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Respiratory compliance and resistance in mechanically ventilated patients with acute respiratory failure*

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Abstract. The purpose of this study was noninvasive assessment of respiratory compliance and resistance in mechanically ventilated patients with acute respiratory failure (ARF). To this end, flow, change in lung volume, and airway pressure were measured at the proximal tip of the endotracheal tubes in twenty nine critically ill unselected patients. Eleven had acute exacerbation of chronic obstructive pulmonary disease (COPD), 8 had adult respiratory distress syndrome (ARDS) and 10 had ARF of various etiologies. Static compliance (Cst,rs), 'intrinsic' PEEP (PEEPi), as well as minimum and maximum resistance (Rrs,min and Rrs,max, respectively) were obtained with end-inspiratory and end-expiratory airway occlusions. We found that: (1) PEEPi was present in all patients with COPD (up to 11.4 cmH_2O) and it was not uncommon in patients with ARF without history of chronic airway disease (up to 4.1 cmH_2O). (2) Without correction for PEEPi average Cst,rs was not significantly different between ARDS and COPD patients, whereas the average corrected compliance was significantly lower in ARDS patients. (3) Substantial frequency-dependence of resistance was exhibited not only by COPD patients, but also by ARDS patients.

Key words: Acute respiratory failure – Mechanical ventilation – Respiratory resistance – Static respiratory compliance – Positive end-expiratory pressure (PEEP) – Chronic obstructive pulmonary disease (COPD) – Adult respiratory distress syndrome (ARDS)

The measurement of the static compliance of the total respiratory system (Cst,rs), computed as the ratio between the expired tidal volume and the difference between a 'plateau' pressure at end-inspiration and the end-expiratory pressure is extensively used to assess the status and progress of acute respiratory failure (ARF), as well as the efficiency of therapeutic interventions in mechanically ventilated patients [7, 12, 26, 27]. Although airway occlusion at the end of the mechanical inflation also enables determination of total respiratory resistance [14, 26] to date changes of respiratory resistance in patients with ARF have not received the same attention. Few measurements of respiratory resistance have been reported for mechanically ventilated patients, and are not routinely used in clinical practice to evaluate the efficiency of therapy (e.g. bronchodilators, aspiration of bronchial secretions, etc.) as well as the progression of the disease. Bates et al. [2] have also shown, in line with the classical analysis by Otis et al. [19] and Grimby et al. [11], that rapid occlusion of the airway during constant flow inflation provides not only measurement of resistance, but also determination of frequency-dependence of resistance, namely a way to quantify the degree of time constant inhomogeneities within the lung. Their results, however, were based mainly on a model analysis [2] and limited to a small number of patients [22] and required further validation. We therefore undertook this study to extend previous observations [22, 23] and to validate the approach by Bates et al. [2]. In fact, time constant inhomogeneities within the lung might play an important role in determining gas exchange impairment in critically ill patients [11, 19].

Methods

Twenty nine unselected, consecutive, patients with ARF of different etiology (Table 1) who needed ven-

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Table 1. Patients' diagnosis

Patient	Sex	Age (years)	Diagnosis
1	F	25	Cystis fibrosis, acute exacerbation
2	F	79	COPD, hydopneumothorax
3	M	63	COPD, pneumothorax
4	F	65	COPD, abdominal surgery
5	M	66	COPD, acute exacerbation
6	F	75	COPD, acute exacerbation
7	F	67	COPD, acute exacerbation
8	F	73	COPD, obesity, acute exacerbation
9	M	79	COPD, acute exacerbation
10	M	62	COPD, vascular trauma, laparotomy
11	F	55	COPD, pancreatitis, pneumonia
12	F	65	Bowel obstruction, laparotomy, ARDS
13	M	51	SLE pneumonia, sepsis, ARDS
14	F	35	Salicylate poisoning, aspiration pneumonia, ARDS
15	M	53	C5-C6 Paraplegia, aspiration pneumonia, ARDS
16	M	61	Actinomyces pneumonia, ARDS
17	F	27	Meningococcal sepsis, ARDS
18	F	35	Barbiturate overdose, pneumonia, ARDS
19	F	69	Partial pancreatectomy, ARDS
20	M	69	Myocardial infarction, phneumonia, CPE
21	M	57	Myocardial infarction, CPE
22	M	73	Coronary bypass surgery, embolic stroke
23	F	46	Pneumonia
24	M	43	Myastenia gravis, pneumonia
25	M	69	Acute cholecystitis, laparotomy
26	M	53	Asbestosis, left side emphyema
27	F	42	Kyphoscoliosis, chronic cor pulmonale
28	M	71	Mitral valve and coronary surgery
29	M	59	Hodgkin, meningitis, bilateral pleuritis

Definition of abbreviations: COPD = chronic obstructive pulmonary disease; ARDS = adult respiratory distress syndrome; SLE = systemic lupus erythematosus; CPE = cardiogenic pulmonary edema

tilatory support in the intensive care unit (Royal Victoria Hospital, Notre Dame Hospital, and Montreal Chest Hospital Centre, Montreal, Canada) were studied. The investigative protocol was approved by the institutional Ethics Committees, and informed consent was obtained from the patients or their next of kin.

Twenty five patients were intubated transorally with Portex cuffed endotracheal tubes, ranging from 7 to 9 mm in internal diameter. Four patients had a cuffed tracheostom tube, one with 6.5 mm and the remaining with 8.5 mm internal diameter. The patients with the tube had been mechanically ventilated with volume cycled ventilators at constant inspiratory flow, using control or assist/control mode (Bennet MA-1 or 2; Bear 1; Siemens 900 B) for a period of 1 to 9 days prior to the present investigation and were clinically stable during the preceeding 12 h. The patients with the tracheostomy were also in stable condition at the time of the study but had been mechanically ventilated for a longer time, i.e. 10, 12, 41, and 25 days for patients nos. 11, 20, 26, and 29 respectively. According to the diagnosis of the disease underlying ARF, the 29 patients were divided into three groups: I: patients with acute exacerbation of chronic obstructive pulmonary disease (COPD), from no. 1 to no. 11; II: patients with adult respiratory distress syndrome (ARDS), from no. 12 to no. 19; III: patients with ARF without COPD or ARDS, from no. 20 to no. 29, "others". Diagnosis of ARDS met standard criteria: 1) bilateral infiltrates on chest X-ray; 2) PaO_2 less than 50 mmHg with FiO_2 of 0.5; 3) presence of one or more risk factors; 4) no history of chronic pulmonary disease; 5) no clinical suspicion of cardiogenic pulmonary edema. Diagnosis of COPD was based upon previous clinical history and routine lung function tests. Ventilator settings were prescribed by the primary physicians, according to their clinical judgement (Table 2). All patients with ARDS, except no. 19, were receiving a positive end-expiratory pressure (PEEP) at the time of the study, ranging from 4.1 to 17 cmH_2O. PEEP was also set by the ventilator in 5 patients of group I (nos. 2, 3, 8, 10, and 11), and in 4 patients of group III (nos. 21, 22, 24, and 25).

Patients were studied in the supine or semi recumbent position. During the study a physician not involved in the procedure was present to provide care. Flow ($\dot{V}$) was measured with a heated pneumotachograph (Fleish no. 2) connected to the proximal end of the en-

Table 2. Blood gases and ventilatory settings

	no.	PaO_2 (mmHg)	$PaCO_2$ (mmHg)	pH	FiO_2	V_T (l)	T_I (s)	T_E (s)	$\dot{V}_I$ (l/s)	PEEP (cmH_2O)
Group I	11	91.5	45.2	7.43	0.43	0.68	1.3	2.6	0.61	6.3
COPD		±28.7	±6.5	±0.07	±0.11	±0.16	±0.2	±0.6	±0.12	±2.2
Group II	8	69.6	39.6	7.43	0.58	0.67	1.3	2.3	0.56	10.0
ARDS		±15.9	±6.4	±0.06	±0.21	±0.14	±0.3	±0.8	±0.14	±4.1
Group III	10	79.9	42.5	7.41	0.44	0.70	1.2	2.6	0.60	5.6
Others		±14.0	±15.5	±0.04	±0.08	±0.20	±0.3	±1.0	±0.19	±1.4

Definition of abbreviations: V_T = tidal volume; T_I = inspiratory time; T_E = expiratory time; $\dot{V}_I$ = constant inspiratory flow; PEEP = positive end-expiratory pressure. Values are mean ± SD

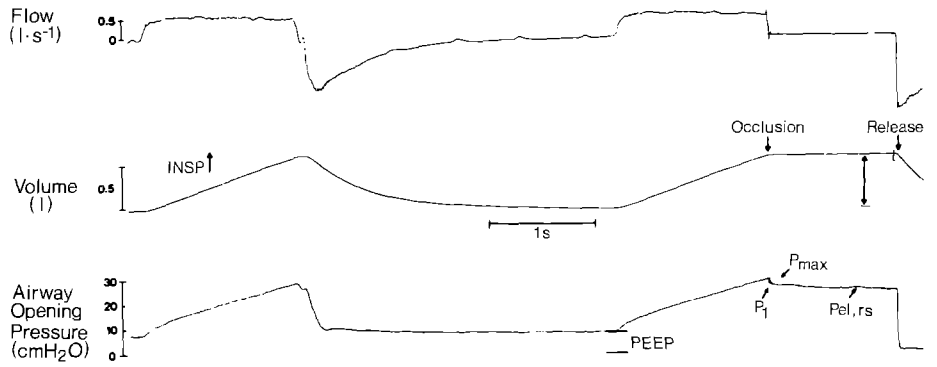

Fig. 1. Tracings of flow, volume and pressure at the airway opening in a mechanically ventilated patient with ARDS with PEEP of 8.5 cmH_2O. Airway occlusion at end-inspiration was performed at point indicated by the arrow. This results in an immediate drop of pressure from a peak value (Pmax) to P1 thereafter decreasing gradually to a 'plateau' value representing the end-inspiratory elastic recoil pressure of the total respiratory system (Pel,rs). In this subject, expiratory flow became nil before the end of expiration, and inspiratory flow started synchronously with the onset of the positive pressure inflation, indicating that the end-expiratory Pel,rs relative to PEEP is zero

dotracheal tube via a cone, and to a differential pressure transducer (Validyne MP 45, ± 2 cmH_2O; Validyne Co., Northdridge, Ca). After the initial rise, inspiratory flow was constant throughout most of the inflation. Volume (V) was obtained by electrical integration of the flow signal (Model 8815A; Hewlett-Packard, Waltham, Ma). A pneumatically operated valve (No. 4200 Hans Rudolph, Kansas City, Mo) was used for rapid occlusion at the airway opening. Pressure at the airway opening (Pao) was measured proximally and distally to the valve using 2 differential pressure transducers (Validyne MP 45). Equipment dead space (not including the endotracheal tube) was 70 ml. All signals were recorded on a six channel pen recorder (Gould-Brush 2600; Gould Instruments, Cleveland, Oh) at a paper speed of 25 or 50 mm/s.

Procedure and data analysis

After insertion of the pneumotachograph and valve into the circuit, mechanical ventilation was resumed with the ventilator settings prescribed by the primary physicians. After a few minutes of routine ventilation, the patient appeared to be relaxed and only occasionally triggered the ventilator. Spontaneous breathing efforts were easily detected by on line inspection of $\dot{V}$, V, and Pao records. At the time of the study, one patient was sedated (morphine) and four patients were paralyzed (pancuronium). No patients were sedated or paralyzed for the purpose of the study.

Before the end of the mechanical lung inflation with constant inspiratory flow, the airway opening was occluded until, after the initial drop from the peak value (Pmax) to a lower value (P1), a plateau in Pao was observed (usually less then 1.5 s) (Fig. 1). This plateau provided further evidence of relaxation of the respiratory muscles as well as equilibration between alveolar and airway opening pressure. Under these conditions the end-inflation Pao plateau represents the elastic recoil pressure of the total respiratory system (Pel, rs) at end-inflation [28]. After the plateau in end-inspiratory Pao during the occlusion was achieved, the expiratory line of the ventilator was disconnected and the occlusion rapidly released, such that the patient expired freely to the atmosphere through the measuring equipment until zero flow was reached or expiration was interrupted by spontaneous inspiratory efforts. In all patients we also determined the end-expiratory Pel,rs by means of the end-expiratory occlusion [20]. The difference between end-expiratory Pel,rs and PEEP set by ventilator, when present, was termed 'intrinsic' PEEP (PEEPi) [23].

The static compliance of the total respiratory system (Cst,rs) was computed as the ratio between tidal volume and Pel,rs minus PEEP, as well as the ratio between tidal volume and Pel,rs minus PEEP minus PEEPi. Inspiratory resistance was measured during the same maneuver according to a previously described method [2, 22]. Briefly, maximum respiratory resistance (Rtot, max) was computed dividing by the flow immediately preceding the occlusion Pmax-Pel,rs. Minimum respiratory resistance (Rtot, min) was computed dividing by the flow Pmax-P1. The pressure drop due to the endotracheal tube and measuring equipment was then subtracted to obtain intrinsic respiratory resistance, both maximum (Rrs,max) and minimum (Rrs,min). Since the pressure-flow relationship of endotracheal tubes has been shown to be curvilinear, the pressure drop was calculated at any given inspiratory flow. In line with the analysis by Bates et al. [2], the difference between Rrs,max and Rrs,min may represent the frequency-dependence of resistance [11].

Table 3. Respiratory compliance and resistance measured at end-inspiration

	no.	PEEPi (cmH_2O)	Cst,rs (l/cmH_2O)	Rtot,max	Rrs,max	Rtot,min	Rrs,min
				($cmH_2O \cdot l^{-1} \cdot s$)			
Group I	11	5.1	0.045	20.2	15.8	12.0	8.1
COPD		±3.2	±0.013	±5.8	±6.3	±4.0	±4.3
Group II	8	1.3	0.033	12.3	9.0	7.0	3.7
ARDSs		±0.2	±0.007	±4.5	±4.6	±7.4	±1.7
Group III	10	2.7	0.044	10.2	7.0	7.3	3.5
Others		±1.2	±0.020	±3.2	±3.3	±2.6	±2.9

Definition of abbreviations: PEEPi = 'intrinsic' positive end-expiratory pressure; Cst,rs = static respiratory compliance; Rtot,max and Rtot,min = maximum and minimum respiratory resistance, including endotracheal tubes and measuring equipment; Rrs,max and Rrs,min = intrinsic maximum and minimum respiratory resistance. Values are mean ±SD. Note that values of Cst,rs have been corrected for PEEPi. Mean values of PEEPi come from 3 ARDS patients and 4 patients in group III

Mean value from three determinations was used for each respiratory variable. Group values are presented as mean ± SD. Statistical analysis of the data was made with the unpaired t-test. A $p < 0.05$ was accepted as significant.

Results

Average results of respiratory mechanics in the three groups are given in Table 3. In all the groups mean Cst,rs was lower than normal [1], the lowest compliance being exhibited by ARDS patients and averaging 0.033 ± 0.007 l/cmH_2O. It was significantly lower than both other groups ($p < 0.05$), while no significant difference was found between group I and III. But this was the case only for the corrected values of Cst,rs, i.e. after subtraction of PEEPi. In fact, a positive Pao at end-expiration during regular ventilation, reflecting PEEPi, was found in 17 of the 29 patients. All COPD patients exhibited PEEPi, up to 11.4 cmH_2O, the average value amounting to 5.1 ± 3.2 cmH_2O. Because 5 patients were receiving PEEP set by the ventilator, that mean value probably underestimates the true amount of PEEPi; in fact PEEP set by the ventilator may replace PEEPi [24]. Also 3 and 5 patients in groups II and III respectively, without any history of chronic airway obstruction, exhibited PEEPi. This was less than 2 cmH_2O with the exception of two patients, nos. 23 and 29, in whom it amounted to 2.3 and 4.1 cmH_2O, respectively. When Cst,rs was computed without the correction for PEEPi, average values amounted to 0.033 ± 0.006, 0.0032 ± 0.008, and 0.042 ± 0.020 l/cmH_2O in group I, II, and III, respectively. It has to be noted that without the appropriate correction for PEEPi patients with ARF due to COPD or ARDS exhibited almost identical values of compliance. The mean ratio between the corrected and uncorrected value of Cst,rs was 36% in the COPD group, up to 100%, and less than 5% in the other two groups. However individual data reached an error of 20% and 40% among the ARDS and other patients, respectively. The relationship between individual measurements of corrected and uncorrected Cst,rs is shown in Figure 2.

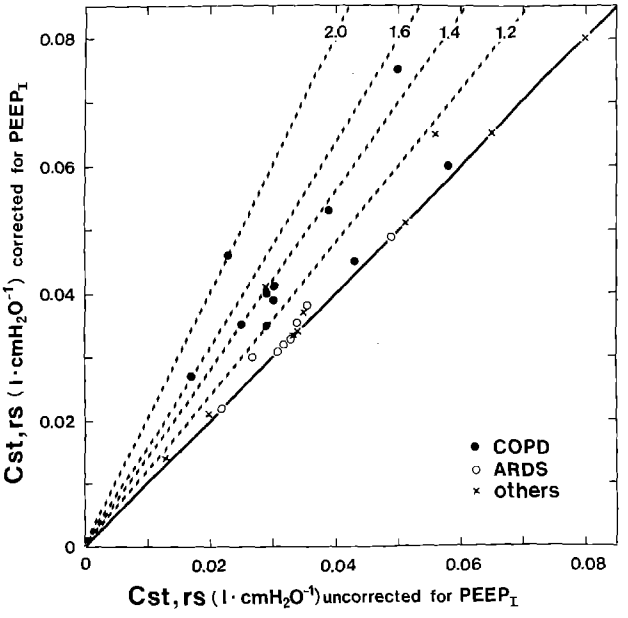

Fig. 2. Relationship between individual values of static respiratory compliance (Cst,rs) corrected and uncorrected for the 'intrinsic' PEEP (PEEPi). Solid line is the identity line and dashed lines are isoplets of corrected to uncorrected Cst,rs ratio

Average values of resistance are also shown in Table 3. Using a similar method, i.e. the end-inspiratory occlusion during a constant flow lung inflation. Not surprisingly the highest value of Rrs,min was found in patients with COPD, while in the other two groups mean Rrs,min was lower and almost the same (Table 3). The absolute difference between Rrs,max and Rrs,min, which may represent the frequency-dependence of resistance [2, 11], averaged (1 SD) 7.2 ± 3.3, 5.5 ± 2.9, and 2.8 ± 1.0 $cmH_2O \cdot l^{-1} \cdot s$ in groups I, II, and III, respectively and was significant-

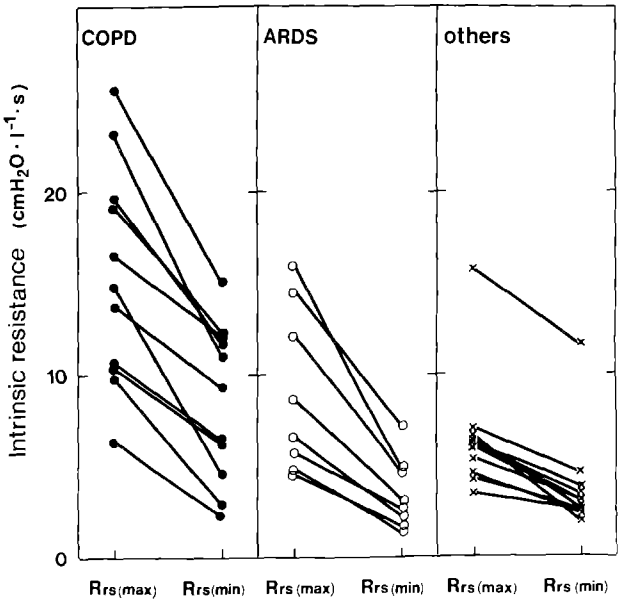

Fig. 3. Individual values of maximum and minimum intrinsic respiratory resistance, Rrs,max and Rsr,min respectively, in the three groups of patients. Patient with high resistance in "others" is patient no. 27 (Table 1)

ly higher for both COPD ($p<0.001$) and ARDS ($p<0.05$) patients compared to group III. Individual measurements of Rrs,max and Rrs,min are presented in Figure 3.

Discussion

The results of this study show that: (1) PEEPi was present in all the patients with ARF due to acute exacerbation of COPD, but was not uncommon in mechanically ventilated patients without history of chronic airway disease, leading to significant underestimation of Cst,rs; (2) substantial frequency-dependence of resistance was found not only in COPD patients, but also in ARDS patients, whose respiratory resistance was also increased.

The implications of PEEPi in terms of hemodynamics and weaning in COPD patients have been extensively discussed elsewhere [8, 16, 17, 20]. However, in view of the presence of PEEPi in mechanically ventilated patients without history of airway disease, it should be stressed here that detection of PEEPi should become a common practice in critically ill patients. In fact, although the average underestimation of Cst,rs, because of unrecognized PEEPi, in non COPD patients did not exceed 5%, individual error approached 20% in three patients (one with ARDS) and was as high as 40% in one patient (Fig. 2). In this contest it has to be mentioned that patients in this study were unselected and most of them were examined after several days they had been mechanically ventilated and treated. The latter characteristic probably led to lower values of PEEPi than in early ARF.

In patients with severe COPD the rate of lung emptying is unduly slowed by high expiratory resistance and expiratory flow limitation, and the time available between two mechanical inflations may be inadequate for the respiratory system to expire. PEEPi was indeed present in all our COPD patients. However total airflow resistance may be increased for a number of reasons in critically ill mechanically ventilated patients. For example the narrow bore endotracheal tubes and the tubings of the ventilator; this may be equally effective in retarding the expiratory flow and thereby contributing to the presence of PEEP even with 'stiff' lung [10].

Static respiratory compliance was, on the average, lower than normal in all mechanically ventilated patients with ARF (Table 3) [1]. In patients with COPD, low compliance probably reflected pulmonary hyperinflation, mechanical ventilation taking place toward the upper flat part of the volume-pressure curve [13]. In ARDS the low Cst,rs reflects mainly loss of ventilating units because of air space flooding [25]. Patients in group III exhibited a wide interindividual variability, due to different etiology underlying ARF, individual measurements ranging from 0.080 to 0.014 l/cmH_2O. This latter which was the lowest among all patients value was found in the patient with kyphoscoliosis. These patients are well known to have restrictive respiratory disease due to stiffness of the chest wall.

In line with the classical analysis by Grimby et al. [11], marked frequency-dependence of respiratory resistance was exhibited by all COPD patients (Table 3, Fig. 3) This extends our previous observations on a smaller group [22], but Figure 3 also shows that substantial frequency-dependence of resistance was also present in patients with ARDS, without history of airway obstruction. In the patients of the third group who did not have neither COPD, nor ARDS, average values of Rrs,max and the Rrs,max-Rrs,min difference were significantly lower than COPD and ARDS patients. Don and Rohson [5] measured Rrs,max in normal anesthetized subjects, and found a mean value of 4.8 ± 2.1 cm$H_2O \cdot l^{-1} \cdot s$. Both our groups of patients with COPD and ARDS had significantly higher Rrs,max than that reference value ($p<0.001$ and $p<0.05$ respectively), while the difference was not significant for group III ($p>0.05$). Unfortunately Don and Rohson [5] did not measure Rrs,min, and, to our knowledge, Rrs,min in normal supine subjects have not been measured yet and therefore reference values are not available. According to the analysis by Bates et al. [2] Rrs,min reflects the flow resistance that would

obtain in the absence of time constant inhomogeneities within the respiratory system, while the substantially greater values of Rrs,max indicate the maximal contribution of the time constant inequalities within the lung to the resistive behaviour of the respiratory system (a part from the small stress relaxation component). This suggest that ARDS may be characterized as peripheral lung disease, with low respiratory compliance and frequency-dependence of resistance, and the latter finding may be in line with inhomogeneous distribution of airspaces flooding through unequal epithelial disruption in the permeability type of edema [18, 25]. Gattinoni et al. [8], in fact, elegantly showed by computer tomography studies that parenchymal lesions are inhomogeneously distributed in ARDS patients. The mechanism leading to increased resistance in pulmonary edema probably involves several factors: liquid in the airway [4], vagal reflexes [3], release of bronchoconstricting mediators [6], as well as reduced lung volume [21], while direct compression of airways by congested arteries and interstitial fluid did not alter bronchial lumen [15]. The importance of increased resistance and frequency-dependence of resistance for gas exchange impairment in ARDS patients remains still unclear and needs to be further investigated.

In summary important variables of respiratory mechanics may be safely and noninvasively measured in mechanically ventilated patients, and can be used to evaluate efficiency of therapy and to monitor progress of the disease, as well as to provide guideline for weaning attempts. Brief occlusions of the airway opening (generally about one second) at end-expiration and at the end of the mechanical inflation allows direct measurement of PEEPi, as well as respiratory compliance and resistance and frequency-dependence of resistance; the latter may provide a quantification of the degree of time constant inequalities within the lung.

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References

1. Agostoni E, Mead J (1964) Statics of the respiratory system. In: Fenn WO, Rahn H (eds) Handbook of Physiology. American Physiological Society, Sec. 3, Vol 1, Respiration, Washington, DC, p 387
2. Bates JHT, Rossi A, Milic-Emili J (1985) Analysis of the behaviour of the respiratory system with constant inspiratory flow. J Appl Physiol 58:1840
3. Chung KF, Keyes SJ, Morgan BM, Jones PW, Snashall PD (1983) Mechanisms of airway narrowing in acute pulmonary oedema in dogs: influence of the vagus and lung volume. Clin Sci 65:289
4. Cook CD, Mead J, Schreiner GL, Frank NR, Craig JM (1959) Pulmonary mechanics during induced pulmonary edema in anesthetized dogs. J Appl Physiol 14:177
5. Don HF, Robson JC (1965) The mechanics of the respiratory system during anesthesia. The effect of atropine and carbon dioxide. Anesthesiology 26:168
6. Esbensahde AM, Newman JH, Lams PM, Jolles H, Brigham KL (1979) Respiratory failure after endotoxin infusion in sheep: Lung mechanics and lung fluid balance. J Appl Physiol 53:967
7. Falke KJ, Pontoppidan H, Kumar A, Leith DE, Geffin B, Laver MB (1972) Ventilation with end-expiratory pressure in acute lung disease. J Clin Invest 51:2315
8. Gattinoni L, Mascheroni D, Torresin A, Marcolin R, Fumagalli R, Vesconi S, Rossi GP, Rossi F, Baglioni S, Bassi F, Nastri G, Pesenti A (1986) Morphological response to positive end-expiratory pressure in acute respiratory failure. Computerized tomography study. Intensive Care Med 12:137
9. Gottfried SB, Rossi A, Higgs BD, Calverley PMA, Zocchi L, Bozic C, Milic-Emili J (1985) Noninvasive determination of respiratory system mechanics during mechanical ventilation for acute respiratory failure. Am Rev Respir Dis 131:414
10. Gottfried SB, Rossi A, Milic-Emili J (1986) Dynamic hyperinflation, intrinsic PEEP, and the mechanically ventilated patient. Int Care Dig 5:30
11. Grimby G, Takishima T, Graham W, Macklem PT, Mead J (1968) Frequency-dependence of flow-resistance in patients with obstructive lung disease. J Clin Invest 47:1455
12. Katz JA, Zinn SE, Ozenne GM, Fairley HB (1981) Pulmonary, chest wall and lung-thorax elastances in acute respiratory failure. Chest 80:304
13. Kimball WR, Leith DE, Robins AG (1982) Dynamic hyperinflation and ventilator dependance in chronic obstructive pulmonary disease. Am Rev Respir Dis 126:991
14. Lavietes MH, Rochester DF (1981) Assessment of airway function during assisted ventilation. Lung 159:219
15. Michel RP, Zocchi L, Rossi A, Cardinal GA, Ploysongsang Y, Poulsen RS, Milic-Emili J, Staub NC (1987) Does interstitial edema compress airways and arteries in the lungs? a morphometric study. J Appl Physiol 62:108
16. Milic-Emili J (1986) Is weaning an art or a science? Am Rev Respir Dis 134:1107
17. Milic-Emili J, Gottfried SB, Rossi A (1987) Dynamic Hyperinflation: intrinsic PEEP and its ramifications in patients with respiratory failure. In: Vincent JL (ed) Update in intensive care and emergency medicine. Springer, Berlin Heidelberg New York, p 192
18. Montaner JSG, Tsang J, Evans KG, Mullen JBM, Burns AR, Walker DC, Wiggs B, Hogg JC (1986) Alveolar epithelial damage; a critical difference between high pressure and oleic-acid induced low pressure pulmonary edema. J Clin Invest 77:1786
19. Otis AB, McKerrow CB, Bartlett RA, Mead J, McIlroy MB, Silverstone NJ, Radford EP (1956) Mechanical factors in distribution of pulmonary ventilation. J Appl Physiol 8:427
20. Pepe PE, Marini JJ (1982) Occult positive end-expiratory pressure in mechanically ventilated patients with airflow obstruction. Am Rev Respir Dis 126:166
21. Ploysongsang Y, Zocchi L, Michel RP, Rossi A, Milic-Emili J, Staub NC (1985) Partitioning of respiratory mechanics in pulmonary interstitiate edema in dogs. Fed Proc 45:1910 (8756 abstract)
22. Rossi A, Gottfried SB, Higgs BD, Zocchi L, Grassino A, Milic-

Emili J (1985) Respiratory mechanics in mechanically ventilated patients with respiratory failure. J Appl Physiol 58:1849
23. Rossi A, Gottfried SB, Zocchi L, Higgs BD, Lennox S, Calverley PMA, Begin P, Grassino A, Milic-Emili J (1985) Measurement of static compliance of total respiratory system in patients with acute respiratory failure during mechanical ventilation. Am Rev Respir Dis 131:672
24. Simkovitz P, Brown K, Golberg P, Milic-Emili J, Gottfried SB (1987) Interaction between intrinsic and externally applied PEEP during mechanical ventilation. Am Rev Respir Dis 135:A202
25. Staub NC, Nagano H, Pearce ML (1967) Pulmonary edema in dogs, especially the sequence of fluid accumulation in lungs. J Appl Physiol 22:227
26. Suter PM, Fairley HB, Isenberg MD (1975) Optimum end-expiratory airway pressure in patients with acute pulmonary failure. N Engl J Med 292:284
27. Suter PM, Fairley HB, Isenberg MD (1978) Effect of tidal volume and positive end-expiratory pressure on compliance during mechanical ventilation. Chest 73:158
28. Zin WA, Pengelly LD, Milic-Emili J (1982) Single-breath method for measurement of respiratory mechanics in anesthetized animals. J Appl Physiol 52:1266

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