REVIEW

Airway resistance measurements in pre-school children with asthmatic symptoms: The interrupter technique

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Summary Measuring airway resistance in pre-school children with the interrupter technique has proven to be feasible and reliable in daily clinical practice and research settings. Whether it contributes to diagnosing asthma in pre-school children still remains uncertain. From the results of previous studies a need for standardisation of the technique has emerged. In this overview we will elaborate on research concerning the position of the interrupter technique in the difficult process of diagnosing asthma in pre-school children.

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Interrupter technique; Pre-school children; Asthma; Lung function
Introduction

Diagnosing asthma in pre-school children is challenging. Many pre-school children present with asthmatic symptoms such as cough, wheezing and shortness of breath, but only part of them actually has developed or will develop asthma. To predict which young child will remain symptomatic and has asthma is to a certain extent based on an interpretation and knowledge of epidemiological derived evidence about risk factors. However, asthma in early childhood is mainly a clinical diagnosis. To be able to distinguish between children who suffer from asthma and children who experience symptoms originating from other causes, would allow an early therapeutic intervention and therefore enhance a more normal lung development in asthmatic children.

Lung function parameters could support the clinical diagnosis of asthma. However, most techniques such as spirometry depend on effort and co-operation of the patient and are not applicable in pre-school children. Therefore lung function measurements that require only passive co-operation and are non-invasive, such as the interrupter technique, could be helpful.

The interrupter technique is developed to measure airway resistance ($R_{in}$) during spontaneous breathing and is therefore very suitable to be used in this group of young patients. The most favourable quality of the interrupter technique is that it only requires passive co-operation making it an appropriate way to assess airway resistance in young children.

In addition to the clinical use of lung function, it could also have value in research, for objective parameters—as obtained from the interrupter technique—are needed in research concerning young children with asthmatic symptoms. Until now, primary study outcome parameters in pre-school children have been predominantly subjective: mostly a parental view on their child’s symptoms, using a diary. Objective endpoints would be less influenced by behavioural components and standardised measurements enable a better comparison with the results from other studies.

The technique has shown to be feasible, valid, sensitive and specific for diagnosing asthma in older children who are also able to perform spirometry (this article). However, a major problem in detecting sensitivity and specificity of a lung function test for diagnosing asthma in pre-school children is that a gold standard for the diagnosis of asthma does not exist for this group. Consequently, every attempt to establish the sensitivity and specificity of such a method in this age group will lead to an approximate estimation of these two qualities, which might subsequently be confirmed or rejected when children are old enough to confirm or reject asthma diagnosis (mainly by means of airway responsiveness tests using spirometry).

In this article we will review the relevant properties and limitations of the interrupter technique regarding its use in clinical practice and research in (pre-school) children and we will conclude with a number of recommendations for standardised use.

Mechanism of the interrupter technique

The interrupter technique is a non-invasive method to measure airway resistance (Fig. 1). The child is sitting in an upright position with the head in a neutral position, and breathes quietly through a mouthpiece (nose clipped) or facemask that is connected to a flow meter and a pressure transducer to measure airflow and pressure. The technique is based on the assumption that during a short interruption (100 ms) of the airflow, while spontaneously breathing through this mouthpiece, mouth pressure changes in time. This pressure change is shaped by airway characteristics and can be divided into two phases: the first rapid pressure increase followed by an oscillatory phase represents the actual pressure change in the airways, the second slow pressure increase phase is a result of gas redistribution and tissue mechanics (Fig. 2). By dividing pressure measured at the mouth by airflow measured just before or immediately after occlusion, resistance can be calculated (Ohm’s law). At this moment various devices using different methods to measure resistance by interruption are being...
used. Standardisation of the interruption technique is crucial for a proper use of the technique in clinical and research setting. Issues that need standardisation and that have been shown to influence $R_{\text{int}}$ results are summarised in Table 1.

### Measuring during in- or expiration

$R_{\text{int}}$ values differ when measured during in- or expiration ($R_{\text{int}}(i)$ or $R_{\text{int}}(e)$), due to differences in lung volume, flow and compliance during in- or expiration. For example the increased airway compliance during expiration (and minimal interference of expiratory muscles), increased variation in glottis opening during expiration or airway compression during expiration explain this phenomenon.5

Bridge et al.6 showed in 2.5–5 year old symptomatic children that $R_{\text{int}}(e)$ value was 4% higher than $R_{\text{int}}(i)$. Beydon et al.7 found that the difference between $R_{\text{int}}(i)$ and $R_{\text{int}}(e)$ decreases with increasing age where ($R_{\text{int}}(i)$ is higher than $R_{\text{int}}(e)$ in children under 5 years and lower in children older than 5 years of age. Oswald-Mammoser et al.5 measured $R_{\text{int}}$ in older children and indeed found higher $R_{\text{int}}(e)$ than $R_{\text{int}}(i)$. Lombardi et al.8 found $R_{\text{int}}(e)$ to be 0.24 kPa higher than $R_{\text{int}}(i)$ as well, in 3–6 year old children. Differences in relative sizes of upper and lower airways and differences in airway compliance9 probably cause these age-differences found in several studies.

Merkus et al. found that $R_{\text{int}}(e)$ might be slightly more sensitive in detecting differences in airway calibre, for $R_{\text{int}}(e)$ increased more than $R_{\text{int}}(i)$ in patients who developed respiratory symptoms and was higher in eczematic and asthmatic patients. This possibly results from increased airway compression and hysteresis during expiration in bronchus obstructed children because of which resistance increases even more.10

On the other hand, in older children (7–16 years), $R_{\text{int}}(i)$ shows higher correlations with FEV$_1$ compared to $R_{\text{int}}(e)$ ($r = 0.75$ for $R_{\text{int}}(i)$, versus 0.69 for $R_{\text{int}}(e)$).11

### Table 1 Issues influencing $R_{\text{int}}$ measurements.

<table>
<thead>
<tr>
<th>Measurement during in- or expiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timing of pressure measurement during valve closure</td>
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<td>Fixation of cheeks and mouth floor</td>
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<td>Number of measurements</td>
</tr>
<tr>
<td>Expression in mean or median values</td>
</tr>
<tr>
<td>Use of facemask or mouthpiece</td>
</tr>
</tbody>
</table>

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**Figure 1** Measuring in a 3 year old patient.

**Figure 2** Pressure ($P$) curve during valve closure using the MicroRint (Micro Medical Limited, Rochester, Kent, England). Both the oscillatory and slow pressure changes can be observed. The fast pressure increase after valve closure ($t$) reflects airway resistance, the slow pressure increase afterward represents tissue resistance. By back-extrapolating pressure values at 30 and 70 ms to 15 ms after valve closure, a pressure value to calculate $R_{\text{int}}$ ($R_{\text{int}} = P_{\text{int}}/$airflow) is generated.
Timing of valve closure and pressure measurement

Different ways to measure the pressure change during valve closure are being used by various devices. Due to the continuous change in pressure measured at the mouth during valve closure, the moment to measure pressure influences the computed $R_{int}$ value. Pressure measured at end-occlusion seems to represent a pressure closest to respiratory pressure mainly in obstructed patients, or young children with small airways who need more time to gain equilibrium between mouth and respiratory pressure. However, in patients who need a longer time to gain equilibrium, end-occlusion might still underestimate the pressure change measured at the mouth and therefore the calculated airway resistance. By measuring pressure at two points in time during valve closure (after 30 and 70 ms) and back-extrapolating these values to the time of valve closure or 15 ms after (device dependant) the speed of pressure increase can be taken into account to address this phenomenon. Which method to choose is not yet well defined, but measurements may differ in outcome and therefore should be well documented.

Fixation of cheeks and mouth floor

To prevent air from shunting in the upper airways, it is important to firmly support the subjects’ cheeks and mouth floor. Unsupported cheeks leads to significantly lower $R_{int}$ values, especially in smaller children and bronchus constricted patients, as a result of an enhanced shunting of air. It has been shown that $R_{int}$ values correlate better with spirometric indices when proper fixation of cheeks has been obtained.

Number of measurements

To perform five to ten correct measurements is feasible in most pre-school children of two years and older. The intra-subject variability proved to be small (Table 2). Reliability does not increase considerably when more than five interruptions are used, and the child’s willingness to co-operate will decrease with more attempts.

Mean or median

The use of the median instead of the mean of five to ten measurements will reduce $R_{int}$ variability since the median value is obviously less affected by extreme values. Acceptability of a measurement requires some experience in observing pressure curves and recognising technical flaws such as swallowing or blowing the cheeks out. In some commercial devices, however, the computer software judges whether values are considered acceptable. Especially with these devices in which the investigator cannot examine the pressure curve, or if measurements are performed by less experienced investigators, outlying values might occur.

Use of a facemask or a mouthpiece

In children younger than 4 years of age a facemask instead of a mouthpiece could simplify the measurement. However, in 4–7 year old children, these measurements take more time and are more difficult, probably due to less acceptance of the mask by the child. Neither reliability, nor repeatability or variability differs between these two methods. Nevertheless, $R_{int}$ values using a facemask are slightly higher, possibly due to an observed change in breathing pattern (more deeply and rapidly), or due to differences in shape between mask and mouthpiece.

Feasibility and validity

The interrupter technique only requires passive co-operation and one measurement merely costs a few
seconds. This makes the technique suitable for pre-school children who usually are not able to perform spirometry. Table 2 shows results of studies concerning feasibility showing a strong relation with age. From the age of 2 years old, more than half of the children is able to perform over five R\textsubscript{int} measurements. At 4 years of age almost all children are capable of performing technically adequate measurements.

Several validation studies have shown a relatively small variability (11–16%) between subjects or between investigators and a high reproducibility within healthy subjects. Variation within and between coughing or wheezing subjects is considerably higher, probably due to the natural variation of airway resistance in these symptomatic children in time (Table 3).

This small variation between healthy subjects and high reproducibility of measurements would facilitate the definition of cut-off points for abnormal values, which still need to be defined.

### Clinical use

In order to evaluate its clinical use, information is needed on the diagnostic capacity of the technique for asthma.

### Wheezing phenotypes

The interrupter technique has shown to be able to discriminate between different phenotypes of wheezing in 4-year-old children.\textsuperscript{18} Phenotypes were categorised according to Martinez’ example.\textsuperscript{1} Persistent wheezers had higher airway resistance measurements than never-wheezers or early

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**Table 3** Validity of the interrupter technique.

<table>
<thead>
<tr>
<th>Study, age (years), n</th>
<th>Variability between subjects</th>
<th>Reproducibility within subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arets\textsuperscript{16}, 1–17, 232</td>
<td>CV: 12.2% Reliability coefficient: 0.90–0.98 increasing with number of interruptions</td>
<td>After 30–60 s: CV: 7.1%</td>
</tr>
<tr>
<td>Beelen\textsuperscript{15}, 3–6, 32</td>
<td>CV: 11.1% (R\textsubscript{int}(i)) – 12.1% (R\textsubscript{int}(e))</td>
<td>After 20 min: delta R\textsubscript{int}: 0.10 kPa/l/s</td>
</tr>
<tr>
<td>Beydon\textsuperscript{7}, 3–8, 91</td>
<td>CV: 16% Interrater reliability: 0.15 kPa/l/s</td>
<td>No data</td>
</tr>
<tr>
<td>Bridge\textsuperscript{33}, 2–5, 271</td>
<td>CV baseline: R\textsubscript{int}(e) = R\textsubscript{int}(i): 30 s: delta R\textsubscript{int}: 0.13–0.2 kPa/l/s (&gt; younger patients)</td>
<td>After 15 min: CV: 20%</td>
</tr>
<tr>
<td>Chan\textsuperscript{35}, 2–10, 174+224</td>
<td>ICC: 0.97 within occasion (CV 6.5%, ns); ICC: 0.75 between occasion in healthy controls (CV 11%); and ICC: 0.56–0.66 (CV 16–15%) between occasion in symptomatic children</td>
<td>After 3 weeks: 32% in healthy controls, 49% in coughers, 52% in wheezers</td>
</tr>
<tr>
<td>Klug\textsuperscript{34}, 2–7, 121</td>
<td>ICC: 0.92</td>
<td>After 15–20 min: CV: 9.8% (&lt; 4 years) – 6.9% (&gt; 4 years)</td>
</tr>
<tr>
<td>Lombardi\textsuperscript{8}, 3–6, 284</td>
<td>No data</td>
<td>Short term: ICC: 0.87 (R\textsubscript{int}(e)); ICC: 0.89 (R\textsubscript{int}(i))</td>
</tr>
<tr>
<td>Merkus\textsuperscript{10}, 2–7, 169</td>
<td>ICC between investigators: 0.98</td>
<td>Long term: ICC: 0.91 (R\textsubscript{int}(i) = R\textsubscript{int}(e))</td>
</tr>
<tr>
<td>Oswald-Mammoser\textsuperscript{5}, 3–18 years (mean 9), Asthma (96), controls (36)</td>
<td>No data</td>
<td>Short-term: ICC: 0.82 (R\textsubscript{int}(e)); ICC: 0.79 (R\textsubscript{int}(i))</td>
</tr>
</tbody>
</table>

CV, coefficient of variation; ICC, Intraclass correlation coefficient; SD, standard deviation.
transient-wheeze. These findings confirm the hypothesis of different phenotypes, but cannot be used in individual cases, because of overlapping $R_{\text{int}}$ distributions.

McKenzie et al. found that wheezers had a higher baseline $R_{\text{int}}(e)$ than coughing children and healthy 2–5 year old children. Coughing did not significantly differ from healthy children in this respect. Bronchodilator response expressed as pre/post-salbutamol ratios differed significantly for all groups: wheezers showed the highest ratio, followed by coughers. Lung function of healthy children improved the least after inhaling salbutamol. Additionally, $R_{\text{int}}$ has been demonstrated to also significantly relate to other markers of atopic disease. Interestingly, in wheezing children higher baseline $R_{\text{int}}$ values are associated with higher (log) IgE levels in wheezers.\textsuperscript{19} $R_{\text{int}}(e)$ increases during respiratory infection, and higher values have been found in eczematic and/or asthmatic children.\textsuperscript{10}

**Doctor’s diagnosed asthma**

Attempts to validate a pulmonary function test in pre-school children and to assess its diagnostic quality have been made by defining an asthmatic group by symptomatic diagnosis. This asthmatic group probably includes non-asthmatic children as well, since wheezing and reversibility is also described in healthy children. Therefore, differences between the asthmatic and the non-asthmatic group might underestimate the validity of the device. Secondly, asthmatic patients might present with a normal lung function due to the variability of the disease.

Correlations were found between spirometric indices (FEV\textsubscript{1}, FEF\textsubscript{50}) and $R_{\text{int}}$, at baseline as well as after bronchodilation in 4–8 year old asthmatic children ($r = 0.73$ for baseline values and $r = 0.64$ for reversibility values of FEV\textsubscript{1}).\textsuperscript{20} Carter\textsuperscript{21} had found similar results: in 107 3–12 year old children with asthma, cystic fibrosis or without respiratory disease high correlations were found between forced expiratory volumes and flow rates and conductance measured by the interrupter technique ($r > 0.67$).

Beydon et al. found significant differences in $R_{\text{int}}$ values between healthy and doctor’s diagnosed asthmatic pre-school (3–8 year) children. Asthmatic children had higher baseline $R_{\text{int}}$ values (healthy: $0.77 \pm 0.2$, asthmatic: $0.92 \pm 0.22$, $P = 0.0001$, 15% of the asthmatic children exceeded the 95%CI of the healthy children). Even though in healthy children resistance proved to decrease after drug induced bronchodilation, the effect of bronchodilation was larger in the asthmatic group (11.2 vs. 18.6% from baseline, and 12.6 vs. 23.2% from predicted). A bronchodilator response of 35% or more decrease in $R_{\text{int}}$ showed a likelihood ratio of 3 for separating healthy from ‘asthmatic’ children. Imported to note is the fact that a large part of the asthmatic children (85.1%) were using inhaled corticosteroids (ICS), which may influence airway resistance.\textsuperscript{22} In another study a significant effect of bronchodilation of 15% in $R_{\text{int}}(i)$ and 12% in $R_{\text{int}}(e)$ from baseline in 3–7 year old healthy children was found, unrelated to height, age, gender or passive smoking.\textsuperscript{7}

In a study of Nielsen et al. asthma was defined as recurrent wheezing, coughing, breathlessness, symptom relief with ICS or bronchodilator and relapse of symptoms during interruption of treatment. Of the asthmatic children 73% used ICS during the measurements. A cut-off of 25% bronchodilator response in airway resistance (Raw) was found, using the whole-body plethysmograph when distinguished between ‘healthy’ and ‘asthmatic’ 2–5 year olds. The interrupter technique (pressure was measured at the end of occlusion) and Impulse Oscillometry (IOS) (resistance and reactance at 5 Hz (Rrs5, Xrs5)) were used to measure resistance as well. Both techniques showed significantly more improvement after bronchodilation in the asthmatic group compared to the healthy group. The following are in order of discriminative capacity in diagnosing ‘asthma’: Raw, Rrs5, $R_{\text{int}}$ and Xrs5 with respective cut-off points (and positive predictive value) of 3 SD (84%), 2.5 SD (74%), 1.5 SD (82%) and 1.0 SD (76%).\textsuperscript{23} The combination of high baseline resistance and a large bronchodilator response might be even more supportive of diagnosing asthma. Provoking the airways with cold air resulted in additional validity of the tests.\textsuperscript{24} Klug et al. investigated the short term outcome of asthmatic pre-school children by separating children in two groups according to their lung function (interrupter technique, IOS and plethysmography). Approximately 3 years later, the children with initially impaired lung function (resistance higher than 97.5% of the range of reference values) had surprisingly similar symptoms and received similar treatment compared to the children with initially normal lung function parameters. Noteworthy is the fact that 65% of the children were being treated with anti-asthma medication at the start of the study. This may have lead to improvement in the following 3 years of their lung function. But the children who were not receiving ICS, e.g. because of fewer symptoms, may have worsened in time.\textsuperscript{25} The predictive value of the interrupter technique
according to the various studies is summarised in Table 4.

**Reference values**

Several investigators have collected reference values for the interrupter technique. In all studies, $R_{\text{int}}$ appeared to be mainly determined by the height of the subject. Age and weight contribute to the $R_{\text{int}}$ value in several reference groups as well. Table 5 shows regression equations of the various studies.

We have previously described that $R_{\text{int}}$ in healthy children was 0.44 kPa/l/s higher than in healthy children who were not exposed to tobacco smoke. This confirms the influence of environmental tobacco smoke exposure on airway resistance, and proves that the interrupter technique is a sensitive method to detect small changes in lung function.

**The interrupter technique in research**

Up till now the effectiveness of maintenance treatment for asthma in pre-school children, has mainly been assessed by subjective outcome parameters. Only a few research groups used lung function tests to evaluate this effect. Nielsen et al. found in 38 2–5 year old asthmatic children (symptomatic diagnosis) an improvement in $R_{\text{int}}$ values (1.2 kPa/l/s at baseline to 1.1) after 8 weeks treatment with budesonide compared to increased $R_{\text{int}}$ values (1.2 at baseline to 1.26 kPa/l/s) in the placebo group. Also reactivity to cold air exposure measured with the interrupter technique and IOS improved after 8 weeks of budesonide (400 μg) treatment. Methacholine hyperresponsiveness however did not improve, possibly due to the short duration of therapy.

Pao et al. used the interrupter technique to investigate the effect of fluticasone propionate 100 μg twice daily in 2–5 year old children with intermittent wheeze in a cross-over trial. Only children sensitised to common allergens improved in $R_{\text{int}}$ by 16% and bronchodilation response by 10% after 6 weeks treatment. No more than four atopic children completed the 10 weeks extension period using placebo. A decrease in $R_{\text{int}}$ of 15% was considered clinically significant. Finally, Straub et al. found an improvement in baseline resistance measured by interrupter technique after treating 30 2–5 year old asthmatic and atopic children with montelukast for 4 weeks. However, these data

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**Table 4** Predictive value of the interrupter technique.

<table>
<thead>
<tr>
<th>Study</th>
<th>Intervention</th>
<th>Comparing groups (age, n)</th>
<th>Cut-off point</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Pos. pred. value</th>
<th>Neg. pred. value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beydon22</td>
<td>Salbutamol-volumatic+10min</td>
<td>74 asthmatic, 84 healthy</td>
<td>2.5</td>
<td>76</td>
<td>80</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>McKenzie19</td>
<td>Salbutamol 400 μg-volumatic</td>
<td>63 controls, 58 coughers, 82 wheezers 2–5 years</td>
<td>2.5</td>
<td>76</td>
<td>80</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>Nielsen23</td>
<td>Cold air</td>
<td>38 asthma (4.6±0.9 years), 29 healthy (4.7±0.9)</td>
<td>2.5 intra-subject</td>
<td>79</td>
<td>87</td>
<td>97</td>
<td>70</td>
</tr>
<tr>
<td>Nielsen24</td>
<td>500 μg terbutaline-nebul-chamber+20min</td>
<td>55 asthmatic (4.6±1.0 years), 37 healthy controls (3.8±1.0 years)</td>
<td>2.5 intra-subject</td>
<td>79</td>
<td>87</td>
<td>97</td>
<td>70</td>
</tr>
</tbody>
</table>

sd, standard deviation.
should be interpreted with caution because this study was not placebo-controlled.\textsuperscript{29}

### Limitations

The interrupter technique has several important limitations. First of all, a single measurement will probably be little informative due to large confidence intervals and overlapping values between healthy and symptomatic children. Moreover, most validating studies have shown differences in $R_{\text{int}}$ values between healthy and symptomatic children at group levels. Performing multiple measurements and adding information on airway hyperreactivity or reversibility, will increase its diagnostic capacity.

Furthermore, not only lower airway resistance but also upper airway restrictions (e.g. large tonsils) or pharynx constriction may increase $R_{\text{int}}$ leading to overestimation. On the other hand, underestimation may be caused by severe lower airway constriction or even occlusion. This can be explained by the fact that pressure will not be able to reach equilibrium between mouth and peripheral air spaces in the short closure time of the valve and because of increased upper airway shunting. This might also play a role in very young children who have smaller airways.

Compliance of the upper airways counteracts a pressure equilibrium that needs to be established. This delay in pressure equalisation may result in underestimating airway resistance. In bronchus-obstructed children aged 5–18 year with asthma or cystic fibrosis ($\text{FEV}_1/\text{VC}<80\%$ and/or $\text{FEF}_{(25-75)}<75\%$) $R_{\text{int}}$ was relatively lower than airway resistance in bronchus-obstructed children measured by whole body plethysmography. The difference between Raw and $R_{\text{int}}$ correlated with the severity of obstruction measured by spirometry, suggesting that the tendency of the interrupter technique to underestimate airway obstruction increases with severity of the obstruction.\textsuperscript{30} When compared to the single breath occlusion technique in wheezy infants, $R_{\text{int}}$ values are also lower. Yet, a good correlation between the interrupter technique and invasive techniques such as the rapid-thoracic-compression technique has been found.\textsuperscript{31}

Finally, the interrupter technique does not distinguish real resistance from compliance (elasticity and inertia), which can be measured with for instance forced oscillometry.\textsuperscript{32} With the interrupter technique the respiratory system is perceived as a rigid and linear model, with only one resistance value as outcome, contrary to the forced oscillation technique, another lung function measurement suitable for pre-school children, that measures both real resistance and reactance.

### Conclusion and recommendations

The interrupter technique is the most feasible objective method for assessing airway resistance in awake pre-school children. It promises to be a valuable contribution in the diagnostic process in young children with asthmatic symptoms: baseline values are often higher in supposedly asthmatic patients and bronchodilator and provocation response in ‘asthmatic’ patients is larger. However, the exact clinical relevant difference in baseline as well as in bronchodilator response needs to be defined more precisely. The interrupter technique could also be useful in research in young children for its feasibility, validity and its objective quality. Studies have shown that the technique is sensitive to changes caused by various interventions. More data need to be collected concerning the interrupter technique in different populations to get insight in the standard deviations and the minimal important clinical difference.

In order to achieve standardised and valid results both in the clinical setting as in research, we

<table>
<thead>
<tr>
<th>Study</th>
<th>$N$</th>
<th>Age (years)</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beydon\textsuperscript{7}</td>
<td>91</td>
<td>3–8</td>
<td>$R_{\text{int}}(i) = 2.29 - 0.014 \times \text{height (cm)}$, $R_{\text{int}}(e) = 2.02 - 0.011 \times \text{height (cm)}$</td>
</tr>
<tr>
<td>Klug\textsuperscript{34}</td>
<td>121</td>
<td>2–7</td>
<td>$R_{\text{int}}(i) = 0.97 - 0.0067 \times \text{height (cm)} - 0.0039 \times \text{age (months)} - 0.0019 \times \text{weight (kg)}$</td>
</tr>
<tr>
<td>Kooi\textsuperscript{36}</td>
<td>557</td>
<td>4–12</td>
<td>$R_{\text{int}}(e) = 1.88 - 0.002 \times \text{age (months)} - 0.01 \times \text{height (cm)} + 0.004 \times \text{weight (kg)}$</td>
</tr>
<tr>
<td>Lombardi\textsuperscript{8}</td>
<td>284</td>
<td>3–6</td>
<td>$R_{\text{int}}(i) = 2.28 - 0.014 \times \text{height (cm)}$, $R_{\text{int}}(e) = 2.13 - 0.013 \times \text{height (cm)}$</td>
</tr>
<tr>
<td>Merkus\textsuperscript{10}</td>
<td>54</td>
<td>2–7</td>
<td>$R_{\text{int}}(i) = 2.61 - 0.016 \times \text{height (cm)}$ and $R_{\text{int}}(e) = 2.59 - 0.017 \times \text{height (cm)}$</td>
</tr>
<tr>
<td>McKenzie\textsuperscript{36}</td>
<td>236</td>
<td>2–10</td>
<td>$\log_{10} R_{\text{int}}(e) = 0.116 - 0.0396 \times \text{age (year)} + 0.528 - 0.00569 \times \text{height (cm)}$</td>
</tr>
</tbody>
</table>
recommend to use the interrupter technique taking the following remarks into account:

- Pressure measurement at end-occlusion represents airway pressure most. By using a two-point back-extrapolating method, speed of pressure change can be assessed, which also represents airway obstruction. Which method is used to measure pressure and flow should be well documented until the optimal method has been defined.

- Cheeks and mouth floor should be supported (preferably by the investigator or technician).

- $R_{\text{int}}$ on expiration might be more sensitive in assessing airway resistance in young children and less susceptible to interference from muscular activity than $R_{\text{int}}$ on inspiration.

- Median values of at least five consecutive measurements are less influenced by extreme values and reflect the actual respiratory resistance best.

- Facemask or mouthpieces are both acceptable but which of both has been used needs to be recorded.

In summary, the interrupter technique might provide valuable additional information in diagnosing asthma in young children in the clinic setting. For research purposes in pre-school children with asthmatic symptoms the use of a standardised technique is recommended.

References


26. Kool EM, Vrijlandt EJ, Boozen HM, Duiverman EJ. Children with smoking parents have a higher airway resistance.