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# Intrinsic PEEP determined by static pressure-volume curves – application of a novel automated occlusion method

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**Abstract.** *Objective:* Evaluation of new computer-controlled occlusion procedure for determination of intrinsic PEEP in mechanically ventilated patients and comparison with the standard end-expiratory occlusion method.
*Design:* Prospective controlled study.
*Setting:* Intensive care unit of a university hospital.
*Patients:* 16 patients with acute respiratory failure of different degree and etiology. All patients were mechanically ventilated, heavily sedated and muscle paralyzed (non-depolarising relaxants). The type of ventilator, the inspiration/expiration ratio, $FIO_2$ and PEEP were selected by the attending clinicians according to the patients'need and independently from the study.
*Interventions:* Static compliance of the respiratory system ($C_{stat}$) was determined at varying external end-expiratory pressure settings: ZEEP (= ambient pressure), PEEP of 5 $cmH_2O$ and 10 $cmH_2O$. All other ventilator settings were kept constant during the entire procedure.
*Measurements and results:* A computer-controlled occlusion method (SCASS) was used for determination of $C_{stat}$. Intrinsic PEEP was determined by SCASS as the extrapolated zero-volume intercept of the regression line of multiple pressure/volume data pairs ($PEEP_{SCASSinspir}$ and $PEEP_{SCASSexpir}$). Directly thereafter intrinsic PEEP in this particular ventilatory setting was determined by end-expiratory occlusions ($PEPP_{EEO}$). The intrinsic PEEP values of the different methods were nearly identical with a significant correlation ($p < 0.0001$). Mean values ± SD: $PEEP_{SCASSinspir}$ 7.1 ± 4.3 $cmH_2O$; $PEEP_{SCASSexpir}$ 7.1 ± 4.5 $cmH_2O$; $PEEP_{EEO}$ 7.1 ± 4.2 $cmH_2O$.
*Conclusion:* Since no significant difference between $PEEP_i$ values measured by the inspiratory and expiratory occlusion method (SCASS) was seen, this indicates that no alveolar recruitment occurred during the respiratory cycle. This study demonstrates that the automated occlusion method for measuring $C_{stat}$ system can also be used with high accuracy for determination of intrinsic PEEP in mechanically ventilated patients.

**Key words:** Intrinsic PEEP – External PEEP – Static compliance – Mechanical ventilation – Alveolar recruitment

Intrinsic PEEP ($PEEP_i$) may be present in many mechanically ventilated patients [1] depending on the underlying pulmonary pathology [2, 3]. Other causes for $PEEP_i$ are high tidal volumes in combination with an insufficient expiratory duration [4], which may be worsened by an increased expiratory apparatus resistance (i.e. endotracheal tube, bacterial filters, expiratory valves etc.) [5]. $PEEP_i$ can cause haemodynamic disturbances [2, 6] by decreasing venous return and consequently the cardiac output. Furthermore, it increase the patient's work of breathing in assisted ventilation modes. On the other hand in inverse ratio ventilation (IRV) $PEEP_i$ is deliberately exploited to achieve an individual PEEP in lung compartments with decreased time constants [7].

Using a newly developed occlusion method (SCASS = "Static Compliance by Automated Single Steps") [8] we detected a positive airway pressure at zero volume in the pressure/volume (PV) curves determined at ZEEP conditions in some patients. We concluded that this positive pressure was related to an intrinsic PEEP under the given ventilatory pattern, and therefore conducted the present study to assess this hypothesis.

## Patients and methods

P/V curves were determined by SCASS in 16 patients with acute respiratory failure of varying degree and different etiologies (Table 1). All patients were heavily sedated, paralyzed with pancuronium bromide or vecuronium, and mechanically ventilated with constant volume during the measurement. The type of ventilator, the inspiration / expiration ratio, $FIO_2$ and PEEP were selected by the attending clinicians according to the patients'needs and independently from the study. In accordance with the study protocol static compliance was determined at varying end-expiratory pressure settings: ZEEP (= ambient pressure), external PEEP of 5 $cmH_2O$ and 10 $cmH_2O$. All other ventilator settings were kept constant during the entire procedure. Each different end-expiratory

**Table 1.** Clinical data

| Patient | Age [years] | Sex | Diagnosis | Lung status | $PaO_2/F_IO_2$ [mmHg] | $PaCO_2$ [mmHg] | Ventilator |
|---|---|---|---|---|---|---|---|
| 1 | 74 | m | Myocardial infarction, cardio-pulmonary resuscitation, comatose | Pneumonia | 188 | 43 | Bennett 7200 |
| 2 | 25 | m | Severe head injury | Normal | 300 | 38 | Bennett 7200 |
| 3 | 33 | m | Tissue infection, sepsis, obese, alcohol abuse | Atelectasis | 200 | 42 | Bennett 7200 |
| 4 | 25 | m | Severe head injury, epidural hematoma | Atelectasis | 206 | 35 | Bennett 7200 |
| 5 | 63 | m | Perforated duodenal ulcer, peritonitis, renal failure | ARDS, pneumonia | 143 | 47 | Dräger Evita |
| 6 | 48 | m | Multiple trauma | Lung contusion | 188 | 37 | Dräger Evita |
| 7 | 27 | m | Thoracic trauma | Lung contusion | 97 | 52 | Bennett 7200 |
| 8 | 56 | m | Multiple trauma | Atelectasis | 136 | 47 | Bennett 7200 |
| 9 | 21 | m | Multiple trauma | Lung contusion | 308 | 42 | Bennett 7200 |
| 10 | 27 | m | Abdominal trauma, high abdominal pressure due to intraabdominal tamponade | Atelectasis | 295 | 37 | Bennett 7200 |
| 11 | 27 | m | Abdominal trauma | Normal | 360 | 39 | Bennett 7200 |
| 12 | 18 | m | Multiple trauma | Lung contusion | 166 | 43 | Dräger Evita |
| 13 | 65 | f | Hypernephroma, post-surgery, acute renal failure obese | Cardiogenic lung edema | 200 | 43 | Dräger Evita |
| 14 | 44 | m | Multiple trauma | Lung contusion | 196 | 34 | Dräger Evita |
| 15 | 61 | m | Cardiac arrhythmia, cardio-pulmonary resuscitation, comatose | COPD | 117 | 41 | Bennett 7200 |
| 16 | 61 | m | Multiple trauma | COPD, pneumonia | 233 | 44 | Dräger Evita |

pressure condition was applied 15 min before the corresponding measurement and continued until this was completed. Directly after each measurement $PEEP_i$ in this particular ventilatory setting was determined by the "conventional" method by an automated end-expiratory occlusion similar to the procedure described by Pepe and Marini [2]. Arterial oxygen saturation (pulse oximetry), arterial pressure and heart rate were monitored continuously. The study protocol was approved by the Ethical Committee of our Medical Faculty.

Respiratory flow was measured with a heated pneumotachometer (Fleisch No. 2, Fleisch, Lausanne, Switzerland. Linearity: ±1% for 0–2.5 l/s) connected directly to the proximal end of the endotracheal tube as well as a differential pressure transducer. Tracheal pressure was measured at the same position with a further differential pressure transducer (both from Dr. Fenyves & Gut, Basel, Switzerland). The data were sampled on-line by an analog/digitalconverter (DT 2801-A, Data Translation, Marlboro, MA, USA) at a rate of 20 hertz, and processed by an IBM AT compatible personal computer. The data acquisition and processing software was programmed with a commercially available software program (Asyst® 3.0, Asyst Software Technologies, Rochester, NY). Volume was obtained by numerical integration of the flow signal. The pneumotachometer was calibrated with the patient's own collected expired gas mixture applied by a motor driven pump delivering 1 l of gas volume with a sinusoidal flow pattern.

## *Intrinsic PEEP determined with SCASS*

The SCASS method was described in detail recently [8]. P/V values are determined by automated computer-controlled occlusions of the airway at various inspiratory and expiratory volume levels in separate breathing cycles. The airway occlusions were performed for 5 s, airway pressure was taken as the mean pressure between the 4th and 5th second. All P/V values are within the tidal volume of the ventilatory setting. At the end of the measuring procedure the P/V values are plotted in a P/V diagram. In these series 6 to 12 P/V data pairs for each in- and expiratory compliance curve were determined. The static compliance of the respiratory system is calculated by regression analysis of the linear portion of the inspiratory and the expiratory slope respectively. The intercepts of the inspiratory and expiratory P/V-curves with the abscissa at endexpiratory lung volume ( = zero volume or FRC at the respective PEEP level) was defined as the intrinsic $PEEP_{SCASS}$ ($PEEP_{SCASSinspir}$ for the inspiratory P/V-curve; $PEEP_{SCASSexpir}$ for the expiratory P/V-curve). Fig. 1 shows inspiratory and exspiratory P/V-curves of one patient.

## *Intrinsic PEEP by end-expiratory occlusion ($PEEP_{EEO}$)*

The apparatus is identical to the apparatus used for SCASS, except for a modification of the valve position and the valve control: the occlusion valve and the valve for pressure release are both in the inspiratory limb of the ventilatory circuit (see Fig. 2). The computer controlled occlusion of the valve occurs during the late expiratory phase. Complete occlusion of the whole circuit is then accomplished when the ventilator's own expiratory valve shuts. Between the individual occlusion maneuvers normal ventilation (eight to ten breath cycles) is achieved. The pressure averaged during the last second of occlusion was taken as end-expiratory occlusion pressure. A single measurement is shown in Fig. 3. This maneuver was repeated five times. The mean value of these five measurements was taken as intrinsic PEEP (= $PEEP_{EEO}$).

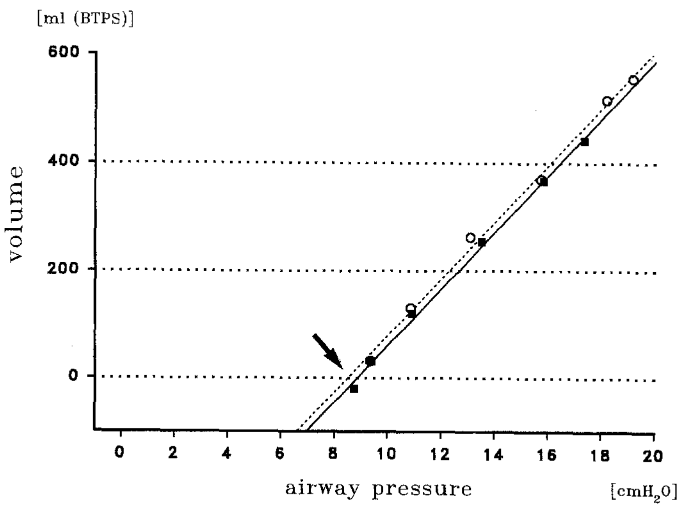


**Fig. 1.** P/V data pairs one patient determined by inspiratory (○) and expiratory (■) occlusion. Intrinsic PEEP was calculated as the intercept of the regression curve with the abscissa (→): $PEEP_{SCASSinspir}$ = 8.5 $cmH_2O$, and $PEEP_{SCASSexpir}$ = 8.8 $cmH_2O$. Corresponding static compliance values were: $C_{stat}$-insp = 52.8 ml/$cmH_2O$ for inspiration, and $C_{stat}$-expir = 52.5 ml($cmH_2O$ for expiration ($r = 0.999$)

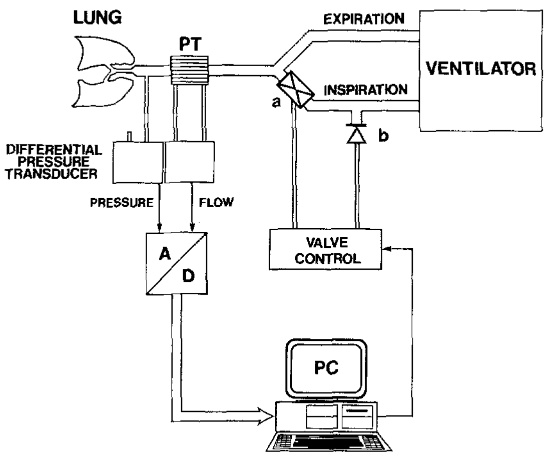


**Fig. 2.** General diagram of the computer-controlled occlusion system (modification of the SCASS system [8]). *a*, pneumatic driven valve occluding the inspiratory circuit; *b*, pneumatic driven valve for pressure release during occlusion; *PT*, pneumotachometer; *A/D*, analog/digital-converter; *PC*, personal computer (see text for details)

*Data analysis*

The two different methods for determination of intrinsic PEEP were compared according to the procedure introduced by Bland and Altman [9]. Furthermore, a simple linear regression by means of the least square method was performed. Paired data were evaluated with the Wilcoxon signed rank test. A $p$-value less than 0.05 was defined as significant.

## Results

The patient's data and the lung status is shown in Table 1. The different intrinsic PEEP values at three external PEEP levels of the 16 patients are listed in Table 2. Additionally, the static compliance of the total respiratory system determined by SCASS for inspiration and expiration are shown. There was no statistical difference between $PEEP_{EEO}$ and $PEEP_{SCASSexpir}$ ($p = 0.39$). Regression analysis shows a highly significant correlation between the $PEEP_{EEO}$ and $PEEP_{SCASS}$ values ($PEEP_{SCASSexpir}$: $r = 0.982$, $p < 0.001$; $PEEP_{SCASSinspir}$: $r = 0.995$, $p < 0.001$). The regression equation was in good accordance with the line of identity ($PEEP_{SCASSexpir}$: $y = 1.04x - 0.1$; $PEEP_{SCASSinspir}$: $y = 1.01x + 0.18$). However, $PEEP_{SCASSinspir}$ was slightly, but significantly higher than $PEEP_{EEO}$ ($p < 0.003$).

The good accordance of the two methods is best assessed by the method of Bland and Altman [9] as illustrated in Figs. 4a and 4b: the mean difference ± 2 SD ("limits of agreement", relevant for clinical measurements) is only $0.2 \pm 1.8\ cmH_2O$ ($PEEP_{EEO}$ vs. $PEEP_{SCASSexpir}$) and $0.3 \pm 0.9\ cmH_2O$ ($PEEP_{EEO}$ vs. $PEEP_{SCASSinspir}$). The intrinsic PEEP values found by inspiratory and expiratory SCASS are also almost identical (Fig. 5).

There was no significant difference between the inspiratory and expiratory static compliance values determined by SCASS ($p = 0.7$), whereas regression analysis revealed a highly significant correlation between the two parameters ($r = 0.975$, $p < 0.001$; regression equation: $y = 0.96x + 3.1$).

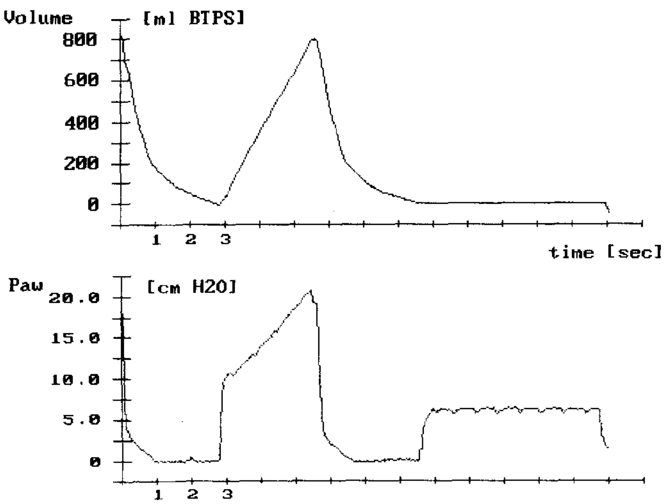


**Fig. 3.** Single end-expiratory occlusion maneuver for 5 s; volume ($V_T$) is shown in the *upper part*, and airway pressure ($P_{aw}$) in the *lower part*

## Discussion

The data of our study demonstrate that the intrinsic PEEP can easily be determined by the SCASS-method with computer-controlled airway occlusion: the intercepts of the inspiratory and the expiratory P/V curves at FRC

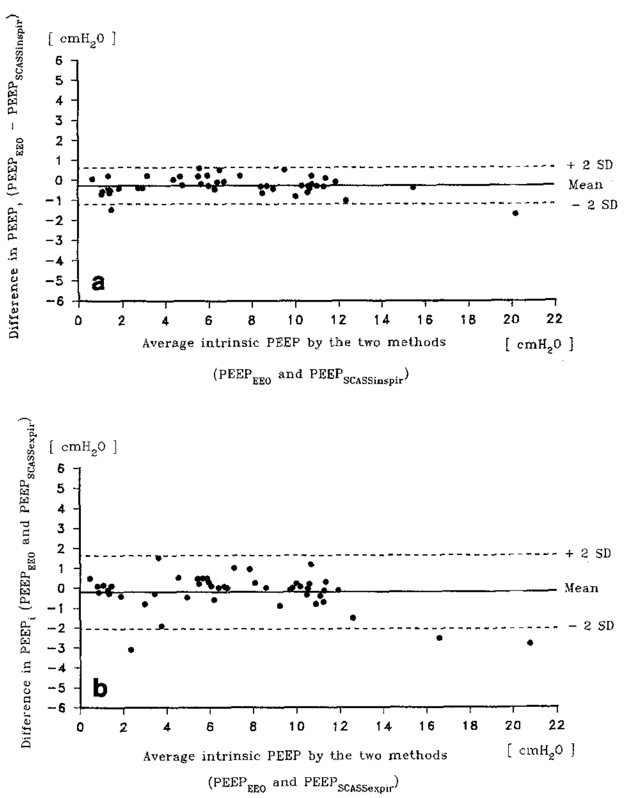


**Fig. 4a, b.** Comparison of the two methods for determination of intrinsic PEEP: Plot of averages against differences of both methods. Lines of mean and double standard deviations (2 SD). **a** End-expiratory occlusion ($PEEP_{EEO}$) against inspiratory SCASS ($PEEP_{SCASSinspir}$); **b** End-expiratory occlusion ($PEEP_{EEO}$ against expiratory SCASS ($PEEP_{SCASSexpir}$)

**Table 2.** Results of measurements of intrinsic PEEP by the two methods and static compliance at different external PEEP levels

| Patient | $PEEP_{ext}$ ($cmH_2O$) | $PEEP_{EEO}$ ($cmH_2O$) | $PEEP_{SCASS}$ inspir. ($cmH_2O$) | $PEEP_{SCASS}$ expir. ($cmH_2O$) | $C_{stat}$-inspir (SCASS) ($ml/cmH_2O$) | $C_{stat}$-expir (SCASS) ($ml/cmH_2O$) | Vt (ml) | $T_{inspir}$ (s) | $T_{expir}$ (s) |
|---|---|---|---|---|---|---|---|---|---|
| 1a | 0.0 | 1.5 | 1.3 | 1.4 | 96.9 | 95.3 | 799 | 2.9 | 2.9 |
| 1b | 4.7 | 5.9 | 5.3 | 5.4 | 101.9 | 103.7 | 765 | 3.0 | 2.9 |
| 1c | 9.4 | 10.1 | m.v. | 9.9 | m.v. | 83.8 | 753 | 3.0 | 2.9 |
| 2a | 0.0 | m.v. | 2.2 | 1.7 | 96.4 | 91.3 | 813 | 3.9 | 2.0 |
| 2b | 4.7 | 6.1 | 6.6 | 6.0 | 103.4 | 96.8 | 790 | 3.9 | 2.0 |
| 2c | 9.4 | 10.5 | 10.9 | 10.5 | 97.6 | 94.4 | 782 | 3.9 | 2.0 |
| 3a | 0.0 | 0.8 | 2.3 | 3.9 | 56.6 | 65.9 | 1012 | 2.9 | 3.0 |
| 3b | 4.0 | 6.1 | 6.6 | 5.8 | 82.3 | 80.5 | 1104 | 3.0 | 3.3 |
| 3c | 8.6 | 9.7 | 10.5 | 9.8 | 83.1 | 80.1 | 1080 | 3.0 | 3.2 |
| 4a | 0.2 | 1.3 | 1.8 | 1.4 | 76.4 | 80.4 | 977 | 3.7 | 2.2 |
| 4b | 4.6 | 5.7 | 5.5 | 5.2 | 98.3 | 100.1 | 958 | 3.8 | 2.1 |
| 4c | 9.6 | 10.3 | 10.9 | 10.7 | 109.5 | 113.5 | 949 | 3.8 | 2.1 |
| 5a | 0.0 | 1.2 | 1.8 | 1.0 | 59.1 | 58.7 | 761 | 3.6 | 2.3 |
| 5b | 5.7 | 7.6 | 7.4 | 6.6 | 57.1 | 54.3 | 776 | 3.5 | 2.4 |
| 5c | 9.8 | 10.7 | 10.9 | 10.5 | 51.2 | 50.2 | 756 | 3.5 | 2.4 |
| 6a | 1.0 | 1.7 | 2.1 | 2.1 | 80.1 | 87.9 | 1227 | 3.0 | 2.9 |
| 6b | 6.1 | 6.7 | 6.8 | 6.6 | 104.1 | 105.7 | 1260 | 3.0 | 2.9 |
| 6c | 11.0 | 11.5 | 11.4 | 11.2 | 97.8 | 96.4 | 1252 | 3.0 | 2.9 |
| 7a | 0.0 | 1.2 | 1.6 | 1.5 | 68.9 | 67.8 | 1113 | 3.9 | 2.0 |
| 7b | 3.2 | 4.8 | 4.6 | 4.3 | 70.3 | 69.7 | 1100 | 3.9 | 1.9 |
| 7c | 7.3 | 8.2 | 8.9 | 8.0 | 67.0 | 64.8 | 1100 | 3.9 | 1.9 |
| 8a | 0.0 | 0.9 | 1.4 | 0.8 | 97.9 | 92.8 | 1267 | 4.0 | 1.9 |
| 8b | 3.9 | 4.7 | 5.0 | 5.2 | 91.1 | 94.5 | 1278 | 4.0 | 1.9 |
| 8c | 7.8 | 8.8 | 9.3 | 9.7 | 86.4 | 88.5 | 1252 | 4.0 | 1.9 |
| 9a | 0.0 | 0.8 | 1.5 | 1.0 | 58.2 | 55.0 | 851 | 3.9 | 2.0 |
| 9b | 3.3 | 4.4 | 4.4 | 2.9 | 79.0 | 71.3 | 893 | 3.9 | 2.0 |
| 9c | 7.2 | 8.3 | 8.6 | 7.4 | 81.1 | 81.0 | 893 | 3.9 | 2.0 |
| 10a | 1.0 | 11.2 | m.v. | 10.1 | m.v. | 44.5 | 779 | 4.0 | 1.9 |
| 10b | 5.1 | 15.3 | 15.7 | 17.8 | 50.7 | 49.5 | 755 | 4.0 | 1.9 |
| 10c | 10.3 | 19.4 | 21.1 | 22.2 | 66.0 | 71.3 | 758 | 4.0 | 1.9 |
| 11a | 0.1 | 0.7 | 0.6 | 0.2 | 46.2 | 46.1 | 889 | 3.7 | 2.3 |
| 11b | 4.8 | 6.1 | 5.9 | 5.6 | 50.4 | 50.9 | 835 | 3.7 | 2.2 |
| 11c | 9.6 | 10.2 | 10.5 | 10.1 | 52.0 | 53.2 | 873 | 3.8 | 2.1 |
| 12a | 1.3 | 11.9 | 12.0 | 12.0 | 64.2 | 64.6 | 915 | 2.8 | 3.0 |
| 12b | 5.7 | 11.2 | 11.5 | 11.3 | 51.0 | 51.4 | 886 | 2.7 | 3.1 |
| 12c | 9.9 | 11.9 | 12.9 | 13.4 | 50.3 | 53.3 | 888 | 2.7 | 3.1 |
| 13a | 0.6 | 6.4 | 6.5 | 6.4 | 68.6 | 64.9 | 803 | 2.9 | 3.1 |
| 13b | 5.2 | 8.6 | 8.9 | 8.6 | 76.7 | 75.3 | 802 | 2.9 | 3.2 |
| 13c | 10.1 | 10.9 | 11.2 | 11.6 | 76.0 | 66.9 | 805 | 3.0 | 3.1 |
| 14a | 1.0 | 2.8 | 3.2 | 4.7 | 51.8 | 49.4 | 805 | 3.4 | 2.5 |
| 14b | 5.4 | 5.9 | 6.2 | 6.5 | 54.4 | 57.9 | 790 | 3.4 | 2.5 |
| 14c | 10.4 | 10.9 | 10.7 | 11.3 | 55.5 | 59.0 | 785 | 3.3 | 2.5 |
| 15a | 0.2 | 3.3 | 3.1 | 3.6 | 75.6 | 83.0 | 957 | 3.3 | 2.5 |
| 15b | 4.7 | 5.6 | 5.8 | 5.4 | 66.0 | 69.0 | 913 | 3.4 | 2.5 |
| 15c | 9.7 | 9.8 | 9.3 | 9.8 | 67.1 | 72.3 | 970 | 3.4 | 2.5 |
| 16a | 0.8 | 2.6 | 3.0 | 3.4 | 69.6 | 74.3 | 786 | 2.9 | 3.1 |
| 16b | 5.6 | 6.8 | 6.3 | 6.8 | 62.6 | 67.1 | 769 | 2.8 | 3.2 |
| 16c | 10.0 | 10.5 | 10.8 | 11.3 | 72.9 | 69.4 | 788 | 2.8 | 3.2 |
| mean ± SD | 4.8 ± 3.8 | 7.1 ± 4.2 | 7.1 ± 4.3 | 7.1 ± 4.5 | 73.5 ± 17.8 | 73.3 ± 17.8 | 919 ± 164 | 3.4 ± 0.5 | 2.5 ± 0.5 |

a, b, and c = different preset external PEEP levels; $PEEP_{ext}$ = applied external PEEP; $PEEP_{EEO}$ = intrinsic PEEP by end-expiratory occlusion; $PEEP_{SCASSinspir}$ = intrinsic PEEP by inspiratory SCASS; $PEEP_{SCASSexpir}$ = intrinsic PEEP by expiratory SCASS; $C_{stat}$-inspir = inspiratory static compliance of the respiratory system determined by SCASS; $C_{stat}$-expir = expiratory static compliance of the respiratory system determined by SCASS; SD = standard deviation; m.v. = missing values

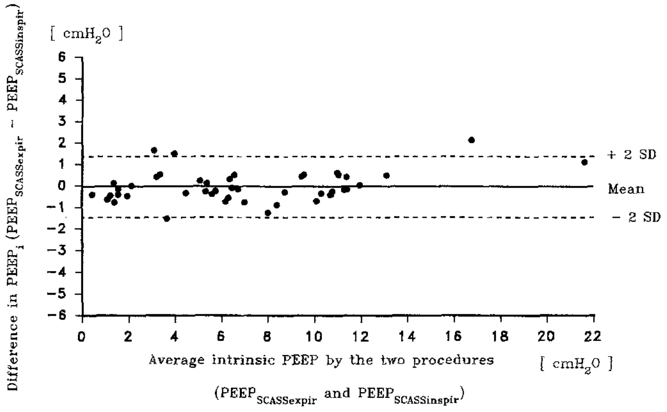


**Fig. 5.** Comparison of the intrinsic PEEP values found by inspiratory (PEEP$_{SCASSinspir}$) and expiratory (PEEP$_{SCASSexpir}$) *SCASS*, Plot of average against differences of both procedures. Lines of mean and double standard deviations (2 SD)

( = end-expiratory lung volume) are closely related to the intrinsic PEEP measured by the "classical" end-expiratory occlusion method.

The SCASS method was developed primarily for determining the static compliance ($C_{stat}$) of the respiratory system in ventilated patients. $C_{stat}$ has been proved to be useful for staging and estimating prognosis of acute respiratory failure [10–12] and for optimizing ventilation. Until now, the $C_{stat}$ in ventilated patients was determined by P/V curves with continuous step-by-step inflation and deflation with a super syringe [13, 14]. In a recent study Fernandez et al. [15] using the syringe method demonstrated that the isovolumetric pressure increment at the beginning of P/V curves is related to a PEEP$_i$ in this ventilatory pattern. However, the syringe technique is associated with a large number of errors due to the ongoing gas exchange, and intrapulmonary changes in the temperature and humidity of the gases [8, 16, 17]. The continuous inflation and deflation of the lungs probably also introduces errors by altering lung history. These artefacts lead to an overestimation of the inflation compliance and an underestimation of the deflation compliance and are responsible for the usually observed hysteresis [8]. This procedure therefore leads to large differences between the inflation and the deflation intercepts at FRC level. The SCASS method avoids these problems: since each single occlusion lasts only five seconds the above mentioned errors are negligible. With SCASS the intrapulmonary volume is taken as the actually measured volume at the moment of the effectively completed occlusion (flow = zero). Airway pressure is taken as the mean value between the fourth and the fifth second to average out the effects of cardiogenic oscillations as can be seen in Fig. 3. Principally there will be a decrease in the intrapulmonary volume and the respective airway pressure depending on the occlusion time (apnoeic time) since oxygen uptake is still ongoing and the alveolar respiratory quotient (R) is decreasing during occlusion. Hurewitz et al. reported a fall of R to nearly 0.2 (0.31 − 0.17) during a 15 s apnoeic period in healthy volunteers [18]. Therefore intrapulmonary volume and $P_{aw}$ will progressively be underestimated with increasing occlusion time (roughly calculated to be −0.2 cm$H_2O$ for 5 s of occlusion). On the other hand in lungs with low time constants a certain time of occlusion is essential to reach static conditions without interalveolar redistribution by pendelluft phenomena. Thus, an estimation of the occlusion pressure within the 4th and 5th seconds seems to be a good compromise between these mentioned errors.

This study demonstrates that the intrinsic PEEP can be determined by the extrapolated P/V curve determined with SCASS (i.e. the intercept of the regression line of several P/V data pairs with the FRC). The prerequisite for this is that the P/V curve is linear or nearly linear. However, this is easily confirmed by visually analyzing the P/V diagrams. In our experience which now encompasses approximately 80 patients with more than 200 determinations, the lower part of the P/V curves derived under static conditions by the SCASS method are almost always linear for all practical purposes: the linear correlation coefficient of the individual curves is always better than 0.985. The P/V curves only depart slightly from the required linearity in very stiff lungs were they take on a sigmoid form. In this special case occlusions have to be performed at almost low tidal volumes to determine the PEEP$_i$. Then PEEP$_i$ can be calculated by extrapolation from non-linear regression.

The excellent accordance of the values of PEEP$_i$ determined by the "conventional" end-expiratory occlusion method and those derived from the expiratory P/V curve of the SCASS method is not surprising, since the expiratory SCASS P/V values at low intrapulmonary volumes are obtained with occlusions near FRC ( = end-expiratory lung volume).

Interestingly enough, the inspiratory and expiratory intercepts at FRC (PEEP$_{SCASSinspir}$ and PEEP$_{SCASSexpir}$) are not significantly different ($p = 0.39$): PEEP$_{SCASSinspir}$ is negligibly higher than PEEP$_{SCASSexpir}$ with a mean difference of $0.1 \pm 0.7$ cm$H_2O$ (Fig. 5). This means that occlusions at low lung volumes also in the inspiratory SCASS P/V curves are related to the intrinsic PEEP. This may give further information about the mechanisms causing intrinsic PEEP. It is generally accepted that the opening pressures required for alveolar recruitment are higher than the closing pressures [19]. If alveolar recruitment was involved, PEEP$_{SCASSinspir}$ should be clearly higher than PEEP$_{SCASSexpir}$. This is not the case. There could theoretically be another reason for this phenomenon: it could be assumed that alveolar recruitment had already been achieved during the five second occlusion period (see "SCASS method"). However, this has been excluded by visual analysis of the analog airway pressure curves at the occlusion period (Fig. 1). In any case, alveolar recruitment does not seem to be significantly involved. The reason for this could be that the short period of time within a single respiratory cycle might be too short to re-open collapsed alveoli. Indeed, alveolar recruitment seems to take much longer as has been nicely shown by resolution of postoperative pulmonary densities in CT scans [20].

There is a statistically significant but very slight difference (mean 0.04 cm$H_2O$) between the PEEP$_i$ values determined by end-expiratory occlusion (PEEP$_{EEO}$) and by inspiratory SCASS ($PEEP_{SCASSinspir}$). However, in clinical practice this difference is not relevant, and only shows the accuracy of the measurements.

The cause of intrinsic PEEP during mechanical ventilation is the incomplete emptying of the lung or regional lung areas during an expiratory time which is too short relative to the volume and which leads to so-called dynamic hyperinflation. This can be caused either by increased time constants and/or a too short expiration time. High tidal volumes and airway collapse are further causes of dynamic hyperinflation. This is common in patients with chronic obstructive pulmonary disease (COPD) but it is also seen in patients without a history of chronic airway disease [21].

In COPD patients with high lung volume, intrinsic PEEP should be avoided, since it increases dynamic hyperinflation with all its negative consequences (increased intrathoracic pressure, reduction of venous return and cardiac output and a higher risk of barotrauma). Furthermore, in spontaneous breathing modes (such as CPAP or pressure support ventilation) intrinsic PEEP increases the patient's work of breathing by the extra load [3]. Therefore, only the estimation of an existing intrinsic PEEP can help improve the adaptation of the ventilatory pattern.

On the other hand, under conditions with decreased lung volume, like ARDS, lung contusion or pneumonia, an applied external PEEP improves pulmonary gas exchange by increasing FRC. Intrinsic PEEP can then even be exploited to improve oxygenation in severe respiratory failure. This principle is used in the inversed ratio ventilation mode (IRV): with constant-volume ventilation or even with pressure release ventilation the intrinsic PEEP is used as an "individual" PEEP, which selectively affects the lung areas with slow time constants [7] leading to a recruitment of non-ventilated lung areas.

Therefore estimation of intrinsic PEEP seems to be clinically essential for optimal adjustment of ventilatory therapy. Since modern microprocessor equipped ventilators offer the possibility to incorporate easily this additive option for clinical monitoring this must now be expressively requested.

We conclude that the intercepts of the inspiratory and the expiratory SCASS-P/V curves with the abscissa at FRC correspond to the intrinsic PEEP. Since there is no real difference between the two intercepts, we also assume that alveolar recruitment does not occur during the short period of a respiratory cycle. Under these conditions intrinsic PEEP seems to be caused solely by airway closure and/or flow limitation.

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