Lung function measured by the oscillometric method in prematurely born children with chronic lung disease

L.P. Malmberg*, S. Mieskonen*, A. Pelkonen*, A. Kari[#],
A.R.A. Sovijärvi[+], M. Turpeinen*

Lung function measured by the oscillometric method in prematurely born children with chronic lung disease. L.P. Malmberg, S. Mieskonen, A. Pelkonen, A. Kari, A.R.A. Sovijärvi, M. Turpeinen. ©ERS Journals Ltd 2000.

ABSTRACT: Premature birth is related to a chronic respiratory morbidity, which may persist until school-age. In these children, the forced oscillation technique would be suitable for evaluation of lung function even at preschool age, since it requires only minimal patient cooperation.

In order to investigate the oscillometric findings related to premature birth, using the oscillation technique and conventional lung function methods 49 school-aged children born prematurely with (n=15) or without (n=34) chronic lung disease (CLD), and 18 healthy children born at full term were studied.

Children with CLD had higher respiratory resistance ($R_{rs,5}$) and lower reactance ($X_{rs,5}$) than prematurely born children without CLD or healthy controls. Both $R_{rs,5}$ (r=-0.55, p<0.0001) and $X_{rs,5}$ (r=0.76, p<0.0001) were significantly associated with forced expiratory volume in one second (FEV_1), the agreement with spirometry being better in $X_{rs,5}$ than in $R_{rs,5}$ (p=0.02). $R_{rs,5}$ was significantly related to airway resistance (R_{aw}) measured by body plethysmography (r=0.63, p<0.0001), but underestimated resistance at high values of R_{aw}. There was no significant relationship between the pulmonary diffusing capacity and the oscillometric findings.

Compared to conventional methods, the oscillometric method yields concordant information on the severity of lung function deficit in children born prematurely, with or without chronic lung disease. In these children, the oscillometric findings are probably due to peripheral or more widespread airway obstruction. As conventional methods are not usually suitable for preschool children, oscillometry may serve as an alternative for early evaluation of chronic lung disease among children with premature birth in clinical or research settings.
Eur Respir J 2000; 16: 598–603.

*Dept of Allergic Diseases, [#]Hospital for Children and Adolescents, and the [+]Laboratory Dept, Helsinki University Central Hospital, Helsinki, Finland.

Correspondence: L.P. Malmberg
Dept of Allergic Diseases
Helsinki University Central Hospital
PO Box 160
FIN-00029 Helsinki
Finland
Fax: 358 947186280

Chronic lung disease (CLD) of prematurity is a major cause of long-term pulmonary sequelae in early childhood. It is associated with bronchial obstruction and hyperresponsiveness, which may persist until school-age or young adulthood [1–6]. In these children, pulmonary function tests are important in the evaluation of the disease severity and the individual response to treatment, both in clinical and research settings. Since conventional lung function measurements require considerable patient cooperation, the lung function of prematurely born children cannot usually be assessed until school-age. Furthermore, the neurological manifestations associated with premature birth may hamper the assessment of ventilatory function in later stages of childhood.

The forced oscillation technique (FOT) [7–10] is of interest, especially in children with pulmonary diseases, since the lung function can be measured during normal tidal breathing. Therefore, the method requires only minimal cooperation and is applicable also at preschool age. By using the oscillometric method, the mechanical properties of the lung have been described in children with asthma [8, 11–15] and cystic fibrosis [8, 16, 17], but there is only little data available on children with a history of premature birth, with or without CLD. DUIVERMAN et al. [18] found only subtle lung function changes with FOT among children with a history of premature birth, but according to the reported neonatal data, the disease severity of their study subjects was probably mild. Furthermore, these authors did not compare the oscillometric results with those obtained with conventional methods. Therefore, the suitability of the oscillometric technique to detect abnormalities in this patient group remained to be solved.

The aim of the present study was to investigate the lung function in school-aged prematurely born children with severe CLD, by using the oscillometric method. In order to evaluate the suitability of the method in expressing the severity of the CLD, the relationship of oscillometric measurements with conventional lung function tests such as spirometry, whole body plethysmography and pulmonary diffusing capacity, was assessed, and the test results were compared with children born prematurely without a history of CLD, and full term healthy controls.

Material and methods

Study subjects

A total of 49 school-aged children, belonging to a group of very low birth weight infants, born prematurely (birth weight <1,500 g and/or gestational age <30 weeks), and treated between 1989–1991 at the neonatal intensive care unit of the Children's hospital (now the Hospital for Children and Adolescents), University of Helsinki, Finland, were studied. Of these 49 children, 15 had a history of chronic lung disease (CLD), defined as the need for continuous supplemental oxygen at postconceptual age of 36 weeks [19]. The neonatal data, collected from the hospital records, relating to the study of children born prematurely have been presented in table 1. A group of 18 healthy, nonatopic children of the same age and born at full term, were recruited as a control group; they had no respiratory symptoms or signs and the results of the flow-volume spirometry were normal. The anthropometric data of the children at the time of the study have been presented in table 2; according to analysis of variance (ANOVA), the groups did not differ significantly with respect to age, weight or height.

The chronic lung disease of the study children was stable during the measurements, and none of the children had respiratory infection at the time of the study. In the CLD group, four children were on inhaled corticosteroids; of these, three used inhaled bronchodilators and two inhaled sodium cromoglycate regularly. In the non-CLD group, only one child received regular inhaled corticosteroid treatment. Additionally, five children in the CLD group and 10 children in the non-CLD group had used inhaled asthma medication as on demand basis, either bronchodilators, cromones or corticosteroids. Two children also received medication for epilepsy (one in the CLD and one in the non-CLD group). β_2-agonists were not allowed for 12 h preceding the test.

Informed consent was obtained from the parents and the study was approved by the local ethics committee.

Methods

Pulmonary function was tested in the Depts of Allergology (oscillometry, spirometry and diffusing capacity) and of Clinical Physiology (whole body plethysmography), Helsinki University Central Hospital. Impulse oscillometry (Jaeger, Würzburg, Germany) [10], a modification of the forced oscillation technique (FOT), was used in this

Table 1. – The neonatal data of the study children with or without a history of chronic lung disease (CLD) due to prematurity

	Non-CLD	CLD
Subjects n	34	15
Birth weight g	1100 (680–1575)	760 (600–1460)***
Gestational age weeks	28.0 (25.3–30.9)	26.9 (24.1–30.7)*
Duration of ventilator treatment days	5.5 (0–43)	48 (7–101)***
Duration of supplementary oxygen days	16.5 (0–69)	101 (60–1670)**

Data expressed as mean (range). *: p<0.05; **: p<0.01; ***: p<0.001.

Table 2. – Anthropometric data of the control subjects and study children with or without the history of chronic lung disease (CLD), at the time of the study

	Controls	Non-CLD	CLD
Subjects n	18	34	15
Sex F/M	9/9	19/15	8/7
Age yrs	8.2 (5.3–10.7)	8.1 (7.3–9.0)	8.4 (7.8–9.2)
Height cm	130 (110–146)	126 (114–137)	127 (112–144)
Weight kg	27.9 (19.5–42.0)	25.4 (19.5–37.0)	24.1 (16.0–47.0)

Data expressed as mean (range). F: female; M: male.

study. Both methods measure input impedance of the respiratory system, FOT by using pseudorandom noise and impulse oscillometry by using rectangular pulse signals containing harmocis up to 35 Hz or higher, while the patient is breathing quietly. The output pressure and flow signals are analysed for their amplitude and phase difference, to determine the resistance (R_{rs}) and reactance (X_{rs}) of the total respiratory system. In oscillometric measurements, the impulse interval was set to 0.3 s, and by using Fast Fourier transformation, R_{rs} and X_{rs} were calculated as a function of the oscillation frequency of 5–35 Hz. The pneumotachograph of the device was calibrated daily, and the system was weekly checked against a reference impedance of 0.2 kPa·L^{-1}·s.

During the measurement, the child was in a sitting position, breathing quietly through a mouthpiece. A nose clip was used and the cheeks were supported by the hands of the investigator, to minimize pressure loss through the upper airway shunt [20]. The pseudorandom noise method [7] applies a statistical coherence function for evaluation of signal-to-noise ratio. As the impulse oscillometry in the present study does not provide such an estimate, flow and impedance versus time tracings were used in order to evaluate signal quality during data acquisition. In a similar manner to KLUG and BISGAARD [14, 15], segments lasting for 20–40 s, characterized by regular breathing pattern and lack of abrupt changes in impedance, were selected for the measurement. The measurements were repeated at least three times, and of these, three reproducible measurements were selected for the analysis, to calculate a mean value for R_{rs} at 5, 10 and 20 Hz, X_{rs} at 5 and 10 Hz and the resonance frequency (fres; the frequency where the reactance has the value of zero). The neonatal data of the study subjects were not available for the investigator at the time of the measurements. The results were compared to the reference values by DUIVERMAN et al. [21].

Flow-volume spirometry was performed with a pneumotachograph (Spirotrac III, Vitalograph Ltd, Buckinghamshire, UK), preceded by the oscillometric measurement at the same day. At least three acceptable forced expiratory curves were recorded according to the reproducibility criteria of the European Respiratory Society [22]. The curve with the highest sum of forced expiratory volume in one second (FEV1) and forced vital capacity (FVC), was selected. The following spirometric parameters were recorded: FVC, FEV1, FEV1/FVC ratio, and maximum expiratory flow at 50% and at 25% of FVC (MEF50 and MEF25, respectively). The reference values by POLGAR and PROMADHAT [23] were used for the analysis.

The pulmonary diffusing capacity and the static lung volumes were measured by the single breath method [24] (Masterscreen-PFT, Jaeger GmbH, Würzburg, Germany). The measurement was performed at the same day as the oscillometry, except in two children, where due to technical reasons, the measurement was performed within two weeks of the oscillometric measurement. In these two children, the condition was stable between the interval. A volume of 90% of inspired vital capacity (VC) was used for breath holding; the washout volume was preset at 500 mL and the sample for expiratory gas fractions was 750 mL. Two to three tests were performed at intervals of 4 min. Mean values of acceptable measurements were used for analysis of the VC, residual volume (RV), total lung capacity (TLC), RV/TLC ratio, pulmonary diffusing capacity ($D_{L,CO}$) and diffusing coefficient for carbon monoxide (K_{CO}). The reference values by POLGAR and PROMADHAT [23] were used for the static lung volumes, and those by COTES *et al.* [25] for $D_{L,CO}$ and K_{CO}.

Whole body plethysmography (Body-Screen II, Jaeger) was performed for the child patients in another laboratory, the median (range) interval between the oscillometry and plethysmographic measurements being 9 (3–33) days. The mean values of three to five successive measurements of TLC, RV, airway resistance (R_{aw}) and specific airway conductance (sG_{aw}) were recorded. The reference values by POLGAR and PROMADHAT [23] were used for the analysis.

Statistical analysis

For statistical analyses, the results of lung function tests were compared between the study groups by using ANOVA, Bonferroni/Dunn's application for multiple comparisons. For the relationship between the different lung function tests, Pearson's correlation coefficient was calculated. Kappa (κ) statistics were used to describe the agreement in lung function between spirometry and the oscillometric method; McNemar's test was used to compare the agreement of different oscillometric variables with spirometry. A p-value $<0.05/3=0.017$ was considered significant in group comparisons, otherwise the null hypothesis was rejected with p-values <0.05.

Results

The pulmonary function data of the study groups are summarized in tables 3 and 4. All the prematurely born children and the control subjects could co-operate (repeated tidal breathing at least 20 s) during oscillometric measurements. In one case, the result was rejected due to technical artefacts. One child with a history of CLD and severe visual deficit and mental retardation was unable to perform satisfactory spirometric measurements. Diffusing capacity could not be measured with the single breath technique in 13 (9 CLD and 4 non-CLD) patients and in five control subjects, due to small lung volumes or insufficient cooperation. Thirty-seven (11 CLD and 26 non-CLD) children participated in body plethysmographic measurements with sufficient cooperation.

The conventional pulmonary function tests showed obstructive ventilatory defect in spirometry, increased airway resistance, pulmonary hyperinflation and decreased diffusing capacity among children born prematurely; FVC, FEV1, FEV1/FVC, MEF50 and R_{aw} were also significantly different between the non-CLD and CLD groups, showing higher degree of deficit in the latter (table 3). The oscillometric findings in prematurely born children were characterized by significantly higher $R_{rs,5}$ and $R_{rs,10}$,

Table 3. – Pulmonary function data in full-term healthy controls and in children with or without a history of chronic lung disease (CLD)

Parameter	Controls	Non-CLD	CLD	Controls *versus* Non-CLD	Controls *versus* CLD	non-CLD *versus* CLD
					p-values	
FEV1 L	1.79±0.39	1.44±0.22	1.11±0.39	0.0004	<0.0001	0.0013
FEV1 % pred	101.0±7.6	91.3±10.6	66.1±13.8	0.0033	<0.0001	<0.0001
FVC L	2.01±0.46	1.69±0.25	1.44±0.44	0.0039	<0.0001	0.028
FVC % pred	102.8±10.4	95.5±9.2	77.3±12.9	0.022	<0.0001	<0.0001
FEV1/FVC % pred	99.2±5.5	94.3±6.4	85.5±13.4	0.047	<0.0001	0.0013
MEF50 L·s⁻¹	2.45±0.60	1.83±0.49	1.22±0.66	0.0004	<0.0001	0.001
MEF50 % pred	102.0±15.7	76.9±20.7	48.8±22.8	<0.0001	<0.0001	<0.0001
VC L	2.18±0.33	1.68±0.24	1.67±0.45	<0.0001	0.0008	0.95
VC % pred	104.2±10.6	96.7±8.3	85.5±18.6	0.047	<0.0007	0.020
RV L	0.59±0.13	0.61±0.09	0.77±0.13	0.59	0.001	0.012
RV % pred	99.2±16.6	120.4±18.6	138.0±17.4	0.0011	<0.0001	0.024
RV/TLC % pred	100.4±19.0	120.7±16.5	148.6±27.4	0.0029	<0.0001	0.0012
TLC L	2.73±0.33	2.29±0.27	2.44±0.49	0.0003	0.07	0.28
TLC % pred	104.0±8.0	104.0±7.3	98.4±14.8	0.99	0.19	0.15
$D_{L,CO}$ mmol·kPa⁻¹·L·s⁻¹	5.20±1.02	4.07±0.60	3.99±1.09	0.0002	0.003	0.84
$D_{L,CO}$ % pred	97.1±11.1	89.6±9.4	79.1±20.3	0.069	0.0025	0.045
K_{CO} nmol·kPa⁻¹·s⁻¹	1.96±0.22	1.83±0.20	1.67±0.19	0.085	0.0048	0.067
K_{CO} % pred	97.0±12.6	88.2±9.9	81.9±9.2	0.017	0.0038	0.17
R_{aw} kPa·L·s⁻¹	–	0.75±0.18	1.05±0.43	–	–	0.0014
R_{aw} % pred	–	126.4±35.8	188.3±67.2	–	–	0.0008

Data expressed as mean±SD. FEV1: forced expiratory volume in one second; FVC: forced vital capacity; MEF50: maximum expiratory flow at 50% of FVC; VC: vital capacity; RV: residual volume; TLC: total lung capacity; $D_{L,CO}$: carbon monoxide diffusing capacity of the lung; K_{CO}: carbon monoxide transfer coefficient; R_{aw}: airway resistance. p-Values refer to analysis of variance, Dunn's application for multiple comparisons.

Table 4. – Results of impulse oscillometry in full-term healthy controls and in children with or without a history of chronic lung disease (CLD)

Parameter	Controls	Non-CLD	CLD	p-values Controls versus Non-CLD	Controls versus CLD	non-CLD versus CLD
$R_{rs,5}$ kPa·L^{-1}·s	0.65±0.16	0.84±0.18	0.96±0.26	0.0016	<0.0001	0.059
$R_{rs,5}$ SD from pred	-0.02±0.91	1.08±1.07	1.90±1.55	0.0019	<0.0001	0.026
$R_{rs,10}$ kPa·L^{-1}·s	0.59±0.15	0.74±0.15	0.78±0.20	0.0034	0.0016	0.44
$R_{rs,10}$ SD from pred	-0.41±0.87	0.43±0.94	0.73±1.23	0.0061	0.0015	0.33
$R_{rs,20}$ kPa·L^{-1}·s	0.55±0.13	0.64±0.12	0.59±0.14	0.03	0.36	0.28
$R_{rs,20}$ SD from pred	-0.75±0.75	-0.30±0.77	-0.56±0.93	0.06	0.49	0.31
$X_{rs,5}$ kPa·L^{-1}·s^{-1}	-0.19±0.06	-0.26±0.09	-0.40±0.14	0.03	<0.0001	<0.0001
$X_{rs,5}$ SD from pred	0.36±0.59	-0.29±1.08	-2.29±1.53	0.049	<0.0001	<0.0001
$X_{rs,10}$ kPa·L^{-1}·s	-0.04±0.04	-0.13±0.07	-0.26±0.12	0.0003	<0.0001	<0.0001
$X_{rs,10}$ SD from pred	0.22±0.64	-0.78±1.00	-2.54±1.28	0.0012	<0.0001	<0.0001
f_{res} Hz	14.4±3.9	21.8±5.1	25.7±4.4	<0.0001	<0.0001	0.0079

Data expressed as mean±SD. $R_{rs,5}$, $R_{rs,10}$ and $R_{rs,20}$: respiratory system resistance at 5, 10 and 20 Hz; $X_{rs,5}$ and $X_{rs,10}$: respiratory system reactance at 5 and 10 Hz; f_{res}: frequency where the reactance has the value of zero.

lower $X_{rs,5}$ and $X_{rs,10}$, and higher f_{res} than in healthy children, expressed both in absolute values and multiples of standard deviations (SD scores) from the predicted value (table 4); however, the difference between controls and the non-CLD group was not statistically significant in $X_{rs,5}$. In the CLD group, the $X_{rs,5}$ and $X_{rs,10}$ were significantly lower (p<0.0001) and f_{res} higher (p<0.008) than in the non-CLD group. The difference in $R_{rs,5}$ and $R_{rs,10}$ did not reach statistical significance between the CLD and non-CLD groups.

Among the prematurely born children, expressed as SD scores, both $R_{rs,5}$ (r=-0.55, p<0.0001) and $X_{rs,5}$ (r=0.76, p<0.0001) correlated significantly with normalized FEV1 (fig. 1). Of the spirometric variables, also FVC, FEV1/FVC and MEF50 were significantly associated with both $R_{rs,5}$ and $X_{rs,5}$. $R_{rs,5}$ was also significantly associated with R_{aw} (r=0.63, p<0.0001), but showed higher values than R_{aw} at low values of resistance and lower values at resistance values above 1 kPa·L^{-1}·s (fig. 2). $X_{rs,5}$ expressed as SD scores was significantly related to RV (r=-0.43, p< 0.01) and RV/TLC, % pred (r=-0.57, p=0.0004) but not to either $D_{L,CO}$ or K_{CO}, expressed as % pred.

Using 80% pred as a lower normal limit for FEV1 [23], and SD scores of 1.65 for $R_{rs,5}$ and -1.65 for $X_{rs,5}$ [21], the agreement between the spirometry and oscillometry was tested in the patient groups. A low FEV1 was associated with increased $R_{rs,5}$ in 10 and with decreased $X_{rs,5}$ in 13 of the 18 children; correspondingly, a normal FEV1 was associated with normal $R_{rs,5}$ in 22 and with normal $X_{rs,5}$ in 27 of the 30 children. The agreement of $R_{rs,5}$ was low (κ=0.29, 95% confidence interval (CI): 0.00–0.57) and that of $X_{rs,5}$ was moderate (κ=0.64, 95% CI: 0.41–0.87) with FEV1. $X_{rs,5}$ yielded significantly more concordant information with spirometry than $R_{rs,5}$ (p=0.02).

Discussion

The present study reports the lung function of children with a history of CLD due to very premature birth, by using the Oscillometric method. Since the purpose of this study was also to compare conventional lung function tests with oscillometry in this subject group, the children included were at or near school-age. The definition of CLD in this study was based on the requirement for additional oxygen at 36 weeks corrected postnatal gestational age, which has been shown to be the best predictor of abnormal outcome among premature babies [19]. The ventilatory function of our series is comparable to those reported earlier with similar inclusion criteria [5, 6]. The present results suggest that in this patient group, the oscillometric method yields concordant information of the disease severity with other conventional lung function methods.
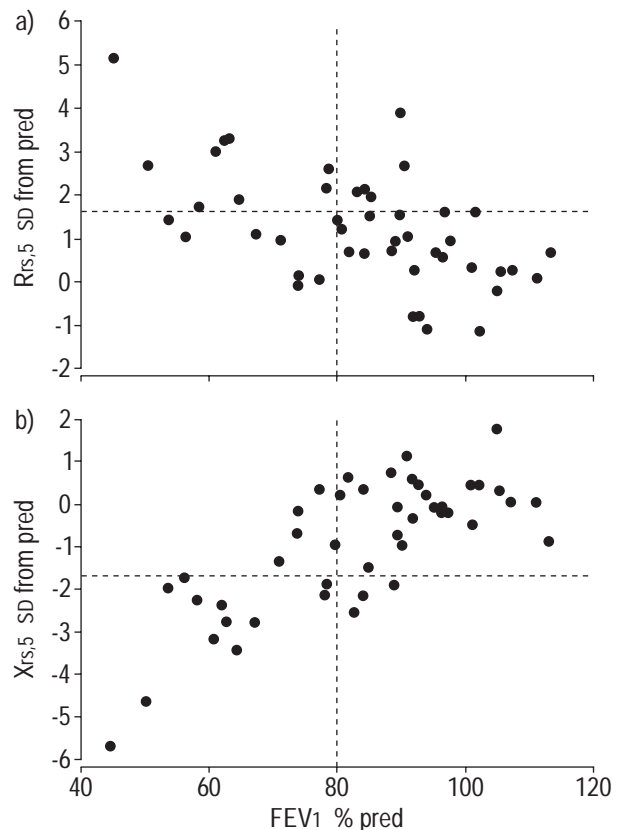

Fig. 1. – The relationship of forced expiratory volume in one second (FEV1) (% pred) with the a) respiratory resistance at 5 Hz ($R_{rs,5}$) and with b) respiratory reactance at 5 Hz ($X_{rs,5}$), measured by the oscillometric technique. The dashed lines indicate lower (FEV1 and $X_{rs,5}$) or higher ($R_{rs,5}$) limits of normality. r=-0.55 for a) and r=0.76 for b) respectively. p<0.0001 for both figures.
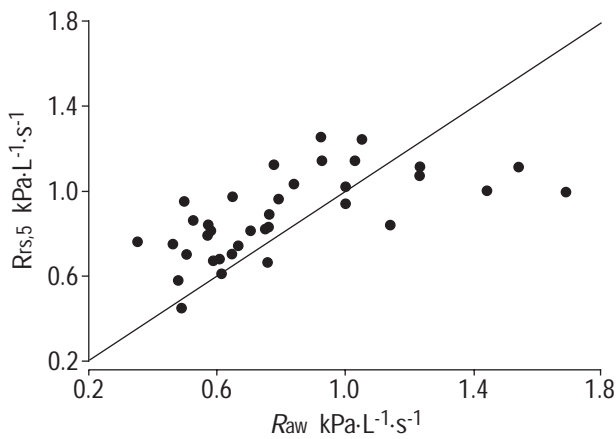
Fig. 2. – The relationship between airway resistance (Raw), measured by the whole body plethysmography, and respiratory resistance at 5 Hz (Rrs,5), measured by the oscillometric technique. Solid line indicates the line of identity. r=0.63 and p<0.0001.

By oscillometric methods, the mechanical properties of the lung have been described in children with asthma [8, 11–15] and cystic fibrosis [8, 16, 17]. In asthma, airway obstruction is associated with increased Rrs, the values measured at lowest oscillatory frequencies (2–5 Hz) showing the best sensitivity [8, 14, 26, 27]. This pattern of abnormality has been similar whether the pseudorandom method [8, 26, 27] or impulse oscillometry was applied [14, 15].

Even though the oscillometric method shows concordant results with spirometry in asthma, in cystic fibrosis, the concordance between FEV1 and respiratory resistance has been reported to be poor [16]. This phenomenon was attributed to the effect of dynamic compression of the airways during forced expiratory manoeuvres; when measuring respiratory resistance at tidal breathing such compression does not occur. In the present study of children with CLD due to prematurity, a significant but low concordance between Rrs,5 and FEV1 has been found. Interestingly, the concordance with the spirometric result was better in Xrs,5. As a group basis, Xrs data seemed also to delineate the severely affected children (CLD group) more accurately than Rrs.

When testing concordance between two methods by classifying the results into normal and abnormal, the reference values and their appropriateness are of utmost importance. For the oscillometry, the reference values of DUIVERMAN *et al.* [21] were chosen, due to the age range of the children. At present, there are no published data available of the agreement between impulse oscillometry and the pseudorandom method which was used in the latter study. However, these predicted equations seemed to conform to the present material satisfactorily enough, since the mean results of the control group did not significantly deviate from that expected.

The better concordance of Xrs with spirometry is in agreement with previous studies of asthmatic children. Xrs measured by the oscillometric method has been shown to correlate well with FEV1 and Raw measurements during challenge tests in asthmatic children [14, 15, 27–29]; compared to an increase in Rrs, a decrease in Xrs has been reported to be more sensitive [14, 15, 28] and specific [29] indicator of intrathoracic obstruction.

Theoretically, Xrs is mainly determined by the elastic and mass-inertial properties of the respiratory system; at low frequencies the former predominate and Xrs varies in relation to the dynamic compliance [9]. The dynamic compliance of the lung, in turn, is decreased in both peripheral airway obstruction and in disorders causing stiffness of the lungs like interstitial fibrosis. Both changes are likely to be present in children with CLD due to premature birth. As a group basis, there was a reduction of diffusing capacity in children with CLD, which confirms earlier findings [30]. However, no significant relationship between Xrs and DL,CO was found, which would suggest that airway obstruction would be the most probable determinant of decreased Xrs values, rather than interstitial fibrosis. However, the most severely affected children could not perform DL,CO testing, which can bias the results.

The determination of airway resistance by whole body plethysmography was, in some children, separated by several weeks from the oscillometric measurement. Even though the disease state of the children had remained stable, this interval may have caused variation when these results were compared. However, the Rrs,5 and Raw were strongly associated. At the lower range of resistance, the oscillometry showed higher values than Raw, which was expected since the method measures total respiratory resistance. At values above 1 kPa·L·s^{-1}, the Rrs,5 underestimated resistance as determined by the body plethysmography, which may be due to upper airway shunt [20]. This phenomenon has been reported in patients with airway obstruction due to adult chronic obstructive pulmonary disease (COPD) [20] and cystic fibrosis [17], even though the cheeks were supported during the measurement. A head generator has been introduced to minimize the problem [20] but may be not convenient for children.

An important finding was that the children with CLD in infancy could be separated from their non-CLD premature and healthy controls, on the basis of their oscillometric profiles. Thus, the oscillometry yielded similar information to that observed with conventional lung function measurements [1–6]. The present results differ by the degree of dysfunction from those reported by DUIVERMAN *et al.* [18], who found in children with CLD only subtle oscillometric changes (slight increase in Rrs,6 and frequency dependence of resistance), and no significant changes in prematurely born children without respiratory problems. The frequency dependence of resistance in this study was regarded as a measure of peripheral airway patency. Since the impulse oscillometry does not provide estimates of this index, direct comparison of the studies in this respect is difficult. The disagreement between the studies is probably explained by the patient selection, since the authors CLD children had a markedly longer duration of supplemental oxygen and therefore, presumably, a more severe disease. The non-CLD children were also born significantly earlier than in the study of DUIVERMAN *et al.* [18]. To the authors′ knowledge, the present study is the only one where oscillometric and conventional measurements of lung function have been compared in CLD due to prematurity.

Due to the ease with which oscillometry is performed, all subjects could cooperate during the measurement, in contrast to spirometry, whole body plethysmography and

diffusing capacity, where cooperation problems precluded the measurement in some cases. Ideally, the respiratory function in children with CLD should be assessed by using methods describing different aspects of lung pathology. In young children, however, the number of suitable methods for lung function testing is limited due to cooperation problems. Earlier reports have shown that the oscillometric measurements can be performed in awake young children from the age of 2–3 yrs [14, 15, 21].

In conclusion, the oscillometric method yields concordant information of lung function with other conventional methods in children born prematurely with or without chronic lung disease. In these children, the oscillometric findings are probably due to peripheral or more widespread airway obstruction. Since conventional methods are not usually suitable for preschool children, the oscillometry may serve as an alternative for early evaluation of lung function for clinical or research purposes among children with premature birth.

References

1. Smyth J, Tabachnik E, Duncan W, Reilly B, Levison H. Pulmonary function and bronchial hyperreactivity in long-term survivors of bronchopulmonary dysplasia. *Pediatrics* 1981; 68: 336–340.
2. Hakulinen A, Heinonen K, Länsimies E, Kiekara O. Pulmonary function and morbidity in school-age children born prematurely and ventilated for neonatal respiratory insufficiency. *Pediatr Pulmonol* 1990; 8: 226–232.
3. Northway W, Moss R, Carlisle K, *et al*. Late pulmonary sequalae of pulmonary dysplasia. *N Engl J Med* 1990; 323: 1793–1799.
4. Pelkonen A, Hakulinen A, Turpeinen M. Bronchial lability and responsiveness in school children born very preterm. *Am J Respir Crit Care Med* 1997; 156: 1178–1184.
5. Gross S, Iannuzzi D, Kveselis D, Anbar R. Effects of preterm birth on pulmonary function at school age: A prospective controlled study. *J Pediatr* 1998; 133: 188–192.
6. Jacob S, Coates A, Lands L, *et al*. Long-term pulmonary sequalae of severe bronchopulmonary dysplasia. *J Pediatr* 1998; 133: 193–200.
7. Landsér F, Nagels J, Demedts M, Billiet L, van de Woestijne K. A new method to determine frequency characteristics of the respiratory system. *J Appl Physiol* 1976; 41: 101–106.
8. Solymar L, Aronson P, Sixt R. The forced oscillation technique in children with respiratory disease. *Pediatr Pulmonol* 1985; 1: 134–140.
9. Solymar L, Landser F, Duiverman E. Measurement of resistance with the forced oscillation technique. *Eur Respir J* 1989; 2: Suppl. 4, 150s–153s.
10. Vogel J, Smidt U. Impulse oscillometry. Frankfurt am Main: Pmi Verlagsgruppe GmbH, 1994.
11. König P, Hordvik N, Pimmel R. Forced random noise resistance determination in childhood asthma. *Chest* 1984; 86: 884–890.
12. Duiverman E, Neijens H, Van der Snee van Smaalen M, Kerrebijn K. Comparison of forced oscillometry and forced expirations for measuring dose-related responses to inhaled methacholine in asthmatic children. *Bull Eur Physiopathol Resp* 1986; 22: 27–33.
13. Lebecque P, Spier S, Lapierre J, Lamerre A, Zinman R, Coates A. Histamine challenge test in children using forced oscillation to measure total respiratory resistance. *Chest* 1987; 92: 313–318.
14. Bisgaard H, Klug B. Lung function measurement in awake young children. *Eur Respir J* 1995; 8: 2067–2075.
15. Klug B, Bisgaard H. Measurement of lung function in awake 2–4 year old asthmatic children during methacholine challenge and acute asthma. *Pediatr Pulmonol* 1996; 21: 290–300.
16. Lebecque P, Stanescu D. Respiratory resistance by the forced oscillation technique in asthmatic children and cystic fibrosis patients. *Eur Respir J* 1997; 10: 891–895.
17. Hellinckx J, De Boeck K, Demedts M. No paradoxical bronchodilator response with forced oscillation technique in children with cystic fibrosis. *Chest* 1998; 113: 55–59.
18. Duiverman E, den Boer J, Roorda R, Rooyackers CMV, Kerrebijn K. Lung function and bronchial responsiveness measured by forced oscillometry after bronchopulmonary dysplasia. *Arch Dis Child* 1988; 63: 727–732.
19. Shennan A, Dunn M, Ohlsson K, Lennox K, Hoskins E. Abnormal pulmonary outcomes in premature infants: prediction from oxygen requirement in the neonatal period. *Pediatrics* 1988; 82: 527–532.
20. Cauberghs M, Van de Woestinje K. Effect of the upper airway shunt and series properties on respiratory impedance measurements. *J Appl Physiol* 1989; 66: 2274–2279.
21. Duiverman E, Clément J, van de Woestijne K, Neijens H, van den Bergh A, Kerrebijn K. Forced oscillation technique. Reference values for resistence and reactance over a frequency spectrum of 2–26 Hz in healthy children aged 2.3–12.5 years. *Bull Eur Physiopathol Respir* 1985; 21: 171–178.
22. Quanjer PH, Tammeling GJ, Cotes JE, Pedersen OF, Peslin R, Yernault J-C. Lung volumes and forced expiratory flows. Official statement of the European Respiratory Society. *Eur Respir J* 1993; 6: Suppl. 16, 5–40.
23. Polgar G, Promadhat V. Pulmonary function testing in children: Technics and standards. Philadelphia: W.B. Saunders, 1971.
24. Cotes JE, Chinn DJ, Quanjer PH, Roca J, Yernault JC. Standardization of the measurement of transfer factor (diffusing capacity). *Eur Respir J* 1993; 6: Suppl. 16, 41–52.
25. Cotes J, Dabbs J, Hall A, Heywood C, Laurence K. Sitting height, fat free mass and body fat as reference variables for lung function in healthy British children; comparison with stature. *Ann Hum Biol* 1979; 6: 307–314.
26. Clément J, Làndsér F, van de Woestijne K. Total resistance and reactance in patients with respiratory complaints with or without airway obstruction. *Chest* 1983; 2: 215–220.
27. Solymar L, Aronsson PH, Engström I, Bake B, Bjure J. Forced oscillation technique and maximum expiratory flows in bronchial provocation test in children. *Eur J Respir Dis* 1984; 64: 486–495.
28. Buhr W, Jorres R, Berdel D, Làndsér F. Correspondence between forced oscillation and body plethysmography during bronchoprovocation with carbachol in children. *Pediatr Pulmonol* 1990; 8: 280–288.
29. Bouaziz N, Beyaert C, Gauthier R, Monin P, Peslin R, Marchal F. Respiratory system reactance as an indicator of the intrathoracic airway response to methacholine. *Pediatr Pulmonol* 1996; 22: 7–13.
30. Hakulinen A, Järvenpää A, Turpeinen M, Sovijärvi A. Diffusing capacity of the lung in school-aged children born very preterm, with and without bronchopulmonary dysplasia. *Pediatr Pulmonol* 1996; 21: 253–360.