

Measurement of airway resistance using the interrupter technique in preschool children in the ambulatory setting

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ABSTRACT: This study describes the feasibility, repeatability, and interrater reliability of the measurement of airway resistance by the interrupter technique (R_{int}) in children 2–5 yrs of age, and examines whether reversibility to bronchodilator can be demonstrated in wheezy children.

The mean of six R_{int} values was taken as a measurement. If subjects could complete one measurement and then a second 15 min after bronchodilator, baseline testing and reversibility testing were considered feasible. To measure repeatability, two measurements 30 s apart and measurements before and 15 min after placebo bronchodilator were compared. Measurements by two testers were compared for interrater reliability. Change in R_{int} in wheezy children was measured after bronchodilator.

Fifty-six per cent of 2–3-yr-olds ($n=79$), 81% of 3–4-yr-olds ($n=104$) and 95% of 4–5-yr-olds ($n=88$) completed baseline testing, and 53%, 71% and 91% completed reversibility testing. Baseline measurements were 0.47–2.56 $\text{kPa}\cdot\text{L}^{-1}\cdot\text{s}$. Repeatabilities (2 SD of the mean differences between measurements) at 30 s in the three age bands were 0.21, 0.17 and 0.15 $\text{kPa}\cdot\text{L}^{-1}\cdot\text{s}$ and 0.19 $\text{kPa}\cdot\text{L}^{-1}\cdot\text{s}$ after placebo. Using 0.21 $\text{kPa}\cdot\text{L}^{-1}\cdot\text{s}$ as the threshold for reversibility, reversibility was demonstrated in most wheezy children. Interrater reliability was 0.15 $\text{kPa}\cdot\text{L}^{-1}\cdot\text{s}$.

Preschool children can undertake measurements of airway resistance by the interrupter technique in ambulatory settings and reversibility to bronchodilator in wheezy children can be demonstrated. This technique promises to be a useful clinical and research tool.

Eur Respir J 1999; 13: 792–796.

Asthma is considered to reflect reversible airways disease. A precise definition has yet to be agreed. It is one of the few organic diseases where diagnosis and treatment are often made only on the parental reporting of symptoms [1], one of which is wheeze. Although there is an assumption that parents know what wheeze is, the history is sometimes vague and often there are no physical signs. In school-children, reversibility of forced expiratory volume in one second (FEV₁) and forced vital capacity (FVC) to bronchodilator treatment can be measured [2] so that, in cases where the history is not clear, objective measurements can be made. Changes in expiratory flow in infants in response to bronchodilator can be measured [3]. There are no readily available lung function tests suitable for children aged between 18 months and 5 yrs.

The measurement of respiratory resistance in young and uncooperative subjects using the forced oscillation technique (FOT) and the interrupter technique (R_{int}) has been evaluated by several laboratories since the 1980s [4–7]. The simplicity of use for the patient and smaller size of the R_{int} device make it attractive for use in children aged 2–5 yrs in the ambulatory setting. Respiratory resistance is measured during quiet tidal breathing and requires minimal cooperation on the part of the subject.

The theoretical background has been well described [5, 6] along with the technical aspects in older children [7]. Although the technique has been tried in a small group of selected preschool children [6], very little has been published on the practicalities of using R_{int} in an ambulatory setting. In contrast to spirometry, only minimal comprehension and co-ordination are needed for R_{int} . This means that even acutely ill or tired children, of all ages, should be able to undertake the test successfully. There is no evidence that either bronchoconstriction or bronchodilation result where extra attempts are required to obtain valid R_{int} data. The main possible disadvantage of R_{int} in an ambulatory setting, which is where it could be of most clinical value, is that quiet tidal breathing could be difficult for very young children. Neck position, upper airway compliance, variations in flow and volume during tidal breathing and the contribution of the glottis are impossible to standardize or correct for, and so the coefficient of variation of a set of values is high [6]. However, the technique essentially provides a valid estimate of airway resistance provided upper airway compliance is minimized by supporting the cheeks and pharynx [8, 9].

Bronchodilator reversibility using the R_{int} technique has been compared with FOT and spirometry in selected

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Keywords: Interrupter technique
lung function
preschool asthma

Received: July 8 1998
Accepted after revision November 23 1998

Supported by the Queen Elizabeth Hospital for Children Research Trust, Glaxo-Wellcome, and Micromedical.

asthmatic schoolchildren and has been shown to be as sensitive as spirometry [10]. The mean of six values of R_{int} was taken as a measurement, and increasing the number of values recorded made no difference to this mean measurement.

The purposes of this study were the following. 1) To investigate the feasibility of the R_{int} technique in the ambulatory setting: can preschool children undertake the test within a reasonable period of time for it to be a useful clinical tool? 2) To measure the repeatability of low and high baseline measurements at 30 s in different age groups, similar pairs of measurements made 15 min later and pairs before and 15 min after placebo bronchodilator. If R_{int} is to be used to measure the effect of interventions on baseline measurements and reversibility to bronchodilator in children of this age, it is important to know how repeatable the measurement is before any change can be ascribed to an intervention. 3) To establish whether a change in R_{int} following bronchodilator can be demonstrated in previously wheezy and wheezy subjects. Further, more rigorous study of the value of reversibility testing in these groups would be justified if reversibility could be confidently demonstrated. 4) To measure the interrater reliability of measurements in this age group of an experienced and an inexperienced tester. This would give guidance for the training of new testers.

The practicalities of testing this group in an ambulatory setting will be discussed.

Methods

Interrupter resistance measurements

Interrupter resistance was measured using a single commercial device (Microlab 4000; Micromedical Ltd, Gillingham, UK) throughout the study. Subjects were seated in an identical comfortable position. They breathed quietly through a cardboard mouthpiece (2.7 mm diameter or, for some of the younger children, 2.0 mm diameter) with the nose clipped, the cheeks and pharynx supported and the neck slightly extended (fig. 1). After a period of quiet breathing, in response to a trigger during expiration at the peak of a tidal flow, a single shutter closed automatically within 10 ms and stayed closed for 100 ms. One or two



Fig. 1. – Interrupter resistance testing: nose clipped, cheeks and pharynx supported and neck slightly extended.

practice attempts were made before starting to record data. Subjects were unable to anticipate the trigger but were able to hear the valve closing. Attempts were not accepted if the subject breathed irregularly or if the mouth pressure–time curve ($P_{mo}(t)$) was not of consistent shape, as previously described [5, 6] (fig. 2). The mean of six acceptable readings was taken to be a measurement. The subject came off the mouthpiece for 3–5 breaths between readings.

Subjects

Consecutive children 2–5-yr-old with and without a history of respiratory symptoms were recruited from hospital outpatients. This study received approval from the local ethics committee.

Feasibility

For the test to be considered feasible, six acceptable R_{int} values with reference to the $P_{mo}(t)$ curve had to be recorded, and then another six values 15 min later following 400 µg salbutamol delivered *via* a spacer. The time for the whole test and reasons for failure were recorded.

Repeatability

This was defined as the variance ($\pm 2SD$) of the mean difference between pairs of measurements 30 s apart. In children able to undertake the test, two measurements, 1 and 2, 30 s apart (six values each) were made. To examine whether repeatability was stable after 15 min (the time of a

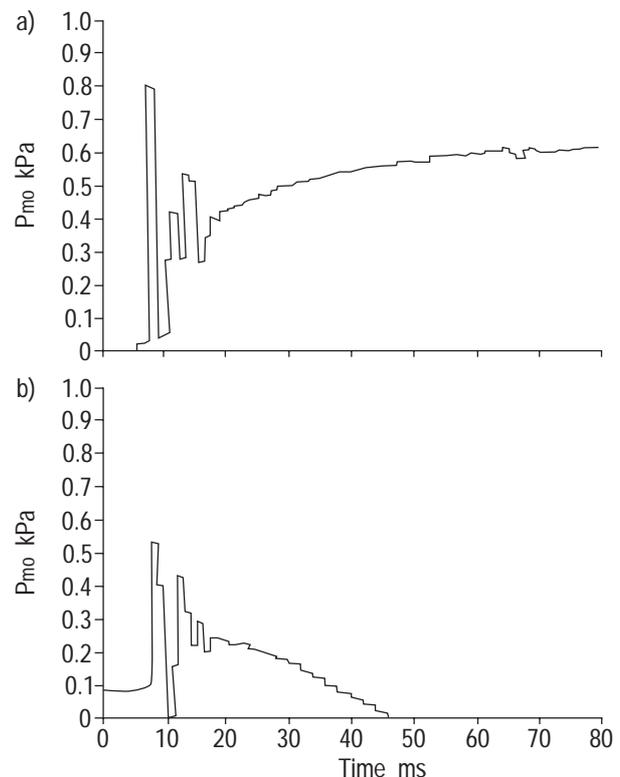


Fig. 2. – Mouth pressure (P_{mo})–time curves. a) Acceptable: a sharp rise in pressure at the time of shutter closure is followed by oscillations before a smooth rise in pressure; and b) unacceptable: a fall in pressure following the first two phases.

reversibility test), two further measurements, 3 and 4, 30 s apart were made 15 min later if time allowed. The variances of the mean differences between pairs 1 and 2, and 3 and 4, were calculated. The differences between measurements 1 and 2 were plotted against the mean of these two measurements [11], and the variances of the mean differences between measurements 1 and 2 at low and high baseline measurements were calculated after splitting the group in half. To measure repeatability over 15 min, subjects with a variety of respiratory complaints were given by metered-dose aerosol, *via* a spacer, 400 µg salbutamol or placebo in random order. Neither subject nor tester knew the sequence. R_{int} was measured 15 min after each inhalation. For those who received the placebo first, the variances of the mean change after placebo for all subjects, and for subgroups with high and low baseline measurements, were calculated as described previously.

Reversibility

A small group of children with a history of wheezing but not wheezy at the time of the test (group 1), and children actively wheezing (group 2), undertook reversibility testing to establish whether change greater than repeatability could be demonstrated. Bronchodilator treatment had not been given for at least 4 h before testing. Differences between measurements $>2SD$ of the mean difference between two readings before and after placebo (previously calculated as described above) were considered to reflect reversibility.

Interrater reliability

Measurements were undertaken by two persons blind to each others' results in random order in subjects selected according to availability. Each tester collected six values which they considered acceptable and calculated the measurement (the mean of the six values). The testers' measurements were compared by the BLAND and ALTMAN [11] technique. Tester 1 was an experienced lung function technician who had made several hundred measurements. Tester 2 was a junior doctor new to the technique.

Results

Feasibility

Successful tests of baseline recordings and reversibility testing are recorded in table 1 according to age. None of the children's respiratory symptoms prevented them from completing the test. Those who failed were either unwilling (*i.e.* shy, tired or frightened) or unable, either because they blew into or sucked on the mouthpiece.

Repeatability

Measurements 1 and 2 in 120 subjects and the mean differences $\pm 2SD$ between measurements 1 and 2 (ΔR_{int}) are shown in figure 3 for different age bands. The larger differences between those measurements with highest baseline values are demonstrated in figure 4. For the 60 measurements ranging 0.47–1.08, the variance of the differences between measurements 1 and 2 was 0.13 kPa·L⁻¹·s, and for the 60 measurements between 1.11–2.65 it was 0.20 kPa·L⁻¹·s. When the same calculations were applied to groups split at the mid-point of the range of

Table 1. – Success of completion of baseline interrupter resistance (R_{int}) measurement, R_{int} measurement after bronchodilator and time to complete reversibility testing

Age yrs	Subjects n	Completed R_{int} measurements		Time to complete min
		Baseline	After bronchodilator	
2–3	79	44 (56%)	42 (53%)	27
3–4	104	84 (81%)	74 (71%)	26
4–5	88	84 (95%)	80 (91%)	25

baseline measurements (0.47–1.56 and 1.57–2.65 kPa·L⁻¹·s) the variances were 0.16 (n=106) and 0.24 kPa·L⁻¹·s (n=14) respectively. Repeatabilities of measurements 3 and 4, in 72 subjects, for the same age bands were 0.19, 0.19 and 0.11 kPa·L⁻¹·s. In all cases, the mean difference between two measurements was 0 kPa·L⁻¹·s.

Of 98 children tested with placebo, 55 (mean age 3.8 yrs) received placebo first. For these 55, the mean difference between baseline and post-placebo measurements was 0.001 kPa·L⁻¹·s and the variance 0.19 kPa·L⁻¹·s for the group. For measurements at low and high baseline R_{int} (0.39–1.00 and 1.01–2.36 kPa·L⁻¹·s), the variances of the mean differences were 0.16 and 0.21 kPa·L⁻¹·s respectively (fig. 5).

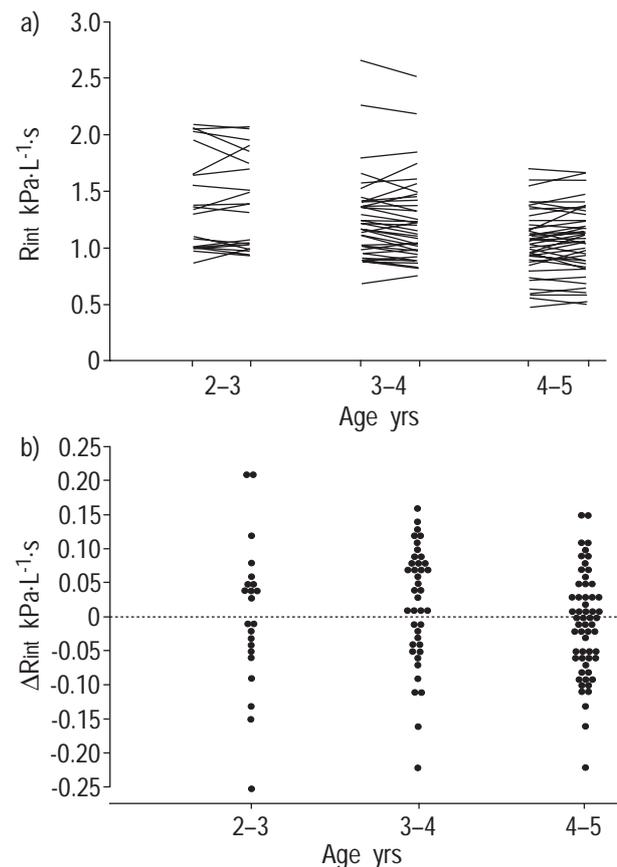


Fig. 3. – a) Individual interrupter resistance (R_{int}) measurements 1 and 2 for different age bands; and b) individual differences between measurements 1 and 2 (ΔR_{int}) for different age bands (repeatability). Mean ($2SD$) ΔR_{int} values were: 2–3 yrs 0 (0.21), n=22; 3–4 yrs 0 (0.17), n=40; and 4–5 yrs 0 (0.15), n=58.

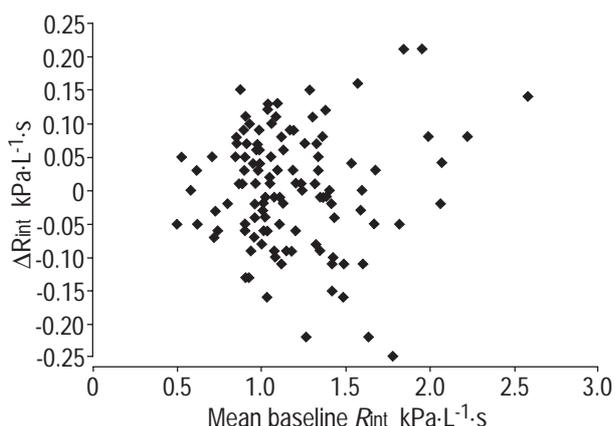


Fig. 4. – Bland–Altman plot of the individual differences between interrupter resistance (R_{int}) measurements 1 and 2 (ΔR_{int}) and mean baseline R_{int} .

Reversibility

The mean ages of groups 1 (n=32) and 2 (n=16) were both 3.8 yrs. Results are shown in figure 6. Mean baseline R_{int} measurements were 1.19 and 1.60, respectively. A change >0.21 kPa·L⁻¹·s (derived earlier from the variance of the mean difference between measurements before and after placebo for subjects with high baseline measurements) following bronchodilator was considered to reflect reversibility. In group 1, 82% (95% confidence interval (CI) 68–96%) demonstrated reversibility and, in group 2, 88% (95% (CI) 72–100%).

Interrater reliability

Forty-eight pairs of measurements were made. Measurement bias (measurement by tester 1 - measurement by tester 2) was -0.007 ± 0.15 (2sd). The mean age of the group tested was 3.9 yrs and the mean R_{int} for the group was 1.0 kPa·L⁻¹·s.

Discussion

R_{int} is an old technique recently considered for measuring airway resistance and bronchodilator responsiveness in children. There are currently no readily available techniques which provide objective measurements of lung

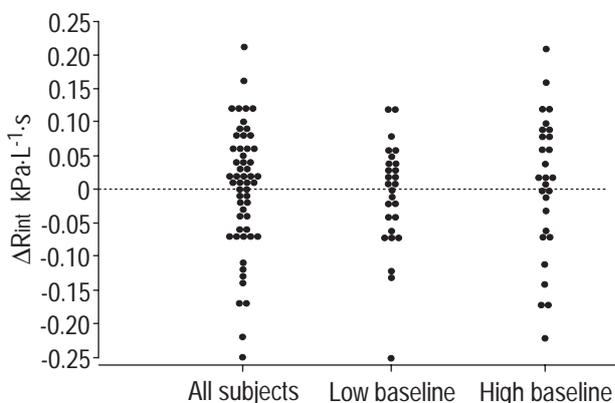


Fig. 5. – Individual differences between baseline and post-placebo measurements for low and high baseline interrupter resistance (R_{int}) values. Mean (2 sd) ΔR_{int} values were: all subjects 0 (0.19), n=55; low baseline 0 (0.16), n=27; high baseline 0 (0.21), n=28.

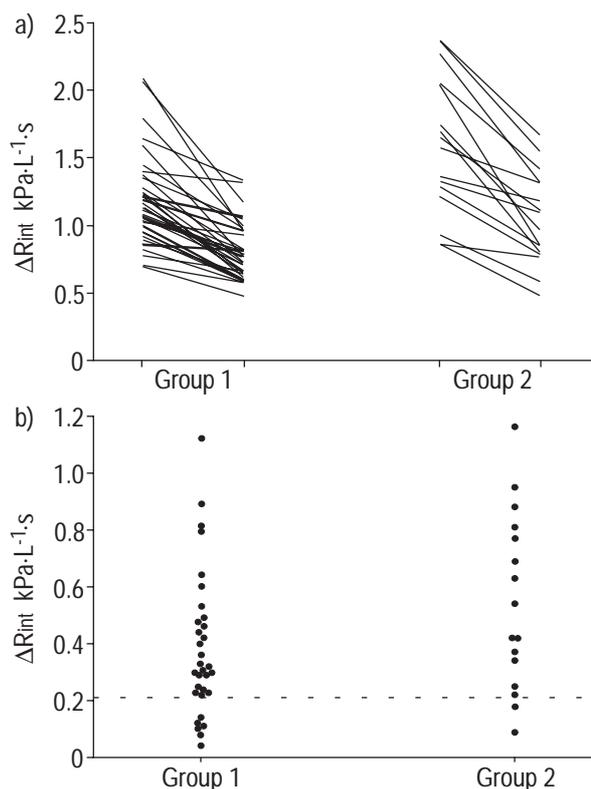


Fig. 6. – a) Baseline and post-bronchodilator interrupter resistance (R_{int}) measurements for group 1 (mean age 3.8 yrs) and group 2 (mean age 3.8 yrs); and b) individual differences between baseline and post-bronchodilator measurement in group 1 (26/32 (82%) above threshold) and group 2 (14/16 (88%) above threshold). Dashed line shows threshold (0.21 kPa·L⁻¹·s).

function in preschool children and R_{int} has shown promise. A reference range of normal values related to height has recently been published [12]. The range is wide and so single measurements in any individual are of limited value. The theory of the technique, *i.e.* what the measurements reflect and standardization [13], need more consideration. Before further work is carried out on standardization, the authors thought it would be useful to know whether consecutive children within the 2–5-yr-old age group, and who were attending a chest clinic, would and could cooperate with the R_{int} technique. The commercially available device used can be operated without a mains supply and the more recent model is similar in size to a hand held spirometer. These factors may be of particular benefit in ambulatory settings within and outside a hospital environment.

Feasibility

The setting of the study was similar to that in other ambulatory children’s departments and family doctors’ offices. Although a small number of children attempted the test soon after arriving in the clinic, when the department was relatively quiet, the majority were tested 1–2 h later when some had already undertaken other investigations. Clinic areas including lung function laboratories can be noisy and distracting. The results were obtained in a realistic setting and the effect of distraction were reflected in the repeatability values. Not surprisingly older children

were better able to complete the test than younger children. It was very encouraging that >50% of 2-yr-olds could perform the test. The reasons children were unable to complete the test, blowing into or sucking on the device, probably reflected previous attempts at peak flow or using a spacer. It is recommended that the test should be attempted soon after arrival and before other invasive tests. Parents should be advised not to encourage their child to blow or suck. There should be a quiet "play" area. For many children, siblings can be a distraction, although it may be helpful for shy or frightened children to see an older sibling undertake the test.

For children 18-months to 2.5-yr-old, development of the method using a face mask may be possible, but this introduces the potential problems of leakage, dead space and the introduction of nasal resistance because noseclips cannot be worn. Since this technique is feasible in young children, it would be interesting to evaluate its use in older children able to manage quiet breathing but unable, for whatever reason, to undertake spirometry.

Most children who could complete the baseline measurement could also complete the reversibility testing. After the 15 min interval, many children took a minute or two to settle down. The repeatability was expected to be poorer but in fact repeatability was slightly better, probably reflecting lower measurements after bronchodilator.

In summary, this technique satisfies two basic requirements for a clinical tool. It can be successfully undertaken in the majority of subjects within a satisfactory period of time. Even if children were unable to complete the test the first time, they could often manage on a second occasion. Tests can be completed within 30 min, a reasonable time for a clinic attendee.

Repeatability and reversibility

Not unexpectedly, repeatability was slightly poorer in the younger age group and/or when the baseline measurements were high. It would be expected that children with high baseline measurements would be younger and more likely to be wheezy. Although these differences are small, reversibility should be considered in relation to age and baseline R_{int} measurement.

When taken in the context of the response to bronchodilator in previously wheezy children and in children wheezy at the time of the test, mean change in R_{int} was well outside the variance (2SD) of 30-s repeatability and, more importantly, the repeatability 15 min after placebo. Those with the highest baseline measurements responded best, suggesting that the test was robust enough to detect changes in R_{int} in circumstances in which lung volume was likely to fall. The response to bronchodilator in this small group is encouraging for the measurement of reversibility in a much larger group.

Interrater reliability

This was remarkably encouraging and indicates that training of technicians to undertake R_{int} testing should not be difficult. The variance (2SD) of the difference between the two testers was less than the variance between measurements made by the most experienced tester. This probably reflects the older age of the group tested and their lower measurements.

Conclusion

Airway resistance measurement by the interrupter technique is feasible in an ambulatory setting in preschool children. In a small group of wheezy children, the mean decrease in interrupter resistance following bronchodilator was very different to the repeatability after placebo. Similarly, reversibility could be demonstrated in most subjects who had been previously wheezy but who were not wheezy at the time of the test. Reversibility to bronchodilator should now be studied in control subjects. The interrupter resistance technique seems promising for both clinical and research purposes. Reversibility testing, undertaken routinely in older subjects, may help clarify the clinical history in young children. Now that repeatability of the test is known, change in interrupter resistance in the individual in response to an intervention can be evaluated.

Acknowledgements. The authors are grateful to M. Healy who advised about data analyses.

References

1. Jones KP. Cough, wheeze and asthma diagnosis in children. *Clin Exp Allergy* 1993; 23: 627–628.
2. Waalkens HJ, Merkus PJFM, van Essen-Zandvliet EEM, et al. Assessment of bronchodilator response in children with asthma. *Eur Respir J* 1993; 6: 645–651.
3. American Thoracic Society/European Respiratory Society. Respiratory mechanics in infants: physiologic evaluation in health and disease. *Am Rev Respir Dis* 1993; 147: 474–496.
4. Lebeque P, Desmond K, Swartbroeck Y, Dubois P, Lulling J, Coates A. Measurement of respiratory resistance by forced oscillation in normal children. A comparison with spirometric values. *Pediatr Pulmonol* 1991; 10: 117–122.
5. Carter ER, Stecenko AA, Pollock BH, Jaeger M. Evaluation of the interrupter technique for the use of assessing airway obstruction in children. *Pediatr Pulmonol* 1994; 17: 211–217.
6. Phagoo SB, Wilson NM, Silverman M. Evaluation of a new interrupter device for measuring bronchial responsiveness and the response to bronchodilator in 3 year old children. *Eur Respir J* 1996; 9: 1374–1380.
7. Oswald-Mammosser M, Llerena C, Speich JP, Donato L, Lonsdorfer J. Measurements of respiratory system resistance by the interrupter technique in healthy and asthmatic children. *Pediatr Pulmonol* 1997; 24: 78–85.
8. Bates JHT, Abe T, Romero P, Sato J. Measurement of alveolar pressure in closed chested dogs during flow interruption. *J Appl Physiol* 1989; 76: 488–492.
9. Bates JHT, Sly PD, Kochli T, Martin JG. The effects of proximal compliance on interrupter measurements of resistance. *Respir Physiol* 1987; 70: 301–312.
10. Bridge PD, Lee H, Silverman M. A portable device based on the interrupter technique to measure bronchodilator response in schoolchildren. *Eur Respir J* 1996; 9: 1368–1373.
11. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; i: 307–310.
12. Klug B, Bisgaard H. Specific airway resistance, interrupter resistance, and respiratory impedance in healthy children aged 2–7 yrs. *Pediatr Pulmonol* 1998; 5: 322–331.
13. Carter ER. It is time to consider standardizing the interrupter technique. *Eur Respir J* 1997; 10: 1428–1429.