Intensive Care Med (1995) 21:399–405

ORIGINAL

E. Zanotti
F. Rubini
G. Iotti
A. Braschi
A. Palo
C. Bruschi
C. Fracchia
S. Nava

Elevated static compliance of the total respiratory system: early predictor of weaning unsuccess in severe COPD patients mechanically ventilated

Received: 10 November 1993
Accepted: 3 May 1994

E. Zanotti · F. Rubini · C. Bruschi
C. Fracchia · S. Nava (✉)
Division of Pneumology,
Centro Medico di Riabilitazione
di Montescano,
Fondazione Clinica del Lavoro IRCCS,
I-27040 Montescano (PV),
Italy

G. Iotti · A. Braschi · A. Palo
Servizio di Rianimazione I,
Ospedale Policlinico S. Matteo,
IRCCS, Pavia, Italy

Abstract *Objective:* To assess in a group of COPD patients mechanically ventilated for an episode of acute respiratory failure the respiratory mechanics with a simple and non invasive method at the bedside in order to evaluate if these parameters may be predictive of weaning failure or success.
Design: A prospective study.
Setting: Intensive care and intermediate intensive care units.
Patients: 23 COPD patients ventilated for acute respiratory failure and studied within 24 hours from intubation.
Methods: Using end-expiratory and end-inspiratory airway occlusion technique, we measured PEEPi, static compliance of the respiratory system (Crs, st) maximum respiratory resistance (Rrsmax) and minimum respiratory resistance (Rrsmin).
Measurements and results: The weaned group (A) and the not weaned group (B) were not different regarding to static PEEPi (group A 8.5 ± 4.0 vs group B 8.9 ± 2.6 cmH_2O), to Rrsmax (22.4 ± 5.3 versus 22.2 ± 9.0 $cmH_2O/l/s$) and to Rrsmin (17.6 ± 5.5 versus 17.9 ± 8.0 $cmH_2O/l/s$), while a significant difference ($p < 0.001$) has been found in Cst, rs (62.7 ± 17.5 versus 111.6 ± 18.0 ml/cm H_2O). The threshold value of 88.5 ml/cmH_2O was identified by discriminant analysis and provided the best separation between the two groups, with a sensitivity of 0.85 and a specificity of 0.87.
Conclusion: Cst, rs measured non invasively in the first 24 h from intubation, provided a good separation between the patients who were successfully weaned and those who failed.

Key words Respiratory mechanics · Weaning prediction · COPD

Introduction

Patients affected by chronic obstructive pulmonary disease (COPD) with chronic respiratory failure are very susceptible to acute exacerbations and they often undergo prolonged mechanical ventilation: in a recent study [1] 28 out of 61 patients chronically ventilated had COPD and the major cause of ventilator dependence was the deterioration of the disease.

Respiratory mechanics are thought to be a useful approach in mechanically ventilated patients with acute respiratory failure for assessing their status and progress [2] and therefore it has been studied in these patients [2–6]. However, of the 76 total patients of the above mentioned studies, only 14 had COPD alone. Difficult weaning has been reported in as much as 20% of mechanically ventilated patients [7]: this group consists mainly of patients with pre-existing lung diseases. A number of factors may be responsible for an unsuccessful weaning such as impaired pulmonary gas exchange and respiratory muscle dysfunction [8], high airway resistance, static and dynamic hyperinflation [9], malnutrition and the increasing number of acute exacerbations [10, 11]. Most of these causes may be related, at least in part, to abnormal respiratory mechanics.

A number of indices, such as minute ventilation [12, 13], vital capacity [14], maximal inspiratory pressure (MIP) [12, 14] and neuromuscular drive as assessed by P.01 [15] have been proposed as predictors of the outcome of weaning, but their predictive power is generally poor [16]. Two of the most reliable indexes, CROP, an acronym for compliance, respiratory rate, oxygenation and MIP [16], and the rapid shallow breathing index [16] may be influenced by concomitant acute pathologies (fever, brain damage, anxiety and others), or require some patient cooperation (MIP), and therefore they need to be recorded in a phase of clinical stability.

In the present study, we assessed the respiratory mechanics with a simple and not invasive method at the bedside, in a group of COPD patients 24 h after the beginning of mechanical ventilation for an episode of acute respiratory failure, in order to evaluate if these indices may be early predictors of weaning failure or success.

Materials and methods

Twenty-three COPD patients, defined following the ATS standard [17], with acute respiratory failure caused by an exacerbation of their disease were studied within 24 h after intubation and institution of mechanical ventilation. None of the subjects had a pre-existing history of asthma. In data analysis patients were divided into weaned from mechanical ventilation (A) or not able to be weaned (B). Patients with evidence of pneumonia or other infiltrative parenchymal process on the X-ray film were excluded from the study as well as patients with concomitant neurological diseases, other respiratory disease, congestive heart failure, cancer and other systemic disease.

Patients' characteristics are reported in Table 1. Pulmonary function tests were recorded in 18 of the patients under stable conditions, while still on mechanical ventilation, during brief periods of spontaneous breathing with supplemental O_2. FEV_1 absolute value, FEV_1 % predicted, and FVC absolute and % predicted value were recorded using a Wright's spirometer connected to the endotracheal cannula. Setting of mechanical ventilation as prescribed by primary physician are shown in Table 2. Informed consent for the study was obtained from the next of kin. The trials were performed in the Intensive Care Unit of Pavia S. Matteo Hospital or in Intermediate Intensive Care Unit of Montescano Rehabilitation Center, Italy. The investigative protocol was approved by the Institutional Ethics Committees.

Table 1 General characteristics of the patients

	Group A	Group B
n	15	8
Tracheostomy	5	4
Sex (M/F)	15/2	1/8
Age (years)	58.8 ± 6	59.2 ± 7
FEV_1 (% pred.)	26.8 ± 11.1	18.7 ± 9.8
FEV_1/FVC (%)	48.5 ± 10.0	35.3 ± 7.7*

*$p < 0.05$

Table 2 Setting of mechanical ventilation pH, and blood gases during mechanical ventilation. Values are mean ± SD

	Group A	Group B
Vt (ml/kg)	11.5 ± 1.3	10.9 ± 1.1
RR (br/min)	14.1 ± 0.3	13.4 ± 0.3
Ti/Te	1:2.9 ± 0.02	1:2.8 ± 0.03
V (l/s)	0.65 ± 0.05	0.68 ± 0.07
FIO_2	0.40 ± 0.2	0.42 ± 0.1
PaO_2 (mmHg)	77.2 ± 13.5	78.1 ± 11.1
$PaCO_2$ (mmHg)	51.6 ± 8.4	52.5 ± 7.8
pH	7.33 ± 0.10	7.34 ± 0.12

Definitions of abbreviations: *Vt* tidal volume; *RR* respiratory rate; *Ti/Te* inspiratory to expiratory time ratio; *V* inspiratory flow

All patients were mechanically ventilated via an endotracheal tube (14 patients) or tracheostomy (9 patients) (Portex cuffed endotracheal tube or endotracheal cannula, internal diameter ranging from 7.5 to 8 mm) in controlled mode (CMV) with a standard ventilator (Caesar, Taema, France or Siemens Servo 900 C, Sweden) with constant inspiratory flow. Some of the patients were tracheostomized after a previous exacerbation of their disease. The time from tracheostomy to the time of the present study ranged from 4–21 months; none of these patients was receiving mechanical ventilation at admission to the ICU. Patients were sedated (benzodiazepine) and curarized (pancuronium bromide 0.1 mg/kg) during the measurements. Airway suctioning was carefully done 3 min before each measurements. During the study period a physician not involved in the procedure was always present to provide for patient care. Pharmacotherapy consisted of antibiotics in 19 of 23 patients, mucolityc agents in 15, oral digoxin in 3. Corticosteroids and bronchodilators, given i.v. or nebulized, were suspended 4 h before the beginning of measurements to avoid potential acute effects on respiratory mechanics [18, 19].

Airway pressure (Paw) and flow ($\dot{V}$) were measured with the pressure transducers incorporated into the ventilators; expired tidal volume (Vt) was obtained by electrical integration of the flow signal. Accuracy of these measurements is reported elsewhere [18]. All the signals were recorded on a eight-channel strip chart recorder (Gould TA 4000, Valley View, OH).

The patients were examined in semirecumbent position. Three to five measurements each of end inspiratory and end expiratory occlusions were done at fixed intervals of 5 min to assess the reproducibility of the measurements.

After several breaths under controlled mechanical ventilation, with the patients relaxed, intrinsic PEEP (PEEPi) was directly measured occluding the airway opening at the end of a tidal expiration, pressing the end-expiratory hold button incorporated in the ventilators (Fig. 1 a).

The occlusion was then released to provide mechanical lung inflation. After several breaths, the airway opening was occluded again at the end of the inflation by the end-inspiratory hold button of the ventilators. After the occlusion there is a sudden decrease in Paw from a maximal value (Pmax) to a lower value (P 1), followed by a gradual decrease until an apparent plateau is reached (P 2) (Fig. 1 b). After this plateau was observed (about 2.5–3 s) the occlusion was released. P 2 represents the elastic recoil pressure of the total respiratory system at the end of the mechanical inflation.

The static compliance of the total respiratory system (Cst, rs) was calculated as the ratio between the expiratory Vt and the differ-

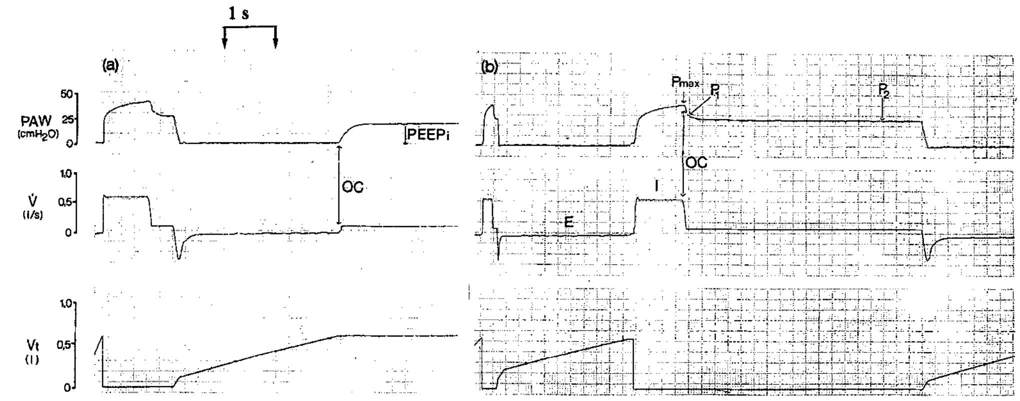

Fig. 1 Records of respiratory mechanics during the study. From *top to bottom: Paw* airway pressure; $\dot{V}$ airway flow; *Vt* expired tidal volume; *E* expiration; *I* inspiration; *OC* occlusion. When occluding airway at the end of a mechanical inspiration (**b**), Paw decreased rapidly from its maximal value (Pmax) to a lower value (P 1) and then slowly until an apparent plateau is reached (P 2). When occluding the airway at the end of expiration (**a**) the amount of airway pressure recorded is static PEEPi. For further details see text

ence between P 2 and the end-expiratory (PEEPi) plateau pressure. The value of compliance so obtained was corrected for the compliance of the ventilators tubings and the gas compression.

The end-inspiratory occlusion technique also allows the determination of the resistive properties of the respiratory system as described by Bates [20]. Briefly, dividing (Pmax − P 1) by the flow immediately preceding the occlusion and subtracting the resistance of the endotracheal cannula and the inspiratory ventilator tubings, yields a resistance that has been called minimum resistance (Rrsmin), that has been suggested to represent the "intrinsic" resistance. Maximum respiratory resistance (Rrsmax) was calculated by dividing (Pmax − P 2) by the preceding constant flow and subtracting the resistance of the endotracheal cannula. Rrsmax includes Rrsmin and may reflect two phenomena: the "pendelluft" resulting from unequal time constant within the lungs and chest wall and the "stress relaxation" due to viscoelastic behavior of the respiratory system.

We computed the flow-resistive properties of the endotracheal tubes in vitro as previously described by Behrakis et al. [21]. The measurements were made using room air and 50% O_2. The pressure-flow relationship of the tubes was curvilinear and fitted the following power function: $P = a\,\dot{V}^b$ where a is the pressure at $\dot{V}$ of $1\,l \cdot s^{-1}$ and b is a number describing the shape of the curve. The resistance of the ventilators inspiratory tubings was calculated by measuring the flow and the pressure while the patient was temporary (few breaths) disconnected. This resistance was flow-dependent, but did not vary significantly changing the Vt, as already reported in literature [22]. In calculation of Rrsmax and Rrsmin, the error due to the closing time of the ventilators valve was corrected according to Kochi et al. [23].

The measurements of respiratory mechanics were also repeated approximatively 3 months after the beginning of mechanical ventilation in group B.

Weaning trials were performed a few days after the beginning of mechanical ventilation with the patients in a phase of clinical stability (range from 5−17 days). This was defined as: a) absence of hyperthermia, b) stable hemo-dynamics (mean arterial blood pressure not varying more than 10 mmHg in the preceeding 3 days), c) patient conscious and cooperative, d) stability in arterial blood gases under mechanical ventilation (not varying more than 5% in the preceeding 3 days).

Weaning success was defined as complete autonomy from the ventilator for at least 48 h with oxygen saturation above 90% (in room air or O_2) and absence of any fatiguing pattern of breathing (tachypnea, important use of neck inspiratory muscles and asynchronous or paradoxic movements of chest wall and abdomen), as defined by Rochester [24].

The weaning trials were performed by one of the caring physicians, unaware of the aim of the study, switching the ventilator to the Pressure Support Mode (PSV) with a Peak Inspiratory Pressure (PIP) (mean 19 ± 5 cmH_2O) able to maintain a good expiratory Vt (about 8−10 ml/kg) with a FiO_2 able to keep the $SaO_2 > 93\%$. In the majority of the patients (19 patients) an external PEEP was also applied (mean 4.1 ± 3 cmH_2O). The hours of ventilation in A/C mode as respect to the ones in PSV mode were gradually reduced. If the patients were able to maintain an $SaO_2 > 93\%$, changing less than 5% the level of $PaCO_2$, during PSV mode for 24 h, the PIP was progressively reduced (around 12−14 cmH_2O) until ventilation was suspended. None of the patients with a successful weaning required again mechanical ventilation during the remaining period of stay in the ICU.

Weaning failure was defined as failure to be disconnected from the respirator after 4 months.

Differences between the group of successfully weaned patients and not weaned group were tested using unpaired *t*-test: a $p < 0.05$ was considered significant. Discriminant analysis was used to determine the threshold value of Cst, rs able to separate the two groups of patients. True positive were defined as those patients whose test predicted weaning success and who actually succeeded. True negative were those patients whose test predicted weaning failure and who actually failed. False positive were patients predicted to wean successfully but who actually failed. False negatives were patients predicted to fail but who actually succedeed. Standard formulas were used to calculate the sensitivity (true positive/[true positives + false negatives]), specificity (true negatives/[true negative + false positives]), positive predictive value (true positives/[true positives + false positives]), negative predictive value (true negatives/[true negatives + false negatives]) [25].

Results

The average time of the experiment was around 50 min. 15 out of 23 patients were successfully weaned from mechanical ventilation (group A), after 8.2 ± 4.4 days, while 8 patients were not able to be weaned (group B) and were still mechanically ventilated at 4 months. A statistically significant difference was observed in the FEV 1/FVC ratio of the two groups (Table 1). Blood gas measurements at a similar FiO_2 during mechanical ventilation are reported in Table 2. In recording the respiratory mechanics,

Table 3 Coefficients of variation for the values of respiratory mechanics. Each subject underwent from 3 to 5 measurements for each set of occlusion manoeuvres

	Group A	Group B
PEEPi (cmH_2O)	0.9	0.8
Rrsmax ($cmH_2O/l/s$)	1.1	2.0
Rrsmin ($cmH_2O/L/s$)	3.5	2.8
Cst, rs (ml/cmH_2O)	2.7	2.5

each subject underwent from 3–5 measurements for each set of manoeuvres; the coefficients of variation of these values are reported in Table 3.

Static PEEPi (Fig. 2) was present in all the patients, with no significant differences between the two groups. Mean value was $8.5 \pm 4\ cmH_2O$ for group A and $8.9 \pm 4.6\ cmH_2O$ for group B. Individual data for the not weaned group ranged from 4.3 to 20.4 cmH_2O.

Also resistances (Fig. 3) did not show any significant difference between the two groups: mean values for Rrsmax were $22.4 \pm 5.3\ cmH_2O/l/s$ in group A and $22.2 \pm 9\ cmH_2O/l/s$ in group B; Rrsmin $17.6 \pm 5.5\ cmH_2O/l/s$ and $17.9 \pm 8\ cmH_2O/l/s$ respectively.

Static compliance of the respiratory system (Fig. 4) was significantly ($p < 0.001$) higher in the not weaned group. It was $62.7 \pm 17.5\ ml/cmH_2O$ in the weaned patients and found to be similar to that described in COPD patients with acute respiratory failure during mechanical ventilation [6], while in not weaned group was much higher ($111.6 \pm 18\ ml/cmH_2O$). Individual data showed that 6 out of 8 patients had values of Cst, rs above 100 ml/cmH_2O, the remaining two had 86 and 92 ml/cmH_2O respectively. The discriminant value for Cst, rs was 88.5 ml/cmH_2O with a sensitivity of 0.85, a specificity of 0.87, a positive predictive value of 0.92 and a negative predictive value of 0.77.

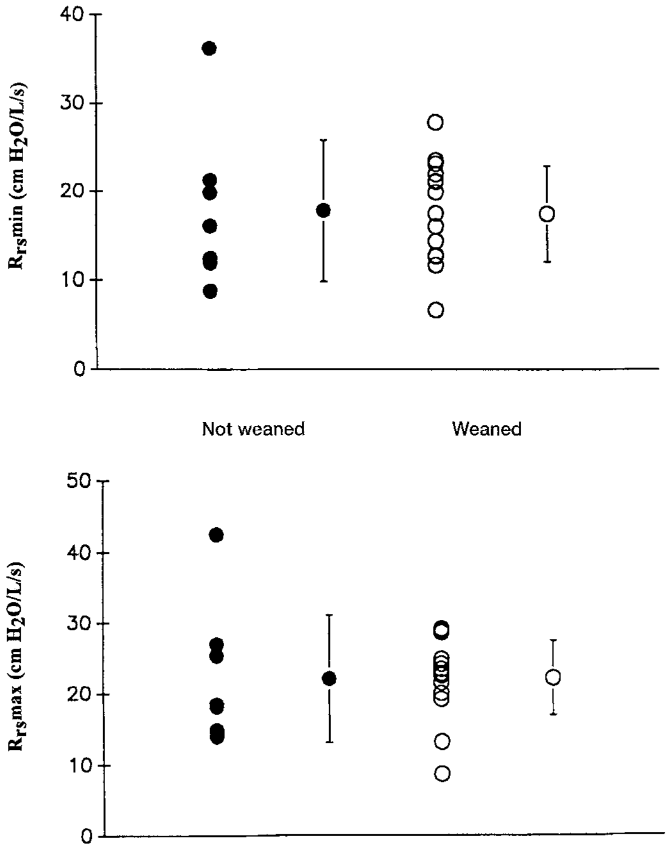

Fig. 3 Individual and mean values of Rrsmin (*top panel*) and Rrsmax (*bottom panel*) for not weaned (*closed circles*) and weaned (*open circles*) group. *Vertical bars* are SD

Measurements of respiratory mechanics were repeated, only in the not-weaned group, after about 3 months from the beginning of mechanical ventilation. As illustrated in Table 4 no significant variations were observed from the values recorded at the time of intubation.

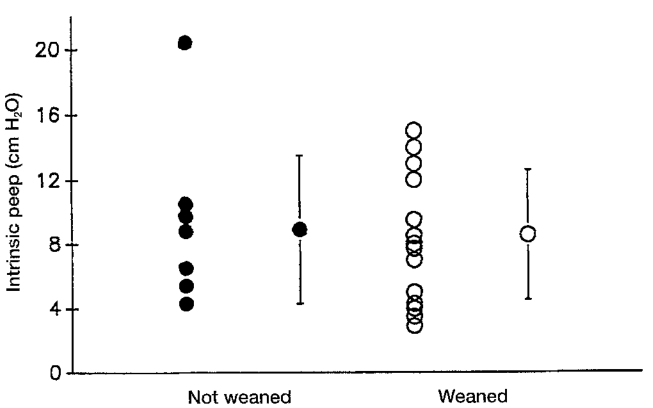

Fig. 2 Individual and mean values of static PEEPi of not weaned group (*closed circles*) and weaned group (*open circles*). *Vertical bars* are SD

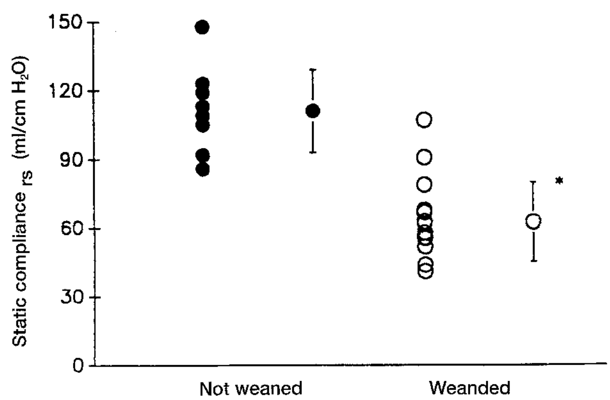

Fig. 4 Individual and mean values of Cst, rs of not weaned group (*closed circles*) and weaned group (*open circles*). *Vertical bars* are SD

Table 4 Measurements of respiratory mechanics, performed in the not-weaned group, at the beginning of mechanical ventilation and after about 3 months still ventilated

	Beginning of MV	After 3 months
PEEPi (cmH_2O)	8.9 ± 4.6	6.1 ± 5.0
Rrsmax ($cmH_2O/l/s$)	22.2 ± 9.0	19.1 ± 8.3
Rrsmin ($cmH_2O/l/s$)	17.9 ± 8.0	15.7 ± 8.1
Cst, rs (ml/cmH_2O)	111.6 ± 18	109.5 ± 16

Discussion

The major finding of this study is that in COPD patients mechanically ventilated for acute respiratory failure there is a significant difference in Crs, st between weaning success and weaning failure groups and therefore this index may be an additional and early tool in predicting weaning outcome.

Difficult weaning is one of the most important problems in the management of patients requiring mechanical ventilation: in fact, as many as 20% of initial trials of spontaneous respiration may not be successful [7]. Weaning may be particularly difficult in patients with chronic lung disease [7], who tend to require ventilation for several days and may take months to achieve spontaneous respiration [26]. Indihar [27] analyzed a 10-year experience with 171 ventilator-dependent patients: several diseases led to chronic ventilator dependence, but 67.1% of these patients had COPD. The possibility of an early judgement of weaning failure or success may enable the physician to identify the subset of subjects who will undergo prolonged mechanical ventilation. This index could be therefore useful in deciding in a relatively brief time whether or not these patients may enter an home care program for mechanical ventilation.

The most accurate weaning indices so far proposed, often require the patient's cooperation. They become difficult to perform and poorly reliable when bronchospasm, increasing bronchial secretions, cardiovascular instability, fever, anxiety, panic reactions etc. are present. These indexes such as CROP, rapid shallow breathing index [16] and inspiratory pressure/maximal inspiratory pressure ratio [8] are therefore reliable only when a clinical stable condition is reached, usually days after the beginning of mechanical ventilation. Indeed it is a common practice to curarize and sedate the patients in the first few days, when mechanical ventilation is applied in the controlled mode. Therefore also a parameter like the neuromuscular drive (P0.1), good predictor of weaning success or failure when the patients are ventilated in an assisted mode [15, 18, 29] may be not reliable when this condition is not reach.

The index we employed may be considered an "early predictor" being performed within the first 24 h from institution of mechanical ventilation when the other indexes could be not easily recorded, and it does not require the patient's cooperation. Moreover, it can be safely, easily and simply assessed at the bedside in every ICU and it has a low coefficient of variation. Comparison with the predictive power of the parameters recorded in other studies is not justified because they were performed in stable patients, ready to be weaned and not confined to COPD patients. However an index with high specificity or positive predictive value is valuable because this means that the number of false positives is small. Despite Cst, rs is a good predictive weaning index, we still think that the caring physician cannot merely rely on this or other indices and therefore a weaning trial must be performed anyway in every patient. Indeed since the recording of respiratory mechanics is obtained under paralysis, this make the repetition of these measurements difficult during weaning. It is also important to note that the threshold value of Cst, rs was obtained in a relatively small population and thus needs to be validated in a larger population with a prospective study.

Our population was composed by severe COPD patients characterized by static PEEPi and high respiratory resistance. The implications of both PEEPi and respiratory resistance in terms of weaning is already known: during inspiration the inspiratory muscles must develop an additional pressure to counterbalance PEEPi [6], which represents a sort of inspiratory threshold load [4]. The obstacle due to the PEEPi is thought to represent one of the most important mechanisms leading to respiratory failure [30] and to a problematic weaning [31], due to the concomitant presence of hyperinflation and decrease in maximum inspiratory muscle pressure [32].

Our patients did not show any significant difference in static PEEPi and in Rrsmin and Rrsmax; these latter reflecting the airway resistance and the Pendelluft and stress-relaxation phenomenon, respectively [20].

Static compliance of the total respiratory system was significantly lower in the group of weaned patients, as compared to the not weaned group and remained constant in these latter patients after 4 months. The mean values of the weaned group are in keeping with already reported data for COPD patients mechanically ventilated for acute respiratory failure [2, 3, 6], while the high values found in the not weaned group, were observed in an other study [33] although the final outcome of those patients was not stated. The importance of Cst, rs as prognostic factor has been already stated in patients with adult respiratory distress syndrome (ARDS). Gattinoni et al. [34] found that a severely reduced static lung compliance is related to a lack of response to conventional mechanical ventilation in ARDS patients. Mancebo et al. [35] in patients with acute respiratory failure suggested that the mortality rate is very high in those patients with a low static pulmonary compliance and treated with conventional mechanical ventilation. However, it is important to note that none of the patients studied in this latter paper had a previous history of chronic pulmonary disease. Our patients, namely the not weaned group, represent an opposite model. Their Cst, rs was in fact far from the normal values (from 50–75 ml/cmH_2O) [21, 36], but on the opposite side with respect to the ARDS patients. Practically, Cst, rs measurements in the two different population may reflect two different mechanisms of lung damage.

It has been shown that the measurement of static compliance in non-COPD patients depends on the lung volume at which it is measured [37]; this is not likely to be true in severe COPD patients where the pressure-volume curves are almost rectilinear and stiffer compared to normal subjects or patients affected by other pathologies. Nevertheless the two groups of COPD may have different degree of pulmonary hyperinflation, but this was not due to the modality of mechanical ventilation, not different in weaned and not-weaned patients (Table 2).

The presence of high levels of Crs, st may suggest that these patients are affected by a severe degree of pulmonary emphysema, with related parenchymal destruction associated with a high degree of hyperinflation. We do not have any direct evidence of different degrees of emphysema between the weaned and not-weaned patients, since the chest X-ray showed in all the patients an increased lucency of the pulmonary field and augmented width of the intercostal spaces. Planimetry demonstrated only a slight and not significant difference in the two groups, but the calculation of this parameter is somehow difficult since X-ray films were recorded while the patients were ventilated and lying on a bed. Nevertheless the diagnosis of pulmonary emphysema is unfortunately up to date histological and there are not other standardized criteria for a quantitative evaluation, since even the correlation between the pathologic grade of the lung and the CT scan is rather low [38].

Emphysema is thought [39] to cause an increase in lung compliance and to reduce the pulmonary recoil pressure at TLC, and although the compliance of the chest wall remains normal, the chest wall curve is shifted to the left, which may contribute to the marked increase in FRC. The reliability of our index of weaning is confirmed by the fact that it can not be modify by any of the standardized therapy for COPD [18, 19, 22]. In fact while pharmacological treatments can significantly reduce airway resistance and static PEEPi, they seem not to acutely influence the Crs, st.

In conclusion, the present study has shown that: i) COPD patients ventilated for acute respiratory failure show high levels of PEEPi, Rrsmin and Rrsmax, but they don't seem to influence weaning from mechanical ventilation; ii) the presence of high level of Cst, rs is a negative factor in their progress and subsequent weaning; iii) noninvasive assessment at bedside of Cst, rs, done in the first 24 hours might be an useful, simple and early tool in predicting weaning failure or success. Further studies need to be done to validate prospectively this index.

References

1. Gracey DS, Viggiano RW, Naessens JM, Hubmayr RD, Silverstein RD, Koenig GE (1992) Outcomes of patients admitted to a chronic ventilator-dependent unit in an acute-care hospital. Mayo Clin Proc 76:131–136
2. 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 58:1849–1858
3. 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 131:414–420
4. Broseghini C, Brandolese R, Poggi R, Polese G, Manzin E, Milic-Emili J (1988) Respiratory mechanics during the first day of mechanical ventilation in patients with pulmonary edema and chronic airway obstruction. Am Rev Respir Dis 138:355–361
5. Tobin MJ, Perez W, Guenther SM, Semmes BJ, Mador MJ, Allen SJ, Lodato RF, Dantzker DR (1986) The pattern of breathing during successful and unsuccessful trials of weaning from mechanical ventilation. Am Rev Respir Dis 134: 1111–1118
6. Rossi A, Gottfried SB, Zocchi L, Higgs BD, Lennox S, Calverley PMA, Begin P, Grassino A, Milic-Emily J (1985) Measurement of static compliance of the total respiratory system in patients with acute respiratory failure during mechanical ventilation. Am Rev Respir Dis 131:672–677
7. Goldstone J, Moxham J (1991) Weaning from mechanical ventilation. Thorax 46:56–62
8. Yang KL (1993) Inspiratory pressure/maximal inspiratory pressure ratio: a predictive index of weaning outcome. Intensive Care Med 19:204–208
9. Begin P, Grassino A (1991) Inspiratory muscle dysfunction and chronic hypercapnia in chronic obstructive pulmonary disease. Am Rev Respir Dis 143: 905–912
10. Roussos C (1979) Respiratory muscle fatigue in the hypercapnic patient. Bull Eur Physiopathol Respir 15:117–123
11. Rochester DF, Martin LL (1985) Respiratory muscle rest. In: Roussos C, Macklem PT (eds) The thorax. Dekker, New York, pp 1303–1328
12. Sahn SA, Lakshminarayan S (1973) Bedside criteria for discontinuation of mechanical ventilation. Chest 63: 1002–1005
13. Stetson JB (1970) Introductory essay. Int Anesthesiol Clin 8:767–779
14. Feeley TW, Hedley-White J (1975) Weaning from controlled ventilation and supplemental oxygen. N Engl J Med 292:303–306
15. Montgomery AB, Holle RHO, Neagley SR, Pierson DJ, Schoene RB (1991) Prediction of successful ventilator weaning using airway occlusion pressure and hypercapnic challenge. Chest 4:496–499

16. Yang KL, Tobin MJ (1991) A prospective study of indexes predicting the outcome of trials of weaning from mechanical ventilation. N Engl J Med 324: 1445–1450
17. American Thoracic Society (1987) Standards for the diagnosis and care of patients with chronic obstructive pulmonary disease (COPD). Am Rev Respir Dis 136:225–243
18. Rubini F, Rampulla C, Nava S (1994) Acute effects of corticosteroids on respiratory mechanics in mechanically ventilated patients with chronic airflow obstruction and acute respiratory failure. Am J Respir Crit Care Med 149: 306–310
19. Gay C, Rodarte JR, Tayab M, Hubmayr RD (1987) Evaluation of bronchodilator responsiveness in mechanically ventilated patients. Am Rev Respir Dis 136:880–885
20. Bates JTH, Rossi A, Milic-Emili J (1985) Analysis of the behaviour of the respiratory system with constant inspiratory flow. J Appl Physiol 58: 1840–1848
21. Behrakis PK, Higgs BD, Baydur A, Zin WA, Milic-Emili J (1983) Respiratory mechanics during halothane anesthesia and anesthesia-paralysis in humans. J Appl Physiol 55:1085–1092
22. Bernasconi M, Brandolese R, Poggi R, Manzin E, Rossi A (1990) Dose-response effects and time course of effects of inhaled fenoterol on respiratory mechanics and arterial oxygen tension in mechanically ventilated patients with chronic airflow obstruction. Intensive Care Med 16:108–114
23. Kochi T, Okubo S, Zin Wa, Milic-Emili J (1988) Flow and volume dependence of pulmonary mechanics in anesthetized cats. J Appl Physiol 64:441–450
24. Rochester DF (1988) Tests of respiratory muscle functions. Clin Chest Med 9:249–261
25. Griner PF, Mayewski RJ, Mushlin AI, Greenland P (1981) Selection and interpretation of diagnostic tests and procedures: principles and applications. Ann Intern Med 94:553–600
26. Morganroth MI, Morganroth JL, Nett LM (1984) Criteria for weaning from prolonged mechanical ventilation. Arch Intern Med 144:1012–1016
27. Indihar FJ (1991) A 10-year report of patients in a prolonged respiratory care unit. Minn Med 74:23–27
28. Sassoon CHS, Mahutte CK, Te TT, Simmons DH, Light RW (1987) Airway occlusion pressure. An important indicator for successful weaning in patients with chronic obstructive pulmonary disease. Am Rev Respir Dis 135: 107–113
29. Murciano D, Boczkowski J, Lecocguic Y, Milic-Emili J, Pariente R, Aubier M (1988) Tracheal occlusion pressure: a simple index to monitor respiratory muscles fatigue during acute respiratory failure in patients with chronic obstructive pulmonary disease. Ann Intern Med 108:800–805
30. Grassino A, Macklem PT (1984) Respiratory muscle fatigue and ventilatory failure. Annu Rev Med 35:625–647
31. Milic-Emili J (1986) Is weaning an art or a science? Am Rev Respir Dis 134:1107–1108
32. Pengelly LD, Alderson AM, Milic-Emili J (1971) Mechanics of the diaphragm. J Appl Physiol 30:797–805
33. Tantucci C, Corbeil C, Chasse M, Braidy J, Matar N, Milic-Emili J (1991) Flow resistance in patients with chronic obstructive pulmonary disease in acute respiratory failure. Am Rev Respir Dis 144:384–389
34. Gattinoni L, Pesenti A, Caspani ML, Pelizzola A, Mascheroni D, Marcolin R, Iapichino G, Langer M, Agostoni A, Kolobow T, Melrose DG, Damia G (1984) The role of static lung compliance in the management of severe ARDS unresponsive to conventional treatment. Intensive Care Med 10: 121–126
35. Mancebo J, Benito S, Martin M, Net A (1988) Value of static pulmonary compliance in predicting mortality in patients with acute respiratory failure. Intensive Care Med 14:110–114
36. D'Angelo E, Calderini E, Torri G, Robatto FM, Bono D, Milic-Emili J (1989) Respiratory mechanics in anesthetized paralyzed humans: effects of flow, volume, and time. J Appl Physiol 67:2556–2564
37. Benito S, Lemaire F, Mankikian B, Harf A (1985) Total respiratory compliance as a function of lung volume in patients with mechanical ventilation. Intensive Care Med 11:76–79
38. Bergin C, Mueller N, Nichols DM, Lillington G, Hogg JC, Mullen B, Grymaloski MR, Osborne S, Pare P (1986) The diagnosis of emphysema. A computed tomographic-pathologic correlation. Am Rev Respir Dis 133: 541–546
39. Sharp JT, van Lith P, Nuchprayoon CV, Briney R, Johnson FN (1968) The thorax in chronic obstructive lung disease. Am J Med 44:39–46