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Flow Resistance in Patients with Chronic Obstructive Pulmonary Disease in Acute Respiratory Failure

Effects of Flow and Volume[1-3]

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SUMMARY The flow and volume dependence of the total resistance of the respiratory system (Rrs) was investigated in six mechanically ventilated patients with chronic obstructive pulmonary disease (COPD) using a simple, rapid method. Isovolume Rrs-flow ($\dot{V}$) relationships obtained at different inflation volumes (range 0.1 to 1 L) fitted ($p < 0.001$) the following function: $Rrs = a/\dot{V} + b + c\dot{V}$, where a, b, and c are constants. The term "$a/\dot{V}$" in this equation represents the hyperbolic decrease in thoracic tissue resistance with increasing flow; the term "$c\dot{V}$" represents the linear increase in airway resistance with increasing flow. Rrs initially decreased with increasing $\dot{V}$ because at low flow the weight of the $a/\dot{V}$ was greater than that of the $c\dot{V}$. At higher flow, however, $c\dot{V}$ became predominant and hence Rrs tended to increase. At an inflation volume of 0.5 L, minimum Rrs occurred at average inflation flow of 1.28 L/s. At low flow, Rrs increased progressively with increasing inflation volume; at inflation $\dot{V} > 1$ L/s, the highest values of Rrs were obtained at low inflation volumes. The flow and volume dependence of Rrs implies that, for comparative purposes, measurements of Rrs should be standardized to a fixed inflation flow and volume.

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Introduction

Several studies have shown that in mechanically ventilated patients with chronic obstructive pulmonary disease (COPD) in acute respiratory failure, the flow resistance of the total respiratory system (Rrs) is markedly increased (1-3). These investigations were carried out at fixed values of inspiratory flow and volume using the technique of rapid airway occlusion during constant-flow inflation. Recently, however, it has been shown that in normal anesthetized paralyzed humans (4), dogs (5), and cats (6) Rrs varies markedly with both inflation flow and volume. In the present investigation we have studied the flow and volume dependence of Rrs in a group of mechanically ventilated COPD patients using a simple method. In addition, at baseline inflation flow and volume, we have partitioned Rrs into airway resistance and the additional effective resistance due to time-constant inequalities and viscoelastic properties of the lung and chest wall (4).

Methods

Six COPD patients admitted to the Intensive Care Unit (ICU) of the Saint-Luc Hospital because of exacerbation of chronic airway obstruction were studied in the supine position 1 to 4 days after intubation. COPD was confirmed by clinical history, physical examination, and respiratory function tests previously done in our laboratory (table 1). Patients were intubated (Sheridan® cuffed endotracheal tube with internal diameter between 7 and 9 mm; Sheridan, New York, NY) and mechanically ventilated with constant inspiratory flow on controlled ventilation mode (Model 7200 ventilator; Puritan-Bennett, Carlsbad, CA). Patients were sedated (intravenous diazepam, 0.1 to 0.2 mg/kg) and paralyzed (pancuronium bromide, 0.1 to 0.2 mg/kg) upon decision of the primary physician. During the study the positive end-expiratory pressure (PEEP) was not applied to any of the patients. The baseline ventilatory settings, which are listed in table 2, were kept constant throughout the study. The fraction of inspired oxygen ($F_{I_{O_2}}$) remained unchanged during the entire procedure (table 1). Tracheal pressure (Ptr) was measured using a low-compliance end-sealed 16 G catheter (1.7 mm inner diameter) provided with six lateral holes, connected to a pressure transducer (Validyne MP45 ± 100 cm H_2O; Validyne Inc., Northridge, CA). The catheter was introduced into the trachea via the endotracheal tube (ET), and its tip was positioned 3 cm beyond the carinal end of the endotracheal tube. With the system used to measure Ptr there was no appreciable shift or alteration in amplitude up to 20 Hz. Flow ($\dot{V}$) was measured with a heated pneumotachograph (Fleisch #3; Fleisch, Lausanne, Switzerland), which was inserted via cones between the proximal end of the endotracheal tube and the Y connector of the ventilator. The pneumotachograph was connected to a differential pressure transducer (Validyne MP45 ± 2 cm H_2O) and was linear over the experimental flow range. The equipment dead space (not including the endotracheal tube) was 169 ml. Special care was taken to avoid air leaks from the tracheal cuff and breathing circuit. For monitoring, changes in volume (ΔV) were obtained by electrical integration of the flow signal (Model 8815A; Hewlett-Packard, Inc., Andover, MA). All signals were calibrated independently and simultaneously recorded on an eight-channel pen recorder (7758A Hewlett-Packard) with a paper speed of 10 mm/s and on magnetic tape (Hewlett-Packard 3968A). The Ptr and $\dot{V}$ signals were played back at a sample frequency of 200 Hz by a 12-bit analog-to-digital converter on an IBM-compatible personal computer for subsequent data analysis. In this analysis volume was obtained by digital integration of the flow signal. Arterial blood gases were measured with an ABL 330 blood gas analyzer (Radiometer, Copenhagen, Denmark). The end-tidal CO_2 concentration was monitored with a CO_2 analyzer (CO_2 monitor; Datex, Helsinki, Finland). The values of $F_{I_{O_2}}$ and blood gases at the time of the investigation are listed in table 1. During the study a physician not involved in the experiment was always

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TABLE 1

CLINICAL DATA OF SUBJECTS WITH COPD

Patient No.	Sex	Age (yr)	Height (cm)	Weight (kg)	FEV_1/FVC (%)	Pa_{O_2} (mm Hg)	Pa_{CO_2} (mm Hg)	pH	$F_{I_{O_2}}$
1	M	68	170	74	45	64	54	7.38	0.28
2	M	68	162	58	55	103	54	7.45	0.50
3	M	62	156	62	38	78	30	7.54	0.40
4	F	60	148	64	33	92	51	7.44	0.28
5	M	62	168	65	42	84	54	7.47	0.40
6	M	61	169	78	35	68	60	7.44	0.30
$\bar{x}$		63.5	162.2	66.8	41.3	81.5	50.5	7.45	0.36
SD		3.6	8.7	7.6	8.0	14.7	10.5	0.05	0.09

Definition of abbreviations: $F_{I_{O_2}}$ = fraction of inspired O_2; FEV_1/FVC (%) was measured in stable state before acute exacerbation.

TABLE 2

BASELINE VALUES OF VARIOUS VENTILATORY VARIABLES IN COPD PATIENTS

Patient No.	ΔV (L)	ΔV/BW (ml/kg)	$\dot{V}$ (L/s)	TI (s)	TE (s)	TI/Ttot	PEEPi (cm H_2O)	ΔFRC (L)	Cst,rs (L/cm H_2O)
1	0.84	11.3	0.90	1.03	3.25	0.24	4.0	0.490	0.096
2	0.64	11.1	0.97	0.84	3.44	0.20	1.4	0.070	0.036
3	0.94	15.1	1.03	1.01	3.27	0.23	6.4	0.555	0.108
4	0.65	10.2	1.10	0.80	3.48	0.19	7.7	0.470	0.039
5	0.79	12.1	1.04	0.88	3.40	0.20	3.7	0.440	0.149
6	0.91	11.7	1.00	1.04	3.24	0.24	4.5	0.495	0.110
$\bar{x}$	0.80	11.9	1.01	0.93	3.35	0.22	4.6	0.420	0.090
SD	0.13	1.7	0.07	0.11	0.11	0.02	2.2	0.176	0.044

Definition of abbreviations: ΔV = inflation volume; $\dot{V}$ = constant inspiratory flow; TI = inspiratory time; TE = expiratory time; TI/Ttot = inspiratory duty cycle; PEEPi = intrinsic positive end-expiratory pressure; ΔFRC = difference between end-expiratory volume during mechanical ventilation and relaxation volume; Cst,rs = static compliance of respiratory system over baseline inflation volume range.

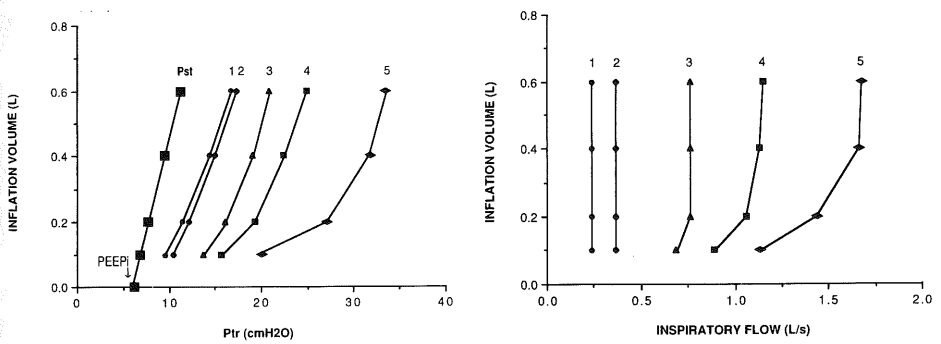

Fig. 1. (*Left*) Relationship between inflation volume and tracheal pressure (Ptr) under static conditions (Pst) and during five inflations made with differing inflation flows. PEEPi, intrinsic PEEP. (*Right*) Inspiratory volume-flow (ΔV-$\dot{V}$) relationships corresponding to left panel. Numbers on top identify ΔV-Ptr and ΔV-$\dot{V}$ relationships obtained during the same inflation. Patient 3.

present to provide patient care. The study was approved by the institutional ethics committee, and informed consent was obtained from the patient or next of kin.

Static Inflation Volume-Pressure (V-P) Relationship of the Respiratory System

Maintaining flow at its baseline value, single-breath airway occlusions were performed at different inflation volumes (ΔV) ranging from 0.1 to 1 L. In each test breath, the occlusion was maintained until an apparent plateau in Ptr was achieved. Because the 7200 Puritan-Bennett ventilator is programmed for a maximal end-inspiratory pause of only 2 s, which may not suffice to achieve a plateau in Ptr, during the 2-s end-inspiratory hold we also occluded the inspiratory and expiratory lines of the ventilator by clamping the ventilator tubings. In this way, longer end-inspiratory occlusion holds could be achieved. By 5 s of end-inspiratory hold, all patients exhibited an apparent plateau in Ptr, and hence Ptr at 5 s was taken to represent the static end-inspiratory elastic recoil pressure of the respiratory system. The inspiratory and expiratory lines were also occluded at end-expiration to determine intrinsic PEEP (PEEPi) (7). Since PEEPi implies dynamic pulmonary hyperinflation, that is, the end-expiratory lung volume (EELV) during mechanical ventilation exceeds the relaxation volume of the respiratory system (Vr), we also measured the difference between EELV and Vr (here termed "ΔFRC") by removing the Y piece of the ventilator from the pneumotachograph during expiration and allowing the patient to exhale to Vr (1). After each test breath baseline ventilation was resumed until the tracheal pressure records returned to baseline (usually in a few breaths). Tests were performed in random order. Since the plateau values of Ptr represent the static elastic recoil pressure of the respiratory system (Pst), plots of ΔV versus Pst allowed us to construct the static inflation V-P curve of the respiratory system. The static compliance of the respiratory system (Cst, rs) was obtained by dividing the baseline ΔV (table 2) by the corresponding value of end-inspiratory Pst minus PEEPi, if present (1).

Total Resistance of Respiratory System

Keeping the inflation volume fixed at its baseline value, a series of single-breath lung inflations at different inspiratory flow rates (up to 2 L/s) was performed in random order. After each test breath baseline ventilation was resumed until the tracheal pressure records returned to the pretest values. The dynamic ΔV versus Ptr relationships obtained at different inflation flows were plotted as shown in figure 1 (left) together with the corresponding static curve. The concurrent ΔV versus $\dot{V}$ relationships were also displayed, as shown in figure 1 (right). Isovolume pressure-flow relationships for the total respiratory system were computed by plotting the resistive pressure (Ptr − Pst) derived from figure 1 (left) against the corresponding flow in figure 1 (right).

Partitioning of Respiratory System Resistance

The records obtained during end-inspiratory airway occlusion at baseline inflation volume and flow (table 2) were used to partition Rrs into the interrupter resistance (Rint) and ΔRrs, as previously described in detail (4). In humans, Rint essentially reflects airways resistance (8) and ΔRrs represents the additional dynamic pressure dissipations within the lungs and chest wall as a result of time-constant inequalities and/or viscoelastic

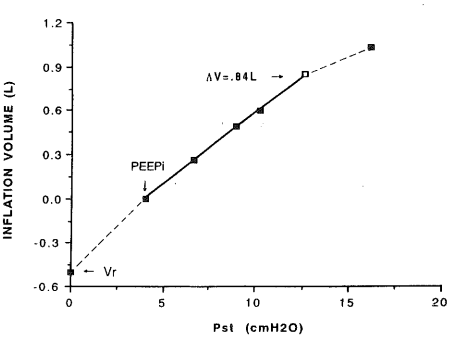

Fig. 2. Static inflation volume-pressure relationship of the total respiratory system in a representative patient with intrinsic PEEP (PEEPi) of 4 cm H_2O. Open square, end-inspiratory point during baseline mechanical ventilation with inflation volume of 0.84 L. Vr = relaxation volume of the respiratory system. Patient 1.

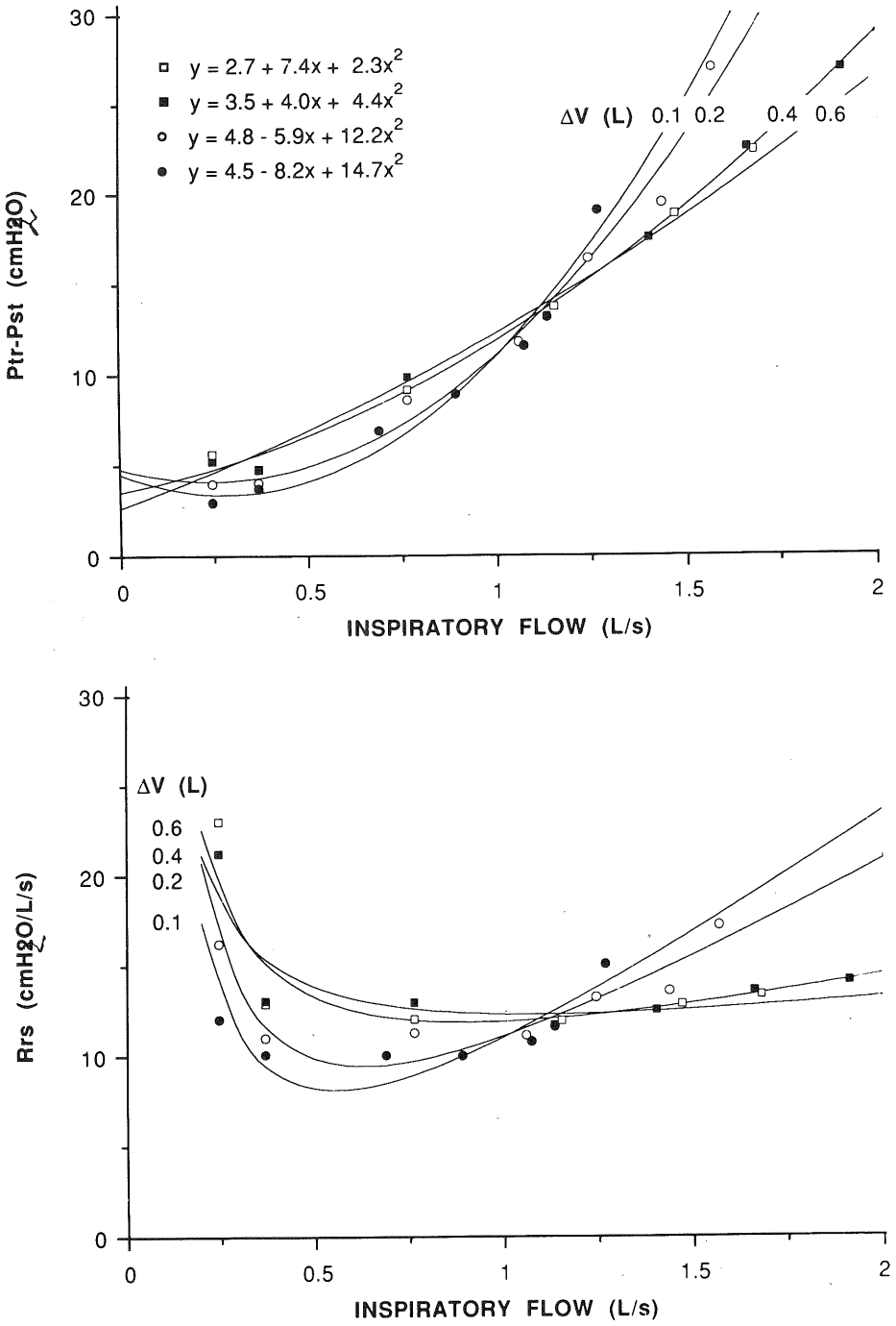

Fig. 3. (*Top*) Relationships between resistive pressure (Ptr-Pst) and inspiratory flow ($\dot{V}$) obtained at different inflation volumes (ΔV) from figure 1. Values of constants of equation *1* are indicated. (*Bottom*) Isovolume relationships between total resistance of respiratory system (Rrs) and inspiratory flow computed according to equation *2* using values of constants in left panel. Patient 3.

mechanisms (4). Because ΔRrs is thought to reflect predominantly viscoelastic pressure dissipations within the pulmonary and chest wall tissues, it is commonly referred to as "thoracic tissue resistance." In calculation of Rint and Rrs, the errors due to the closing time of the ventilator valve were corrected according to Kochi and coworkers (9). The whole experimental protocol could be completed in less than 8 min.

Regression analysis was made with the least-squares method. The regression coefficients were analyzed by analysis of variance (ANOVA) for dependence with inflation volume. Values are mean ± SD unless otherwise specified.

Results

All patients exhibited PEEPi ranging between 1.4 and 7.7 cm H_2O, with a mean value of 4.6 ± 2.2 cm H_2O (table 2). PEEPi was associated with substantial dynamic pulmonary hyperinflation, as indicated by the values of ΔFRC, which averaged 0.420 ± 0.176 L (table 2). The respiratory system's static compliance measured during baseline inflations was relatively high in most patients (except Patients 2 and 4), averaging 0.090 ± 0.044 L/cm H_2O (table 2). The static inspiratory V-P curves of respiratory system of two representative patients are depicted in figure 1 (left) and figure 2. Both curves are linear over the baseline inflation volume range, decreasing at higher ΔV because of pulmonary overdistension (figure 2). At baseline end-expiratory lung volume, Pst is still positive, reflecting PEEPi. Similar results were obtained in all patients.

Figure 3 (left) shows the isovolume relationship between the resistive pressure (Ptr − Pst) and inspiratory flow in Patient 3. At each inflation volume the relationship was curvilinear and fitted a second-order polynomial equation:

$$Ptr - Pst = a + b\dot{V} + c\dot{V}^2 \quad (1)$$

where a is the y intercept at $\dot{V} = 0$. Similar isovolume pressure-flow relationships were obtained in all patients, with correlation coefficients ranging between 0.95 and 0.99 ($p < 0.001$) for different inflation volumes. The average values of the constants a, b, and c for different inflation volumes are reported in table 3. None of these constants was influenced significantly by the inflation volume. Since Rrs = (Ptr − Pst)/$\dot{V}$, it follows from equation *1* that

$$Rrs = \frac{a}{\dot{V}} + b + c\dot{V} \quad (2)$$

The different isovolume relationships between Rrs and $\dot{V}$ for Patient 3, computed according to equation *2*, the average isovolume relationships between Rrs and $\dot{V}$ of the six patients are illustrated

TABLE 3

RELATIONSHIPS OF RESISTIVE PRESSURE WITH FLOW OBTAINED AT DIFFERENT INFLATION VOLUMES IN 6 COPD PATIENTS*

ΔV (L)	a (cm H_2O)	b (cm H_2O/L/s)	c (cm H_2O/L²/s²)
0.1	3.32 ± 2.29	2.83 ± 6.59	5.48 ± 7.20
0.2	3.24 ± 1.68	6.24 ± 6.96	3.31 ± 4.54
0.4	3.32 ± 2.30	8.21 ± 4.94	1.76 ± 1.48
0.5	3.21 ± 1.95	8.78 ± 5.39	1.83 ± 1.34
0.6	3.31 ± 1.87	8.79 ± 4.66	1.84 ± 1.82

Definition of abbreviations: Ptr = dynamic tracheal pressure at different inflation volumes; Pst = static tracheal pressure at corresponding inflation volumes; ΔV = inflation volume; $\dot{V}$ = inspiratory flow; a, b, c = constants.

* ptr − Pst = a + b$\dot{V}$ + c$\dot{V}^2$. Values are mean ± SD.

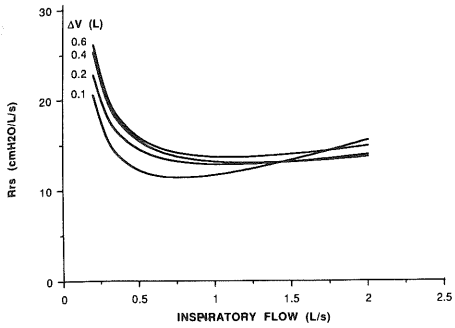

Fig. 4. Average isovolume (ΔV) relationships between total resistance of respiratory system (Rrs) and inspiratory flow of six COPD patients.

in figure 4. At each inflation volume, Rrs initially decreased markedly with increasing $\dot{V}$ until a minimum value was reached at a flow that varied for different ΔV; thereafter, Rrs tended to increase slowly with increasing $\dot{V}$. The average relationship between Rrs and $\dot{V}$ for ΔV corresponding to 10 ml/kg of the six patients are shown in figure 5. At $\dot{V}$ of 1 L/s, Rrs averaged (± SEM, standard error of the mean) 13.6 ± 3.3 cm H_2O/L/s. By differentiating equation *2* with respect to $\dot{V}$ and setting the result to zero, it is possible to compute the value of $\dot{V}$ corresponding to minimum Rrs, which is given by $\sqrt{a/c}$ (9). For ΔV of 10 ml/kg this averaged (± SEM) 1.16 ± 0.47 L/s.

At baseline inflation flow and volume, we partitioned Rrs into Rint and ΔRrs. The individual values obtained in the six patients are reported in table 4. Rint, which reflects airway resistance, amounted to 8.0 ± 4.4 cm H_2O/L/s, representing 59% of Rrs. ΔRrs amounted to 5.5 ± 2.4 cm H_2O/L/s and accounted for 41% of Rrs.

Discussion

In COPD patients, ventilatory failure is largely due to increased flow resistance. Accordingly, measurements of Rrs are fundamental to assess the status and progress of COPD patients with acute ventilatory failure. The present paper provides a new approach for measuring the flow resistance of the respiratory system (as well as the compliance) that is simple and rapid and provides a detailed description of the flow and volume dependence of Rrs. Because Rrs varies with both inflation flow and volume, for comparative purposes its measurements of Rrs need to be standardized.

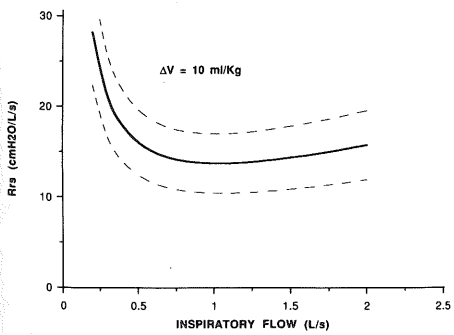

Fig. 5. Average ± SEM relationship between total resistance of respiratory system (Rrs) and inspiratory flow for inflation volume of 10 ml/kg of six COPD patients.

TABLE 4

BASELINE VALUES OF RESPIRATORY SYSTEM RESISTANCE AND ITS COMPONENTS IN PATIENTS WITH COPD*

Patient No.	Rrs (cm H_2O/L/s)	Rint (cm H_2O/L/s)	ΔRrs (cm H_2O/L/s)
1	11.2	7.2	4.0
2	24.2	16.2	8.0
3	9.9	7.6	2.3
4	16.2	8.3	7.9
5	10.8	4.2	6.6
6	8.3	4.4	3.9
$\bar{x}$	13.5	8.0	5.5
SD	5.9	4.4	2.4

Definition of abbreviations: Rrs = respiratory system resistance; Rint = interrupter resistance; ΔRrs = additional resistance.

* Measurements were obtained at ventilator settings indicated in table 2.

Static Inflation V-P Curve

In line with previous reports (1, 2, 7), all our patients exhibited dynamic pulmonary hyperinflation, as reflected by ΔFRC and PEEPi. Our values of PEEPi (4.6 ± 2.2 cm H_2O) were somewhat lower than those of previous studies (1, 2), presumably reflecting in part the relatively longer duration of expiration used in the present investigation (3.35 ± 0.11 s). A prolongation of expiratory duration has been shown to result in a decrease in PEEPi (10). The values of Cst,rs of four of our patients were relatively high (table 2), presumably reflecting a prevailing component of emphysema. The nature and implications of PEEPi in COPD patients have been previously discussed in detail (1, 2, 10, 11).

Flow and Volume Dependence of Rrs

Studies in anesthetized and paralyzed experimental animals (5, 6) and normal humans (4) have shown that thoracic tissue resistance, as reflected by ΔRrs, is not independent of flow as previously believed (12). On the contrary, it exhibits characteristic viscoelastic behavior that theoretically can be explained by a spring-and-dashpot model (4, 5, 13). At a fixed inflation volume, the relationship between ΔRrs and $\dot{V}$ can be described by an empirical hyperbolic function of the type (4, 6)

$$\Delta Rrs = \frac{a}{\dot{V}} + b' \qquad (3)$$

where a and b′ are constants. The average values of a of our patients are provided in table 3. The value of this constant did not change with inflation volume, amounting to about 3.3 cm H_2O. Since a was independent of inflation volume, using the values of ΔRrs in table 4 it is possible to estimate the baseline values of b′ of our patients based on equation *3* ($b' = \Delta Rrs - a/\dot{V}$). For baseline inflation flow (1 L/s) and volume (0.8 L), b′ should amount to 2.2 cm H_2O/L/s. In normal supine anesthetized and paralyzed subjects, the average values of a and b′ amounted to 1.12 cm H_2O and 0.64 cm H_2O/L/s, respectively (4). This is considerably lower than in our patients, indicating that COPD profoundly affects the viscoelastic properties of the lung.

Studies on anesthetized, paralyzed humans (4) have shown that, at fixed inflation volume, airway resistance (as reflected by Rint) is related to flow by the classic Rohrer's equation

$$Rint = K_1 + K_2\dot{V} \qquad (4)$$

where K_1 and K_2 are constants.

Since Rrs is the sum of ΔRrs and Rint, from equations *3* and *4*, it follows that

$$Rrs = \frac{a}{\dot{V}} + b' + K_1 + K_2\dot{V} \qquad (5)$$

For $b' + K_1 = b$ and $K_2 = c$, equation *5* becomes equal to equation *2*. Thus, the constant b in table 3 should correspond to the sum of b′ and K_1, and the constant c should represent Rohrer's constant K_2. In 16 normal supine anesthetized and paralyzed humans K_2 averaged 0.52 ± 0.08 cm $H_2O/L^2/s^2$ at an inflation volume of 0.47 ± 0.01 L (4). As indicated in table 3, at a similar inflation volume (0.5 L), the values of c ($=K_2$) of our patients were considerably higher (1.83 ± 1.34 cm $H_2O/L^2/s^2$). As indicated previously, we estimated that in our patients the constant b′ amounted to 2.2 cm H_2O/L/s. Since b in table 3 corresponds to the sum of b′ and K_1, it follows that at an inflation volume of 0.5 L the average value of K_1 of our patients was 6.58 cm H_2O/L/s. This is considerably higher than in normal subjects in whom K_1 measured at a similar inflation volume (0.47 L) amounts to 1.94 ± 0.51 cm H_2O/L/s (4). A marked increase in K_1 and K_2 in stable patients with severe

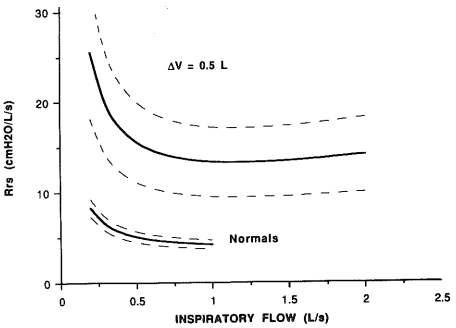

Fig. 6. Average ± SEM relationships between total resistance of respiratory system (Rrs) and inspiratory flow at inflation volume (ΔV) of 0.5 L in six COPD patients of present study and in 16 normal anesthetized paralyzed subjects (4).

COPD has been previously found by Fry and coworkers (14).

At low flow rates the weight of the $c\dot{V}$ term of equation *2* is less than that of the $a/\dot{V}$ term, and consequently Rrs decreases initially with increasing $\dot{V}$ (figures 4 and 5). At higher flow rates, however, the increase in airway resistance (as reflected by $c\dot{V}$) becomes more important than the concomitant decrease in ΔRrs due to $a/\dot{V}$, and as a result Rrs tends to increase. The initial decrease in Rrs with increasing flow represents a clinically important aspect because it occurs in the inflation flow range commonly used in the ICU setting (0.5 to 1 L/s).

The relationship between Rrs and inspiratory flow obtained in 16 normal anesthetized and paralyzed subjects at an inflation volume of 0.47 ± 0.01 L by D'Angelo and coworkers (4) is compared in figure 6 with that found at a similar inflation volume in our patients. At all comparable flow rates, Rrs was about threefold higher in the COPD patients, the high values of Rrs at low flows reflecting mainly increased ΔRrs and the increase in Rrs at higher flows was mainly due to an increase in Rohrer's constant K_2. In normal subjects, the maximal inspiratory flow studied amounted to 1 L/s. Up to this flow, Rrs continuously decreased. D'Angelo and coworkers (4), however, were able to compute the flow corresponding to minimal Rrs, which in their normal subjects should amount to 1.81 ± 0.19 L/s. This is higher than in our patients, in whom minimal Rrs for inflation volume of 0.5 L, computed according to Kochi and coworkers (9), amounted to 1.28 ± 0.59 L/s. This difference is due essentially to the higher value of K_2 of the COPD patients.

The aforementioned studies performed in both normal humans (4) and animals (5, 6) also demonstrated that at a fixed inflation flow ΔRrs increases with increasing inflation volume. Since this increase is quantitatively more important than the concomitant decrease in Rint, Rrs increases with increasing inflation volume. This is also true in COPD patients at inflation flows of up to about 1 L/s, as shown in figure 4. In contrast, at higher flows Rrs is higher at low inflation volumes because of a disproportionate increase in airway resistance with increasing flow. Indeed, at low inflation volumes the values of the constant c ($=K_2$) were much higher than at higher inflation volumes (table 3).

Broseghini and coworkers (1) studied a group of COPD patients during the first day of mechanical ventilation. The study was carried out at zero end-expiratory pressure at an inflation flow of 0.62 L/s and an inflation volume of 0.69 L. The values of Rrs amounted to 26.4 ± 13.4 cm H_2O/L/s. At a comparable inspiratory flow and inflation volume, Rrs in our patients amounted to 14.9 ± 10.2 cm H_2O/L/s, which is lower than the values obtained by Broseghini and coworkers (1). Since our patients were studied on Days 1 to 4 of mechanical ventilation, this discrepancy presumably reflects that in COPD patients the impairment of respiratory mechanics is in general more severe on the first day of mechanical ventilation than later (15). Indeed, Bernasconi and coworkers (2) studied a group of COPD patients who had been mechanically ventilated between 1 and 9 days and found a value of Rrs of 15.8 ± 6.3 cm H_2O/L/s at an inflation flow and volume close to those used by Broseghini and coworkers (1). This value of Rrs is close to that found in the present study at a comparable inflation flow and volume. It should be noted, however, that comparison of the present results with previous studies is problematic because previously the values of Rrs were derived from pressure measurements obtained proximal to the ET or in the ventilator itself (1, 2) after correction for the pressure dissipations within the ventilator tubings and/or endotracheal tubes. The resistance of the latter was measured in new isolated tubes. *In situ*, however, the flow resistance of the ET may be higher as a result of adherent secretions or tube deformation (such as kinking), for example (16, 17).

In our patients Rint amounted to 8.0 ± 4.4 cm H_2O/L/s at baseline inflation flow and volume. This is about three times greater than in normal subjects in whom, at the same $\dot{V}$ but at a lower ΔV (0.47 ± 0.01 L), Rint amounts to about 2.5 cm H_2O/L/s (4). Considering that Rrs was threefold greater than normal at a comparable inflation volume and flow (figure 6), it follows that COPD markedly affects ΔRrs as well as Rint. Although the factors involved in the increase in airway resistance in COPD patients are reasonably well understood (18), this is not the case for ΔRrs. Time-constant inequalities within the lungs in COPD necessarily play a greater role than in normal individuals (4). Clearly, however, in COPD patients a substantial part of the dynamic work of breathing is due to ΔRrs, especially at low inflation flows and high inflation volumes. This suggests that the rapid and shallow breathing pattern characteristic of COPD patients with acute respiratory failure (19) may reduce the dynamic work of breathing. In view of the flow and volume dependence of Rrs, the present results indicate that measurements of Rrs must be standardized to a fixed inflation flow and volume.

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