criteria for acceptability should be independent from age or height. However, our data show that none of the ATS start-of-test criteria are independent from growth. Age and height are negatively correlated with Vbe%FVC and positively correlated with Vbe. This can be explained by the rise in FVC during growth.

The parameter Vbe, although an “absolute” parameter, is most independent from age and height and therefore this parameter seems to be the most appropriate start-of-test criterion. The Vbe < 0.15 L criterion was met by over 94.5% of children under the age of 15 years and 85.4% of children aged 15 years and older (Table 3). The ERS criterion of Vbe < 0.10 L excludes up to 50% of MEFV curves in older children. We suggest to adjust the advised minimal Vbe to 0.12 L in children aged < 15 years; in that case 90% of children would be able to reach the acceptability standard (Table 3).

End of test criteria

The second part of the MEFV manoeuvre was far more difficult to perform for children. The ATS criterion for acceptability demands a minimal FET
of 6 sec, unless there is an obvious plateau in the volume time curve display. The ATS recommendations state that in children shorter exhalation times are acceptable, but fail to be more specific. The ERS working group does not present numeric criteria for maximally prolonged expiration. In this study all children had extensive experience with lung function testing and were maximally encouraged to reach complete exhalation. Nevertheless only 36% of the oldest age group in our study exhaled for over 6 seconds. Although mean FET rises with age, even adolescents not always exhaled (forcefully) during more than 6 seconds, making this criterion unsuitable for use in paediatric practice.

Desmond et al found comparable results. In their study a minimal FET of 6 seconds was reached by 28% and 7% of children over and under the age of 7 years respectively. In contrast a recent study by Enright et al. showed that display of a real time tracing of exhaled volume versus time, used to stimulate subjects and PFT technicians, allowed higher FETs in children over the age of 9 years. However, start-of-test criteria were less easily reached, compared to our group of children. These results show that the use of a particular device will enable more children to satisfy specific criteria but probably not all criteria. In our study we considered a complete expiration and not an exhalation time of 6 seconds as the goal of MEFV measurement. We endorse the statement of Enright and co-workers that underestimation of the FVC is not clinically very important when monitoring children with obstructive pulmonary disease. Therefore, when necessary, especially in inexperienced and young children, we recommend the use of computerized visual incentives that visually stimulate especially a rapid and forced start of maximal expiration such as images of burning candles.

Warwick et al. described that young children may empty their lungs within 1 sec because of small lung volumes. This causes the FEV$_1$ to be equal to FVC and could reduce the usefulness of FEV$_1$ and FEV$_1$/FVC as an index of airway obstruction. Kanengiser stated that for this age group the FEV$_{0.5}$ could be more appropriate for determination of airway obstruction. As could be expected the degree of airway obstruction was positively related to the FET. The correlation of FET with age was more evident than with height (Table 4), which suggests that apart from lung volume also ageing, and therefore probably effort and co-operation, influences FET. Although Enright et al. found better results using specific stimulation one may question how many adults can reach this FET criterion during routine pulmonary function testing.
In our study we defined time criteria which were reached by 90% of children. Assuming that the flow volume curve shows no abrupt termination of expiratory flow and/or the volume time curve shows a plateau (Table 5) we propose to decrease the minimal FET to 2 seconds for children over the age of 8 years and to 1 second for children under the age of 8 years. Other researchers suggested to take 3 sec or 4 sec as goals for exhalation times. Our data show that when children reach a FET of at least 2 seconds, this confirms a maximal effort in more than 90 percent of children.

Reproducibility

In our study the children, especially the younger ones, had no problems in meeting the “absolute volume” criteria for reproducibility (Table 3). This is to be expected because of small lung volumes in children, but does not guarantee reproducibility. Reproducibility criteria using absolute differences for both FVC and FEV₁ are significantly influenced by age and height (Table 4). Criteria using the relative difference as mentioned by the ERS are not correlated with either age or height and therefore seem to be more appropriate in paediatric practice. The 5% difference criteria was reached by 87.9% and 87.2% of children for FVC and FEV₁, respectively (table 3). Increasing these numbers to 90% would require a cut-off point of 5.3% for FVC and 6.2% for FEV₁ (Table 5). The current 5% criteria seems to be more useful in childhood than the absolute criterion of 100 or 200 ml.

It should be stressed that all children in our study were experienced with MEFV manoeuvres. Most children underwent regular PFT during visits to the outpatient clinic. The mean number of PFTs performed by the children before the study was rather high. This means that for inexperienced children several attempts may be necessary to reach the same skills and results. As it could be the start of a “pulmonary testing career” that may last for many decades in children with chronic respiratory symptoms it is important for inexperienced children to become familiar with the procedure and especially use the first laboratory visits to adapt to the situation and get a positive experience. If the first “PFT battle” is lost one may loose a good compliance and performance in later visits.
Conclusion

Even MEFV manoeuvres of experienced children do not reach the goals of all ERS and ATS criteria. However, most of their MEFV curves are useful for interpretation. We propose a re-evaluation of international criteria for MEFV measurements in children. Based on evaluation of MEFV measurements in 446 experienced children we propose as minimum criteria:

Start of test: Vbe < 0.12 L (<15 years) and < 0.15 L (>15 years); end of test: FET > 2 sec (>8 years) and FET > 1 sec (<8 years), provided that complete exhalation with a gradual, asymptotic approach of the flow volume curve to the volume axis is seen; reproducibility: dFEV₁ and dFVC < 5%.
References


