Effects of PEEP on inspiratory and expiratory mechanics in adult respiratory distress syndrome

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Abstract The purpose of the present study was to assess the mechanical behavior of the respiratory system separately during inspiration and expiration in adult respiratory distress syndrome (ARDS) and the influence of PEEP on any phasic variations of the mechanical respiratory parameters. Airways pressure (P), flow (V'), and volume (V) signals were recorded in nine patients with ARDS and 10 patients without known respiratory disorder (control group). All patients were artificially ventilated at three levels of positive end-expiratory pressure (PEEP): 0, 5, and 10 hPa. Data were analyzed separately for inspiratory and expiratory records using multiple linear regression analysis (MLRA) according to the equation: $P = \mathrm{Ers}\, V + \mathrm{Rrs}\, V' + P_0$, where Ers and Rrs represent, respectively, the intubated respiratory system elastance and resistance, and P_0 the end-expiratory pressure. In the ARDS group expiratory Ers (Ers_{EXP}=45.58 ± 4.24 hPa/L) was substantially higher ($p < 0.01$) than inspiratory Ers (Ers_{INSP}=36.76 ± 2.55) with a marked effect of applied PEEP in diminishing the difference between Ers_{EXP} and Ers_{INSP} ($p < 0.01$). For the ARDS group inspiratory Rrs (Rrs_{INSP}) decreased significantly with increasing PEEP (PEEP=0: Rrs_{INSP}= 16.43, PEEP= 10: $\mathrm{Rrs}_{INSP=}$ 13.28, $p < 0.01$). The found differences between Ers_{EXP} and Ers_{INSP} could be attributable to an influence of mechanical ventilation by positive airway pressure on pulmonary edema and interstitial fluid during the inspiratory phase of the respiratory cycle.

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Keywords Adult respiratory distress syndrome; positive end-expiratory pressure; multiple linear regression analysis; respiratory mechanics.

INTRODUCTION

The acute respiratory distress syndrome (ARDS) is defined as a syndrome of inflammation and increased permeability, that is associated with a constellation of clinical, radiological, and physiologic abnormalities that cannot be explained by, but may coexist with, left atrial or pulmonary capillary hypertension (1). The ARDS is known to affect adversely the mechanical properties of the respiratory system, with reduced compliance as a hallmark (2,3), that few years earlier was a part of its definition. The resistance is also increased (4–6). Several noninvasive methods have been applied for the evaluation of respiratory mechanics during mechanical ventilation, such as the end-inspiratory pause technique, the forced oscillations method (7,8), Fourier analysis of the original pressure and flow signals, the Mead&Whittenberger method (iso-volume paired points) (10,11), and the multiple linear regression analysis (MLRA) (12,13). The usual application of all these methods is based on the assumption of uniform mechanical behavior during the whole respiratory cycle (14). A limited number of studies have, however, measured inspiratory and expiratory parameters separately and their results indicate that respiratory mechanical parameters during inspiration and expiration may differ from each other. Chang and Mortola (15) were the first to describe differences between the inspiratory and the expiratory airway resistance, which were attributed to the geometric characteristics of the endotracheal tube. Peslin *et al*. (16) studied the respiratory impedence separately during inspiration and expiration in artificially ventilated humans with COPD, but they focused especially on the frequency dependence of impedence, while Matamis *et al*. (17) observed phasic variations of compliance in ARDS patients, however, without analyzing the differences between inspiration and expiration in detail. Vassiliou *et al*. (18) have also described large phasic variations of the respiratory system

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impedance during experimental artificial ventilation measured with the forced oscillation technique. Jonson *et al*. (19) have studied the influence of positive end-expiratory pressure (PEEP) on the mechanical parameters of the respiratory system in patients with ARDS using the low flow inflation technique and found higher compliance during inflation from zero end expiratory pressure compared with inflation from PEEP. Amato *et al*. (20) have studied the impact of a protective ventilation strategy, with low tidal volume and PEEP above the lower inflection point on the static pressure–volume curve, in patients with ARDS and found that the protective strategy was associated with improved survival and a lower rate of barotraumas. In a recent study the ARDS Network (21) confirned that benefit. Chelluci *et al*. (22) have assessed the association of PEEP with different inflation volumes on passive lung deflation and alveolar recruitment in ARDS patients and described that the recruitment was more important when higher tidal volumes had been used. Tobin (23) reviewed all these articles and concluded that the use of PEEP improved oxygenation in patients with ARDS, with the intention of recruiting previously nonfunctioning lung tissue due to alveolar collapse and interstitial edema. In a very recent study, Crotti *et al*. (24) reported that the rules governing recruitment equally applied in an oleic acid model and in human ARDS.

The purpose of the present study was to provide systematic measurements of the respiratory system mechanical properties during the inspiratory and the expiratory phases separately in mechanically ventilated patients with ARDS and in patients without known respiratory disorder (control group) in normal respiratory conditions. Furthermore, to assess the influence of PEEP on any phasic variations of the mechanical respiratory parameters of ARDS patients in comparison with a control group.

The methodology of MLRA, with its advantage of applicability with any mode of ventilation and usefulness for continuous monitoring (20), was used for the calculation of respiratory mechanical coefficients after digital acquisition of airways pressure (PaO) and flow (V') data under dynamic respiratory conditions. The method has already been used in experimental animals (25–27) as well as in artificially ventilated humans (13,14,16,18,25,26).

MATERIALS AND METHODS

Patients

The study included 19 patients in the intensive care unit of the Athens Red Cross Hospital. The patients or their family had, prior to the measurements given informed consent for their participation in the study and approve of Ethics Committee.

The patients were classified into two groups defined as follows:

- Control group (seven men, three women (mean age $\pm$ SD=46.1 $\pm$18.3 years.)), characterized by absence of any previously known respiratory disorder, present clinically normal status of the respiratory system, and normal values of blood gases.
- ARDS group (three men, six women (57.2 $\pm$ 17.7 years.)). Diagnosis based on the criteria defined by the American–European Consensus Committee (8).

The patients were under full sedation with Midazolame (0.03–0.2 mg/kg/h) or Propofol (5–10 mg/kg/h) and muscle relaxation with Atracurium besilate (0.3–0.6 mg/kg/h) or Cisatracurium besilate (0.03–0.6 mg/kg/h).

Mode of ventilation

The patients were all ventilated by a Draeger Evita II respirator. The mode of ventilation was constant flow-volume control with mean values of expiratory tidal volumes 0.613 $\pm$ 0.011 (control group) and 0.496 $\pm$ 0.084 l (ARDS group). The initially set tidal volume of the ventilation was 10 ml/Kg (mean value 0.6 l) for the patients of both groups, but the ARDS patients finally managed to receive 0.496 $\pm$ 0.084 l as tidal volume, while the control group received 0.613 $\pm$ 0.011. The breathing frequencies varied between 10 and 19 cycles per minute with an inspiratory/expiratory time ratio of 1:2 and an end-inspiratory pause of 0.5–1.6 s. The internal diameter of the endotracheal tube (ET) ranged from 7.5 to 9 mm.

Data acquisition

The humidification filter was removed during measurements. Flow (V') was measured with a Lilly-type Pneumotachograph (Jaeger GH, Germany) placed between the ET and the Y connection of the ventilator (Fig. 1). A pressure transducer (Jaeger) immediately connected to the pneumotachograph was used for pressure (P) measurement. The P and V' pressure transducers were matched for amplitude and phase up to 15 Hz. The P and V' signals were digitally acquired through an A/D-board (Jaeger) at a sampling rate of 100 Hz.

Measurements were done at three levels of externally applied PEEP — 0, 5, and 10 hPa. Data sampled from five consecutive respiratory cycles under constant breathing conditions were stored on the hard disk of the PC for later off-line analysis. The pressure signal was not corrected for the pressure drop along the ET. Volume was calculated by numerical integration and zero reset of flow signal (11).

Measurements of P, V' and V were analyzed with a specifically developed software in TURBO PASCAL (ver. 7.0

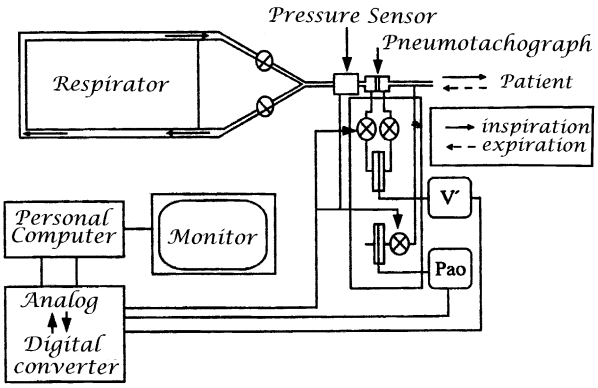

FIG. 1. Experimental setup.

for DOS). The elastance (Ers) and the resistance (Rrs) of the patients' respiratory system were calculated through MLRA. This was done separately for inspiratory and expiratory records on a cycle-per-cycle basis according to the equation

$$P_t = \mathrm{Ers}V_t + \mathrm{Rrs}V'_t + P_0, \qquad (1)$$

where P_t is the airways opening pressure at moment t, V_t the volume above FRC at moment t, Ers the respiratory system elastance, Rrs the respiratory system resistance, V'_t the respiratory system flow at moment t, and P_0 is the end-expiratory pressure.

The time constants of the respiratory system during the whole respiratory cycle (τ), the inspiration (τ_{Insp}) and the expiration (τ_{Exp}) were calculated according to the equations

$$\tau = \mathrm{Rrs}/\mathrm{Ers}, \qquad (2)$$

$$\tau_{\mathrm{Insp}} = Rrs_{\mathrm{Insp}}/Ers_{\mathrm{Insp}}, \qquad (3)$$

$$\tau_{\mathrm{Exp}} = Rrs_{\mathrm{Exp}}/Ers_{\mathrm{Exp}}. \qquad (4)$$

Statistical analysis

The calculated parameters of respiratory mechanics (elastance, resistance, and time constant) were analyzed separately in a multivariate, repeated measures ANOVA with patient-groups, PEEP-level, and inspiration/expiration as independent factors using SYSTAT 8.0. Regression analysis was used for correlation of inspiratory and expiratory values. The significance level was set at 5%.

RESULTS

The calculated values of the respiratory systems elastance, resistance, and time constant during inspiration (Ers_{INSP}, Rrs_{INSP}, τ_{INSP}, respectively) and passive expiration (Ers_{EXP}, Rrs_{EXP}, τ_{EXP}, respectively) were averaged for all five consecutive respiratory cycles of the same record as the inter-cycle coefficient of variation had been found to be less than 4% for all estimated parameters. The resulting mean values for each patient for inspiratory and expiratory elastances, resistances, and time constants are listed in table I and depict in Fig. 2.

Control group:

Elastance

The inspiratory and expiratory elastances did not change significantly with changes in PEEP. However, a small difference between inspiratory Ers and expiratory Ers (Δ-Ers=Ers_{EXP} – Ers_{INSP}) was found to diminish significantly

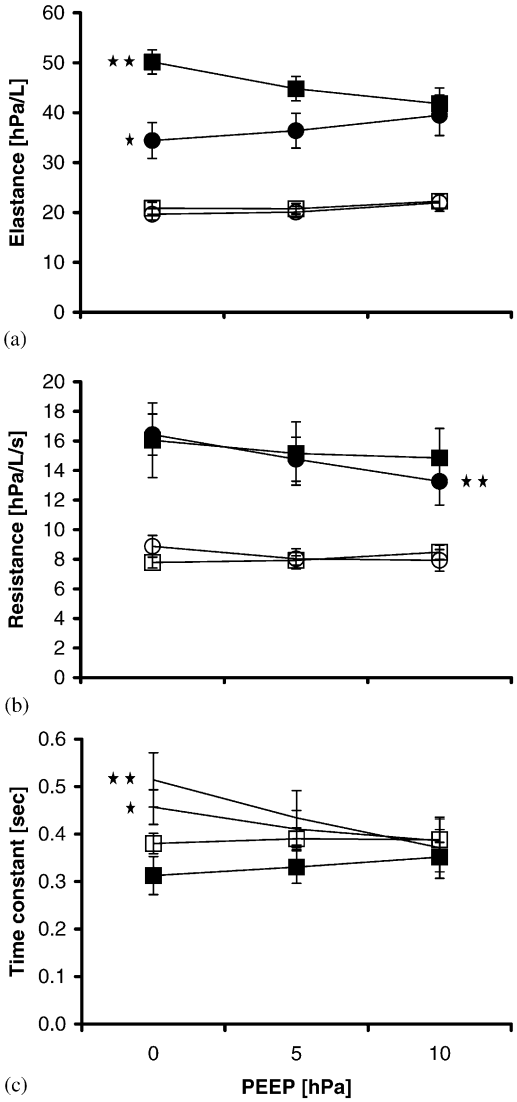

FIG. 2. Plots of mean values for control and ARDS patients for inspiratory and expiratory values of respiratory system elastance (plot a), resistance (plot b), and time constant (plot c) for PEEP levels of 0, 5, and 10 hPa. Open symbols represent control patients and filled symbols ARDS patients. Squares represent expiratory values and circles inspiratory values. Error bars represent SEM. '' indicates $P \leq 0.05$ while '' indicates $P \leq 0.01$ by multivariate ANOVA.

as PEEP was increased from 0 to 5 and 10 hPa ($P<0.05$) (see Table 1 and Fig. 2.(a).

Resistance

There were not statistically significant changes in inspiratory or expiratory Rrs with changes in PEEP. For Δ-Rrs (=$Rrs_{EXP} - Rrs_{INSP}$), however, there was a significant effect of altered PEEP level ($P<0.01$) (Figure 2(b)) with $Rrs_{INSP} > Rrs_{EXP}$ at PEEP = 0 hPa, $Rrs_{INSP} \tilde{} Rrs_{EXP}$ at PEEP = 5 hPa, and $Rrs_{INSP} < Rrs_{EXP}$ at PEEP = 10 hPa.

Time constant

The expiratory time constant did not change significantly as PEEP was increased, while the inspiratory time constant decreased significantly ($P<0.05$). Δ-ô diminished significantly as PEEP was increased from 0 to 5 and 10 hPa ($p<0.01$) [Fig. 2.(c)].

Regression analysis

Regression analysis of the values measured at PEEP = 0 hPa found the following relations between inspiratory and expiratory parameters, as illustrated in Fig. 3:

$$\begin{aligned} Ers_{INSP} &= -0.18 + 0.95 Ers_{EXP}, & P<0.001,\ R=0.99,\\ Rrs_{INSP} &= -5.01 + 1.78 Rrs_{EXP}, & P<0.001\ R=0.90,\\ \tau_{INSP} &= -0.09 + 1.43\tau_{EXP}, & P<0.05\ R=0.84, \end{aligned}$$

while at a PEEP level of 10 hPa the following relations between inspiratory and expiratory parameters were found (Fig. 3):

$$\begin{aligned} Ers_{INSP} &= -5.56 + 1.24 Ers_{EXP}, & P<0.001, R=0.98,\\ Rrs_{INSP} &= -3.96 + 0.47 Rrs_{EXP}, & P<0.001, R=0.53,\\ \tau_{INSP} &= -0.16 + 1.41\tau_{EXP}, & P<0.05, R=0.66, \end{aligned}$$

Where R is the correlation coefficient.

ARDS group:

Elastance

There was a marked interaction between applied PEEP and difference between inspiratory and expiratory values ($P<0.01$) with diminishing Δ-Ers with higher PEEP-levels. This was mainly due to a linear decrease in expiratory Ers as PEEP was increased to 5 and 10 hPa ($P<0.01$) (Fig. 2.(a)), while a concomitant increase in inspiratory Ers with higher levels of PEEP was borderline significant ($P=0.05$).

Resistance

There was a significant effect of PEEP-level on Rrs_{INSP} ($P<0.01$), which decreased with increasing levels of PEEP, while Rrs_{EXP} did not change significantly.

Time constant

The inspiratory time constant decreased significantly as PEEP was increased to 5 and 10 hPa ($P=0.01$), while $\hat{o}_{EXP}$ did not change. The time constant also showed a pattern very similar to that seen for the elastance with a markedly diminishing Δ-τ with higher PEEP-level ($P<0.01$).

Regression analysis

Regression analysis of the values measured at PEEP=0 hPa revealed the following relations between inspiratory and expiratory parameters, which are also illustrated in Fig. 3:

$$\begin{aligned} Ers_{INSP} &= -7.35 + 0.83 Ers_{EXP}, & \text{n.s.},\ R=0.50,\\ Rrs_{INSP} &= -9.55 + 0.43 Rrs_{EXP}, & P<0.05,\ R=0.63,\\ \tau_{INSP} &= -0.35 + 0.53\tau_{EXP}, & \text{n.s.},\ R=0.37, \end{aligned}$$

while at PEEP=10 hPa the following relations between inspiratory and expiratory parameters were found (figure 3):

$$\begin{aligned} Ers_{INSP} &= -4.65 + 1.06 Ers_{EXP}, & P<0.01, R=0.82,\\ Rrs_{INSP} &= -4.18 + 0.61 Rrs_{EXP}, & P<0.05, R=0.76,\\ \tau_{INSP} &= 1.03\tau_{EXP}, & \text{n.s.}, R=0.24. \end{aligned}$$

Control vs. ARDS group:

Elastance:

There was a highly significant difference between the two groups of patients as a whole for all levels of PEEP and Insp./Exp.-measurements ($P<0.001$).

The effect of higher PEEP on the difference between inspiratory and expiratory values was significantly more marked for the ARDS group ($P<0.001$). However, the pattern of diminishing difference as PEEP increased was the same for the two groups of patients [see Fig. 2(a)].

There was no difference between the two groups with respect to the effect of higher levels of PEEP on inspiratory Ers. So when the two groups were pooled and analyzed together this effect of PEEP became more evident with $P<0.05$.

In contrast, there was a marked difference between the groups with respect to the effect of higher levels of PEEP on expiratory Ers ($P<0.001$) as there was no significant change for the controls.

Resistance:

There was a highly significant difference between the two groups of patients as a whole for all levels of PEEP and Insp./Exp.-measurements ($P=0.001$), while there was no statistical difference between the two groups of patients with regard to the effect of higher levels of applied PEEP [see Fig. 2(b)].

Table I. (a). Mean values and SD for control and ARDS patients for inspiratory (INSP) and expiratory (EXP) values and (b). Mean values and SEM for control and ARDS patients for within-subjects differences between inspiratory and expiratory (EXP-INSP) values of respiratory system elastance (Ers) (hPa/l), resistance (Rrs) (hPa/l/s), and time constant (τ) (sec) for PEEP levels of 0, 5, and 10 hPa. *P*-values based on multivariate ANOVA.

	PEEP (hPa)			
Parameter	0 Mean (SD)	5 Mean (SD)	10 Mean (SD)	*P*-value
(a) Mean values and SD for control and ARDs patients				
Controls				
N	10	10	10	
Tidal Volume [L]	0.624 ± 0.10	0,610 ± 0.10	0,606 ± 0.01	
Breath. Freq. [/min]	13.73	13.74	13.74	
Ers_{INSP}	19.65 (3.57)	20.07 (3.55)	21.95 (5.46)	n.s.
Ers_{EXP}	20.85 3.73	20.75 3.36	22.25 (4.35)	n.s.
Rrs_{INSP}	8.87 (2,34)	8.03 (2.16)	7.93 (2.31)	n.s.
Rrs_{EXP}	7.78 (1.18)	7.92 (0.99)	8.47 (1.51)	n.s.
τ_{INSP}	0.46 (0.12)	0.41 (0.12)	0.39 (0.15)	< 0.05
τ_{EXP}	0.38 (0.07)	0.39 (0.07)	0.39 (0.07)	n.s.
ARDS				
N	9	9	9	
Tidal Volume [L]	0.496 ± 0.10	0.504 ± 0.09	0.500 ± 0.08	
Breath. Freq. [/min]	14.82	14.83	14.83	
Ers_{INSP}	34.42(10.74)	36.39 (10.49)	39.48 (12.20)	=0.05
Ers_{EXP}	50.16 (7.31)	44.79 (7.33)	41.80 (9.43)	< 0.01
Rrs_{INSP}	16.43 (4.17)	14.76 (4.46)	13.26 (4.81)	< 0.01
Rrs_{EXP}	16.04 (7.57)	15.15 (6.40)	14.85 (5.99)	n.s.
τ_{INSP}	0.51 (0,17)	0.43 (0.17)	0.37 (0.19)	=0.01
τ_{EXP}	0.31 (0.12)	0.33 (0.10)	0.35 (0.09)	n.s.
(b) mean values and SEM for control and ARDS patients				
Controls				
N	10	10	10	
Δ-$Ers_{EXP-INSP}$	1.20 (0.15)	0.68 (0.26)	0.30 (0.43)	< 0.05
Δ-$Rrs_{EXP-INSP}$	− 1.09 (0.43)	-0.11 (0.52)	0.55 (0.74)	< 0.01
Δ-$\tau_{EXP-INSP}$	−0.077 (0.024)	−0.021 (0.025)	0.003 (0.036)	< 0.01
ARDS				
N	9	9	9	
Δ-$Ers_{EXP-INSP}$	15.74 (2.97)	8.40 (2.53)	2.32 (2.36)	< 0.01
Δ-$Rrs_{EXP-INSP}$	−0.39 (1,69)	0.39 (1.32)	1.58 (1,30)	n.s.
Δ-$\tau_{EXP-INSP}$	−0.201 (0,056)	−0.104 (0.057)	−0.020 (0.056)	< 0.01

Time constant:

The patterns of changes in inspiratory and expiratory time constant values as PEEP was increased were very similar for control patients and the patients with ARDS [see Fig. 2(c)]. However, the decrease in difference between inspiratory and expiratory values with higher PEEP levels was statistically slightly more pronounced for the ARDS group ($P = 0.05$).

DISCUSSION

The current study presents a separate analysis of inspiratory and expiratory mechanical parameters of the respiratory system of ARDS patients and patients without pulmonary disease and the effect of PEEP on these parameters. The results suggest that the expiratory elastance is importantly higher than the inspiratory elastance in mechanically ventilated patients with ARDS and that these phasic variations of Ers tended to diminish with the application of increasing PEEP. There was a striking difference between the ARDS patients and those without any respiratory disorder, who not only had much lower Ers but also presented much less phasic variation in Ers.

The high elastance in ARDS has been described in several previous studies (2,3,18) and has been attributed to pulmonary edema (28) and to the loss of ventilated pulmonary units, and it is so closely connected to ARDS that until recently it was included in the diagnostic criteria (2). The present study is, however, the first to describe significant phasic differences in elastance based on separately measured inspiratory and expiratory mechanics under dynamic conditions and to analyze the influence of PEEP on the observed phasic differences.

The observed phasic differences of elastance are in accordance with the corresponding differences between inspiratory and expiratory compliance in ARDS patients reported by Matamis *et al* (18). The different numerical values can be explained by the fact that our measurements have been made under dynamic conditions, using MLRA, in contrast to Matamis *et al*., who used the method of airway occlusion under static conditions. The analysis with MLRA is based on the assumption of linearity of the respiratory mechanical properties, which is considered to be generally sufficient at moderate tidal volumes even in various respiratory disorders such as ARDS (12,13), although it has been proved that respiratory system declines from linearity even during normal respiration (29,30). The inertance term of airways pressure has been excluded from the linear model, since the magnitude of the inertance term is extremely low, at conventional ventilatory frequencies (31).

Furthermore, the observed influence of PEEP on the inspiratory elastance is in accordance with the results of the recent studies (19–24).

The mechanism behind the phasic elastic differences could be related to pulmonary congestion, which also exists to some extent in the patients of the control group, who were under relaxation and muscle paralysis, but it mainly concerns the ARDS patients (18,19). The positive pressure during inspiration and the end-inspiratory

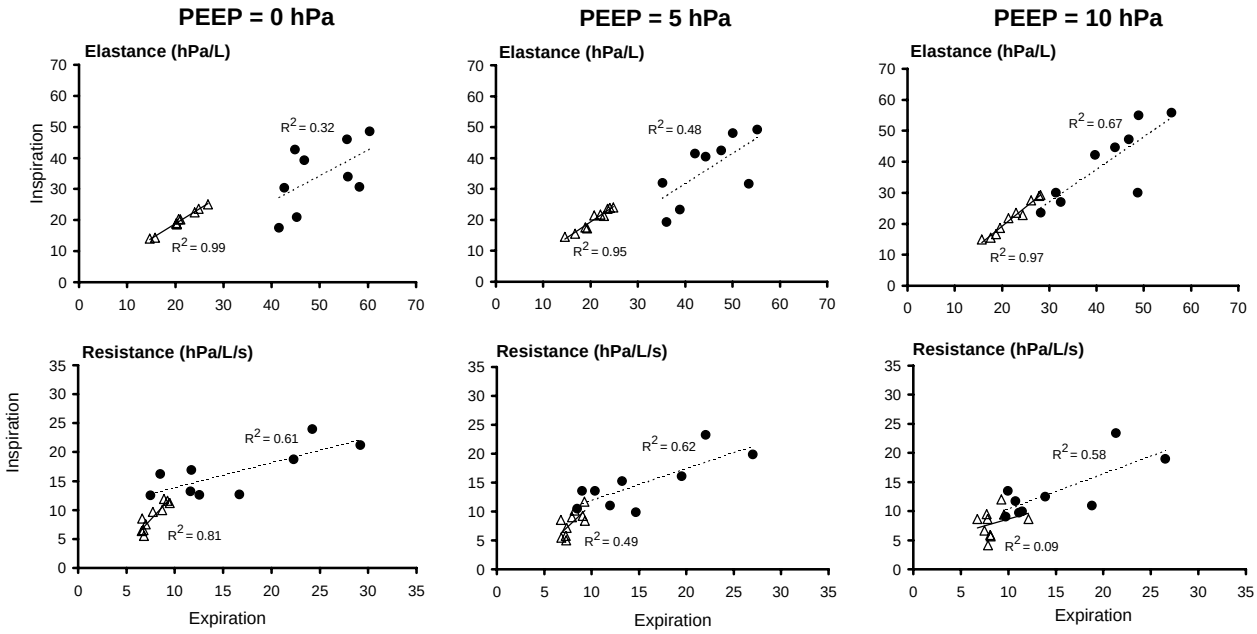

Fig. 3. Regression plots of expiratory values (horizontal axis) *vs.* inspiratory values (vertical axis) for elastance (upper row) and resistance (lower row) for each patient at PEEP levels 0, 5, and 10 hPa. Open triangles represent control patients and filled circles represent patients with ARDS. R^2-values express the fitness of the corresponding regression.

plateau may cause a partial compartment shift of the congestion from the alveolar space and the mucosa towards the interstitial space. This would make the interstitial lung parenchyma more rigid during the following expiration, which could explain the increased expiratory elastance. The plausibility of this hypothesis is strengthened by the results from the ARDS group under application of PEEP (5 and 10 hPa), which showed a progressive decrease of Δ-Ers with increasing PEEP. The influence of PEEP on the elastance has mainly been attributed to the recruitment of previously collapsed lung units (19–24], as it is well known that ARDS is characterized by the presence of atelectatic areas of the lung parenchyma. Consequently, a part of the inspiratory pressure could be spent on the recruitment of nonaerated areas, and be recorded as increased elastance during inspiration (20,22,23): The recruitment of nonfunctioning lung tissue caused by PEEP can explain the positive effect of PEEP on the total elastance of the respiratory system in ARDS patients, but not the observed phasic variations, and particularly the decrease of the elastance during inspiration. One should not disregard the fact that PEEP also contributes significantly to the reduction of the pulmonary congestion (19,24,32). PEEP restricts the leakage of liquids from the vessels of pulmonary circulation towards the interstitial space as a result of the increase of the perivascular pressure of pulmonary microcirculation. Through PEEP, increased alveolar pressure is also installed in the expiratory phase (24). This may gradually restrict the movement of fluid to and from the alveolar space and the mucosa and as a result the phasic variation in Ers also diminishes. Nevertheless, Tobin *et al* (23) reported that PEEP had no effect on the alveolar filling and the major result of the implementation of PEEP is the recruitment of the collapsed lung units. However, that concerns particularly the late stages of ARDS, and one should not disregard that our patients were studied in the first days after the onset of ARDS, where the alveolar congestion is the major pathophysiologic characteristic.

Another important point in relation to the current results was that for the control group of patients there was a high degree of correlation between inspiratory and expiratory elastance values both at the 0 and the 10 hPa PEEP-level (Fig. 3). For the ARDS group a different pattern was observed, which may be related to the phasic differences in elastance.

At zero PEEP level, the correlation between inspiratory and expiratory elastance was low, while at higher levels of PEEP (5 and 10 hPa), and the presumed consequent reduction of pulmonary edema, the correlation between inspiratory and expiratory elastance tended to reach a degree of correlation corresponding to that seen for normal subjects. The distance between the plots of the ARDS and of the control group correlating inspiratory and expiratory Ers could possibly be used as a measure of evaluation of the severity of ARDS. Changes in the plot along the course of ARDS and its tendency to reach the corresponding diagram of normal subjects might be a useful index for the observation of the clinical course of ARDS.

Although we did not have any independent evidence for concomitant expiratory flow limitation (EFL), some of the ARDS patients might experience EFL. In a previous study, large phasic variations of the imaginary part of the RS impedance (Im[Zrs]) have been observed during experimental artificial ventilation with the forced oscillation technique (15 Hz), in cases of EFL (17). A characteristic and significant decrease of Im[Zrs] during expiration was described during EFL, which actually corresponds to the equivalent increase of Ers (Ers=-(Im[Zrs]* $2\pi f$). Phasic variations of RS resistance were not reported as systematic and this is also true for our measurements. Conclusions from experimental results obtained at such a high frequency should very carefully be extended to normal respiratory frequency in human mechanical ventilation, but the similarity of these findings to the present should not be disregarded. The phasic variations of pulmonary edema and interstitial fluid, that we suggested above as a possible explanation of phasic Ers differences in ARDS patients, could also account for the development of EFL.

In the present analysis, pressure data were not corrected for the pressure drop along the which is generally recognized as an important resistor and the main site of flow turbulence (11). The subtraction was, however, omitted mainly because the clinician will have to monitor the intubated respiratory system as a whole. With the currently used mode of ventilation with regard to flow pattern and tidal volumes and the diameters of used ET, the ratio between the airway pressure measured just outside and just inside the ET may be estimated to have been less than 1.1 (30). Furthermore, even though the inclusion of the ET in the total measured RS will influence the calculated absolute values then it does not change the within-subject comparisons of inspiratory and expiratory values. Neither is it expected to influence the groupwise comparisons as there was no systematic difference between the two groups with regard to average ET diameter.

The respiratory system resistance was found significantly higher in the ARDS group in comparison with the control group. This finding concerns both inspiratory and expiratory values of Rrs as well as those of the whole respiratory cycle. The last has also been reported in previous studies (4,14). An extended narrowing or occlusion of the airways and increased tissue component of resistance with enhanced regional time constant inequalities are known to characterize ARDS (5). Nevertheless, phasic differences in Rrs was much less marked than for Ers in both the control and the ARDS group. The inspiratory and expiratory values of elastance and resistance and

their response to changes in PEEP explain the observed variations of the respiratory time constant, which were similar to that observed for the elastance. The lack of differences in ô between control and ARDS groups is expectable, since both factors (elastance and resistance), determining its value, are elevated in ARDS.

In conclusion, the present study on separate inspiratory and expiratory mechanics in ARDS reveals large phasic variations of the respiratory system elastance that could be attributed to the effect of mechanical ventilation during inspiration on pulmonary edema and interstitial fluid. This explanation is supported by the effect of PEEP on Δ-Ers. Nevertheless, our results need further and deeper exploration, as the phasic differences of elastance, especially in ARDS, could become a useful diagnostic tool for the evaluation of the severity of the underlying disease as well as for the accurate monitoring and the regulations for the most effective ventilation.

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