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Original Articles

Oscillatory respiratory impedance and lung tissue compliance

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The respiratory impedance was measured by means of the forced oscillation technique (Landser *et al.*) and the lung tissue compliance was measured with an oesophageal balloon in 30 patients with a wide range of values of lung tissue compliance. According to the model of respiratory impedance of Nagels *et al.* it is unlikely that the impedance data are markedly affected by the lung tissue compliance. This hypothesis has not been clinically tested yet.

The semistatic compliance (Css) or specific compliance (Cspec) were not statistically correlated with any of the impedance data. Consequently the oscillatory respiratory measurements are not systematically influenced by the compliance of the lung tissue during quiet breathing. However, the dynamic compliance and the frequency dependence of the compliance showed a low but significant correlation with the reactance and resonant frequency (varying from r=0·41, P<0·05 to r=−0·54, P<0·01). A significant correlation was found between the frequency dependence of the lung tissue compliance and the frequency dependence of the oscillatory resistance, both being indicative of peripheral airway obstruction (varying from r=−0·54, P<0·01 for the whole group, to r=−0·75, P<0·001 for 15 patients with severe peripheral airway obstruction: mean (SD) FEV_1 59·5 (24·8)% pred, mean (SD) MEF_{50} 30·9 (25·8)% pred.

Introduction

The airway impedance is defined as the pressure change applied to the airways divided by the flow caused by this pressure change. The factors which influence the pressure changes in a linear system have been described by Mead in the equation consisting of a single resistance, a single capacitance and a single inertance in series (1):

$$\Delta Prs = V/Crs + Rrs \times \dot{V} + Irs \times \ddot{V}$$

ΔPrs: Pressure difference applied to the respiratory system. V: Volume, $\dot{V}$: Flow, $\ddot{V}$: Volume acceleration, Crs: Compliance of the respiratory system, Rrs: Resistance of the respiratory system, Irs: Inertance of the respiratory system.

In such a simplified system, Rrs depends on Crs, in accordance with the rewritten equation: $Rrs = \Delta Prs/\dot{V} - V \times \dot{V}/Crs - Irs \times \ddot{V}/\dot{V}$. This is also the case in a more realistic and complex representation of the respiratory system. The total respiratory compliance consists of two compliances in series: the chest wall – and the lung tissue compliance. The chest wall compliance is difficult to measure and depends on several factors (body posture, age, body size, lung volume and time history). The normal values of the chest wall compliance are varying from equal values to lower values as compared with the lung tissue compliance (2,3). On the base of the equation of Mead it seems unlikely that the compliance of the respiratory system or the lung tissue will substantially affect the impedance of the respiratory system.

The impedance data acquired by means of the forced oscillation technique are divided into a real part (resistance, Rrs) and an imaginary part (reactance, Xrs). The resistance is mainly determined by the calibre of the central airways. The reactance describes the elastic and mass inertial factors of the airways, the lung tissue and the thoracic wall and the inertia of the air within the bronchi.

The purpose of this study was to test the hypothesis that the impedance data from the forced

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oscillation technique were not systematically influenced by the (semi-) static lung tissue compliance.

In the model of Nagels *et al.* (4), the imaginary part of the impedance data (Xrs) is directly linked with the dynamic compliance of the respiratory system (C dyn rs) and depends on the oscillatory frequency (f). This theoretical relationship between the reactance and the dynamic compliance of the lung tissue, was also tested in this study.

Methods

MEASUREMENT TECHNIQUE

The total respiratory impedance was measured by means of the forced oscillation technique as described by Landser *et al.* (5). The subjects, sitting in an upright position, with a clip on the nose, supported the cheeks and submandibular tissue with their hands and breathed quietly through the apparatus (Oscillaire®, Jones, Chicago, U.S.A.). The pseudo-random-noise pressure oscillations generated by a loudspeaker were superimposed on spontaneous breathing. The ensuing flow was measured with a pneumotachograph. The pressure and flow signals were recorded at the same time by two identical differential transducers (Validyne MP445). The impedance values were calculated at each frequency by digital filtering (Fourier analysis) from 2,4,6,8 ... to 26 Hz. The impedance data consist of a real part and an imaginary part. The real part or resistance (Rrs) was computed as the ratio between the pressure and flow signals which were in phase. It represents the total resistance of the airways, the lung tissue and the thoracic wall. The imaginary part or reactance (Xrs) was computed as the ratio between the pressure and flow signals which were 90° out of phase. It represents the compliance of the airway walls, the lung tissue and the thoracic wall, as well as the inertia of the lung tissue, thoracic wall and the air within the bronchi. In this way, Rrs and Xrs values (both expressed in cm $H_2O\ l^{-1}\ s^{-1}$) were obtained at each frequency and the average values of all frequencies were computed. The frequency at which the Xrs was zero was called the resonant frequency (R.F.) In this study the frequency dependence of the resistance (FD_{Rrs}) was defined as the ratio (Rrs 6 Hz − Rrs 26 Hz)/Rrs 26 Hz. The data-collecting time was 16 s. The validity of the data was measured by computing the coherence function evaluating the signal/noise ratio. Only values with a coherence function of 0·95 or more were retained. Three adequate measurements were averaged for further calculations (5).

The lung tissue compliance (l/kPa) was measured with an oesophageal balloon positioned in the oesophagus 40 cm from the nares in semistatic and dynamic conditions [measurement technique according to ECCS standards (6)]. The semistatic compliance (Css) was calculated as the slope of the pressure–volume curves (mean of three technically satisfactory measurements) at a breathing level between FRC and FRC+0·5 l. The dynamic compliance (Cdyn) was defined as the compliance measured at a breathing frequency of 50 breaths min^{-1}. The specific compliance (Cspec) was calculated by expressing the semistatic compliance value (l/kPa) in volume changes in percentage of predicted TLC (total lung capacity) per kPa. The frequency dependence of the compliance (FD_C) was expressed as the compliance measured at 50 breaths (C50) divided by the compliance measured at 10 breaths min^{-1} (C 10).

Flow volume data (Discom 21, Chest Corp. Tokyo, Japan) were taken to compare the oscillatory impedance values with the parameters acquired from the forced expiration data as indirect indices of the airway resistance.

SUBJECTS

Thirty patients from our out-patient clinic were studied [21 males, 9 females, mean (SD) age 51·3 (11·2) years, mean (SD) FEV_1 66·2 (24·6)%, range 23–110% of ECCS reference values (6)]. The patient characteristics are shown in Table 1. The patient group comprised subjects with a chronic obstructive pulmonary disease (COPD, *n*=18) and asthma (*n*=6). The other six patients had an interstitial lung disease and restrictive lungfunction data (sarcoidosis, *n*=5 and interstitial pulmonary fibrosis, *n*=1). The lung tissue compliance was compared to the reference values (7) and considered to be increased when it was 1 SD above this value and to be decreased when it was 1 SD below this value. On the basis of these values the patient group was divided in three subgroups, (a) patients with an increased lung tissue compliance (*n*=14), (b) patients with a normal compliance (*n*=10) and (c) patients with a decreased lung tissue compliance (*n*=6).

From the whole group 15 patients were separately studied on the basis of a severe peripheral airway obstruction (without restrictive lung disease), with a mean (SD) FEV_1 59·5 (24·8)% pred. and a mean (SD) MEF_{50} 30·9 (25·8)% pred. The study was approved by the local ethical committee. Informed consent was obtained from all subjects.

For a mathematically adequate calculation of the correlations the whole study group included 30 patients with a wide range of lung tissue compliance parameters and hence a wide range of forced expiratory measurement data.

Table 1 Patient characteristics. Mean values (SD) of each group

Group	1: flaccid	2: normal	3: stiff
n	14	10	6
Age (years)	49 5 (14·1)	52·5 (6·8)	53·6 (11·3)
Sex	11M, 3F	7M, 3F	3M, 3F
Rrs 6 (cm H_2O l^{-1} s^{-1})	4·54 (1·53)	4·90 (2·88)	4·79 (2·21)
Rrs 26	3·74 (1·18)	4·08 (1·51)	3·72 (1·03)
Rrsav	4·11 (1·27)	4·48 (2·23)	4·15 (1·49)
Xrs	−0·35 (1·08)	−0·31 (1·67)	−0·77 (1·68)
R.F. (Hertz)	17·5 (9·2)	15·3 (10·1)	17·6 (10·6)
FD_{Rrs}	0·25 (0·32)	0·18 (0·44)	0·27 (0·48)
FEV_1 (%ref)	60 8 (23·6)	70·4 (22·9)	71·7 (26·8)
FEV_1/FVC (%)	58·2 (10·8)	64·5 (12·5)	66·5 (12·3)
MEF_{50} (%ref)	30·3 (20·7)	36·4 (16·3)	35·5 (22·6)
Css (l/kPa)	5·58 (3·01)	3·32 (0·84)	2·00 (0·86)
Cspèc (%TLC kPa^{-1})	87·7 (61·1)	49·4 (9·4)	33·6 (11·5)
Cdyn (l/kPa)	1·51 (0·85)	1·47 (0·51)	0·93 (0·27)
FD_C (%)	73·8 (22·9)	88·1 (16·1)	80·7 (16·7)
P100 (%ref)	67·9 (19·6)	83·4 (19·8)	132·9 (38·8)
P 90 (%ref)	66·3 (21·2)	77·5 (18·1)	107·0 (6·7)

Table 2 Coefficients of correlation (Spearman's) between lung function data and oscillatory respiratory impedance data

	Rrs 6	Rrs 26	Rrs_{av}	Xrs_{av}	RF	FD_{Rrs}
Css	−0·22	−0·24	−0·25	0·14	−0·07	0·03
Cspec	−0·11	−0·13	−0·14	0·09	0·004	0·02
Cdyn	−0·28	0·01	−0·21	0·41*	−0·43**	−0·27
FD_C	−0·20	−0·27	−0·01	0·46**	−0·54**	−0·54**
FEV_1 (%ref)	−·46**	−0·17	−0·25	078***	−0·78***	−0·79***
MEF50 (%ref)	−0·52**	0·01	−0·37*	0·69***	−0·71***	−0·68***

Level of significance: **P*<0·05, ***P*<0·01, ****P*<0·001.

DATA ANALYSIS

Coefficients of correlation (Spearman's) between the impedance data and the compliance data and between the impedance and the flow volume data were computed for the whole group. A *P*-value <0·05 was considered to be significant.

Results

Table 1 shows the patient characteristics and the mean values (SD) of the lung function data of each patient subgroup.

All coefficients of correlation between the impedance data and the semistatic (Css) or specific compliance (Cspec) were low (0·25 or less) and not statistically significant (Table 2). Visual inspection of the scatter plots of the semistatic compliance data *vs.* the various oscillatory impedance data, did not suggest any linear or non-linear relationships. However, Cdyn showed a statistically significant correlation with the reactance and the resonant frequency. The frequency dependence of the compliance (FD_C) was found to be correlated with the reactance, the resonant frequency and frequency dependence of the resistance.

The FEV_1 and the MEF_{50} data were correlated with the resistance at 6 Hz, the reactance, the resonant frequency and frequency dependence of the resistance (Table 2).

In the 15 patients with severe peripheral airway obstruction the frequency dependence of the resistance closely correlated with the frequency dependence of the compliance ($r=-0·75$, $P<0·001$). The other correlations between the impedance and compliance data were the same as those found in the whole group (Table 2; $n=30$).

Discussion

In this study no significant correlation was found between the semistatic and specific lung tissue compliance and the respiratory impedance data. According to Nagels' model on pulmonary impedance (4) [based on Mead's model (8)] it is unlikely that the impedance data or the reactance data are affected by the (semi)static lung tissue compliance. These data imply that using the forced oscillation technique the measurement data of the pulmonary impedance during quiet breathing are not systematically influenced by the compliance of the lung tissue. Furthermore, it has been shown that stiffness of the thoracic wall does not affect the oscillatory impedance data (9). However, the dynamic compliance and the reactance are equivalent expressions. According to the model of Nagels, a correlation was expected between the dynamic compliance of the whole respiratory system and the reactance. Since the dynamic compliance of the lung tissue reflects the dynamic compliance of the whole respiratory system, a correlation between these compliances is expected. This hypothesis was confirmed in this study.

The dynamic lung tissue compliance is influenced by the semistatic compliance, the inertia and the unevenness of ventilation. During high breathing frequencies (50 breaths min^{-1}) the inertial properties of the lung and the unevenness of ventilation are getting more important in the value of the dynamic compliance. This could explain the correlation found between the dynamic compliance and the reactance. Furthermore, the frequency dependence of the lung tissue compliance showed a significant correlation with the frequency dependence of the oscillatory resistance. This is consistent with the notion that both parameters are linked with unevenness of ventilation and are considered to be indicative of peripheral airway obstruction (10–12).

This is consistent with the more close correlation ($r=-0{\cdot}75$, $P<0{\cdot}001$) between the frequency dependence of the resistance and the frequency dependence of the compliance which was found in the 15 patients with severe peripheral airway obstruction. Kjeldgaard *et al.* (11) also described a close correlation between the frequency dependence of the total respiratory resistance and the frequency dependence of the dynamic compliance ($r=0{\cdot}82$, $P<0{\cdot}001$). However, other investigators have found low correlation coefficients between those two parameters, presumably by 'some artifacts in the measurements at high respiratory frequencies' (13).

A low but significant correlation was found between the oscillatory resistance at 6 Hz (Rrs6) and the FEV_1 and MEF_{50} values. A closer correlation was found between the flow–volume data and the reactance, the resonant frequency and the frequency dependence of the resistance. Other authors found correlations between the respiratory impedance and the forced expiratory flows ranging from $r=-0{\cdot}47$ for FEV_1 and Rrs (10 Hz), and $r=-0{\cdot}51$ for resonant frequency and FEV_1 in normal adults, to $r=-0{\cdot}88$ for FEV_1 and Rrs (6 Hz) in asthmatic children (14,15). This suggests that these two methods measure different properties of the respiratory system.

It can be concluded that no correlation was found between the oscillatory impedance data and lung tissue compliance during quiet breathing. Consequently, when measuring the respiratory resistance by means of the forced oscillation technique no corrections have to be made for the compliance of the lung tissue. The dynamic compliance was correlated with the reactance and the resonant frequency. In patients with severe bronchial obstruction the frequency dependence of the compliance was closely correlated with the frequency dependence of the respiratory resistance. Both parameters are considered to be associated with peripheral airway obstruction.

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