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EXPERIMENTAL

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Elastic pressure-volume curves of the respiratory system reveal a high tendency to lung collapse in young pigs

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Abstract *Objective*: To study pressure-volume (P/V) curves over a wide pressure and volume range in pigs.
Design: Dynamic and static P/V curves (P_{dyn}/V and P_{st}/V) and compliance of the respiratory system were studied. The effects of recruitment, positive end-expiratory pressure (PEEP) and body position were analysed.
Setting: Research animal laboratory.
Materials: Seven anaesthetised, paralysed and ventilated healthy pigs of 21 kg.
Measurements: P/V curves up to a pressure of about 40 cmH_2O were recorded with a computer-controlled ventilator. P_{st}/V curves were obtained with the static occlusion method and P_{dyn}/V curves during an insufflation at a low, constant flow rate.
Results: P_{dyn}/V recording showed a complex pattern. During the insufflation compliance increased, fell, increased and fell again. A 2nd P_{dyn}/V recording immediately following the 1st one was displaced towards higher volumes and showed only one maximum of compliance. The difference between the two curves reflected: (1) lung collapse during a period of 5 min of ventilation at zero end-expiratory pressure (ZEEP) following a recruitment manoeuvre, (2) recruitment during the measurement of the 1st P_{dyn}/V curve. These observations were similar in the supine and in the left lateral position. After ventilation at PEEP, 4 cmH_2O, the signs of collapse and recruitment were reduced. It was confirmed that PEEP offers a partial protection against collapse. P_{st}/V curves showed higher volumes and higher compliance values compared to P_{dyn}/V curves. This reflects the influence of viscoelastance on P_{dyn}/V curves.
Conclusion: The study demonstrates a particularly strong tendency to lung collapse in pigs.

Key words Animal · Porcine · Mechanics · Compliance · Elastic recoil · Recruitment

Introduction

The elastic pressure-volume (P/V) curve is becoming an established tool in the care of patients with critical respiratory failure [1, 2, 3, 4, 5]. In spite of the extensive literature on elastic lung properties in healthy and diseased mammals and man, a full understanding of factors influencing the P/V curve is lacking. New phenomena are still being found, like an important dependence upon the expiratory pressure from which the insufflation starts [6].

Few studies describe respiratory mechanics in pigs [7, 8, 9]. These studies do not cover the entire P/V curve and do not analyse factors which contribute to non-linear features. The pig is used for models of acute lung injury. As a reference, therefore, an increased knowledge

of respiratory mechanics in healthy pigs is needed. The potential use of porcine lung for xenotransplantation merits increased knowledge about these lungs [10].

Our objective was to study the P/V curve over a wide pressure and volume range in healthy, mechanically ventilated pigs. The influence of volume history, positive end-expiratory pressure (PEEP) and body position on the P/V curve was explored. Static P/V (P_{st}/V) curves were determined with an automated flow interruption method [11] and dynamic P/V curves (P_{dyn}/V) with a technique based on continuous insufflation at a constant low flow rate [4, 12].

Materials and methods

The study was performed in seven Swedish Landrace pigs with a mean weight of 20.9 ± 1.5 kg. The Ethics Board of Animal Research, University of Lund, Sweden, approved the experimental protocol.

Anaesthesia and preparation

The animals were fasted overnight but allowed free access to water. Thirty minutes before the induction of anaesthesia the pigs were pre-medicated with azaperon (Stresnil, Janssen, Beerse, Belgium) 6 mg/kg intramuscularly. Anaesthesia was induced with sodium-pentothal (Pentothal, Abbott, North Chicago, Ill., USA), 12.5 mg/kg i.v. The animals were then orotracheally intubated with an ID 6.5 mm Portex cuffed tube and connected to a ventilator. The tube cuff was inflated and frequently tested to avoid air leakage. Anaesthesia was maintained by a continuous i.v. infusion of fentanyl (Leptanal, Janssen, Beerse, Belgium), 75 μg/kg per h, pancuronium bromide (Pavulon, Organon Teknika, Boxtel, Holland), 0.4 mg/kg per h, and midazolam (Dormicum, Hoffmann-La Roche, Basel, Switzerland), 0.25 mg/kg per h. The pigs were hydrated with Ringer acetate, 10 ml/kg per h, and warmed to maintain a constant temperature. After the experiment all animals were killed with an overdose of potassium chloride.

Ventilation

Volume-controlled ventilation with a constant inspiratory flow was given with a Servo Ventilator 900 C (Siemens-Elema, Sweden). Frequency was set at 20 breaths/min, inspiratory time 33% and post-inspiratory pause time 5% of the respiratory cycle. The inspired fraction of oxygen (FIO_2) was 0.21. Minute ventilation was adjusted to give an arterial carbon dioxide tension ($PaCO_2$) of 4.5–5.0 kPa, which was then maintained constant throughout the study. This resulted in a tidal volume of, on average, 10 ml/kg. The end-expiratory pressure was either + 4 cmH_2O (PEEP) or zero (ZEEP).

The left carotid artery was cannulated for blood sampling and measurement of pressure. The left external jugular vein was cannulated for infusions. A pulmonary artery catheter was inserted through the internal jugular vein to measure pulmonary artery pressure. Blood gases were analysed on an ABL 505 (Radiometer, Copenhagen, Denmark).

Equipment

The Servo Ventilator was connected to an IBM compatible personal computer through a ventilator/computer interface, as has previously been described [4, 11, 12]. The computer emitted analogue signals, which, when fed to the external control socket of the ventilator, allowed the computer to take over control of the respiration rate, PEEP and minute ventilation. P/V curves were recorded using the flow and expiratory pressure transducers of the ventilator. These were calibrated daily against a 1-l syringe and a water manometer. Flow and volume were calibrated to yield data at body temperature and pressure, and saturated with water vapour, i.e. BTPS.

The signals of pressure and flow were fed to the computer and A/D converted at 50 Hz. Airway flow rate was calculated by correcting the measured flow rate for gas compression in the tubings. Volume (V) was calculated by integration of flow. During the procedure the computer continuously recorded pressure and flow. These data were automatically transferred to a spreadsheet (EXCEL 5.0, Microsoft) so prepared that analysis and data presentation were automatically performed.

Recording of static pressure-volume curves

P_{st}/V curves were recorded according to the flow interruption principle [13], which is based on interruption of the inspiratory flow during a number of so-called study breaths. Each of these is interrupted at an increasingly large volume, as has been described in detail [11]. The tidal volume insufflated was automatically increased between breaths to cover volumes from 0 to about 1300 ml, or until a pressure of 40 cmH_2O was reached. The static pressure was read 3 s into a post-inspiratory pause following the insufflation. This latency is long enough to allow viscoelastic pressure to decay to an insignificant value, but not long enough to have a significant volume decrease by oxygen uptake [14]. P_{st}/V curves were then constructed by plotting the volume versus the elastic recoil pressure of the respiratory system for each interrupted breath.

Recording of dynamic pressure-volume curves

P_{dyn}/V curves were recorded during one single insufflation at constant flow [12]. After a first ordinary complete breath and a second ordinary inspiration, the following expiration was prolonged to 6 s to allow for complete flow cessation (Fig. 1). When PEEP was used, PEEP was maintained during the prolonged expirations, which preceded recording of P_{dyn}/V and P_{st}/V data. The volume retained by PEEP was calculated as the difference between the volume after the ordinary expiration at PEEP and the volume after a prolonged expiration at ZEEP. The duration of the following inspiratory phase, denoted the insufflation, was prolonged to 6 s. The computer controlled the flow rate during the insufflation so that volume reached 65 ml/kg body weight during the 6 s. This insufflated volume (V_{insuff}) was chosen to result in a peak pressure of about 40 cmH_2O. Flow rate during the insufflation was accordingly about 1300/6 = 220 ml/s. The insufflation was automatically interrupted at a pressure of 40 cmH_2O. During a prolonged expiration following the insufflation, lung volume was allowed to return to the baseline level at ZEEP or at PEEP.

To obtain the dynamic elastic recoil pressure of the structures of the respiratory system (P_{dyn}), the resistive pressure drop in tubing and airways during the insufflation was subtracted from the measured pressure. This resistive pressure drop was calculated from tube resistance measured in vitro and resistance of the airways measured from the initial ordinary breath according to Varène and Jaquemin [15], as previously described [4].

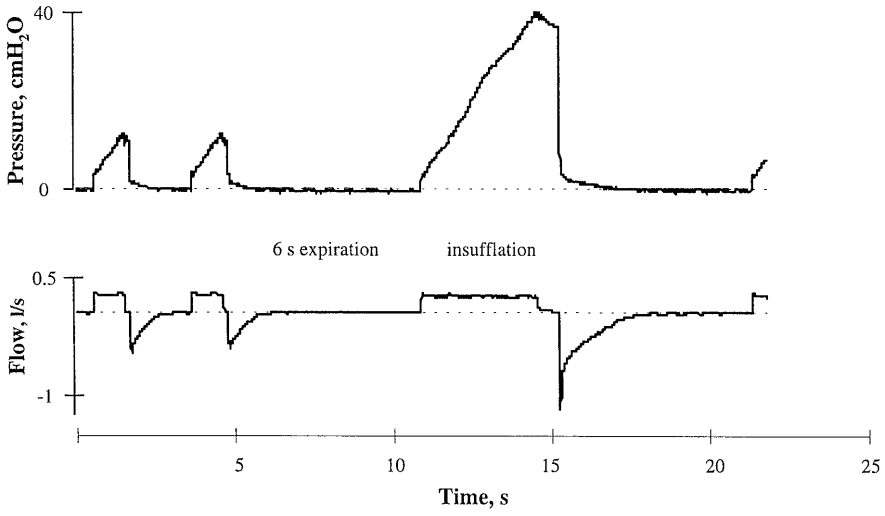

Fig. 1 Raw data for a P_{dyn}/V recording at ZEEP. The uneven rate of pressure change during the insufflation at constant flow reflects variations in C_{dyn}

Table 1 Protocol

PHASE	POSITION	VENTILATION	RECORDINGS
Animal preparation	Supine	ZEEP	
45 minutes pause	Supine	ZEEP	
Recruitment manoeuvre	Supine	30 cm H_2O, 15 s	
5 minutes pause	Supine	ZEEP	
Stage I measurements	Supine	ZEEP	1st P_{dyn}/V, 2nd P_{dyn}/V, P_{st}/V
Change of position	Left lateral	ZEEP	
30 minutes pause	Left lateral	ZEEP	
Stage II measurements	Left lateral	ZEEP	1st P_{dyn}/V, 2nd P_{dyn}/V, P_{st}/V
Setting of PEEP	Left lateral	PEEP 4 cm H_2O	
30 minutes pause	Left lateral	PEEP 4 cm H_2O	
Stage III measurements	Left lateral	PEEP 4 cm H_2O	1st P_{dyn}/V, 2nd P_{dyn}/V, P_{st}/V

Dynamic compliance (C_{dyn}) was obtained by moving regression applied to the P_{dyn}/V curve during insufflation. Then C_{dyn} was plotted versus P resulting in a P/C_{dyn} curve. Static compliance (C_{st}) and the P/C_{st} curve were produced according to the same principle.

Protocol

After preparation of the pigs, including surgery, a stabilisation period of 45 min was allowed (Table 1). Then a recruitment manoeuvre was performed by inflating the lungs with a pressure of 30 cmH_2O for 15 s to eliminate atelectasis and standardise lung volume history and conditions among the animals. Data were acquired at three stages: stage 1, supine position at ZEEP; stage 2, left lateral position at ZEEP; stage 3, left lateral position at a PEEP of 4 cmH_2O. At each stage haemodynamic data were collected. Then two P_{dyn}/V recordings were performed (1st P_{dyn}/V and 2nd P_{dyn}/V) followed by a P_{st}/V recording. About 20 s elapsed between 1st P_{dyn}/V and 2nd P_{dyn}/V, and between 2nd P_{dyn}/V and P_{st}/V. After stage 1 the position was changed and after stage 2 PEEP was set. Thirty minutes were allowed for stabilisation with the new conditions.

Statistical analysis

The results are expressed as the means ± SE. Using a two-tailed Student's *t*-test for paired and unpaired data, comparisons were made between measurements at different stages. A p less than 0.05 was considered significant.

Results

No significant changes in heart rate, pulmonary artery pressure, arterial pressure and blood gases were observed during the experiment (Table 2). At stage 1, i.e. supine position at ZEEP, an uneven rate in the increase in airway pressure during constant flow insufflation was observed in every animal (Fig. 1). The 1st P_{dyn}/V curve had complex features as shown in a representative pig (Fig. 2, stage 1). In each pig the corresponding 1st P/C_{dyn} diagram displayed two peaks in compliance, as is vaguely reflected by average values (Table 3). The lowest value of C_{dyn} in the 1st P_{dyn}/V recording was observed at a distending pressure of 20–25 cmH_2O. In the 2nd P_{dyn}/V curve, recorded 20 s after the first one, compliance increased in the initial part of the P_{dyn}/V curve

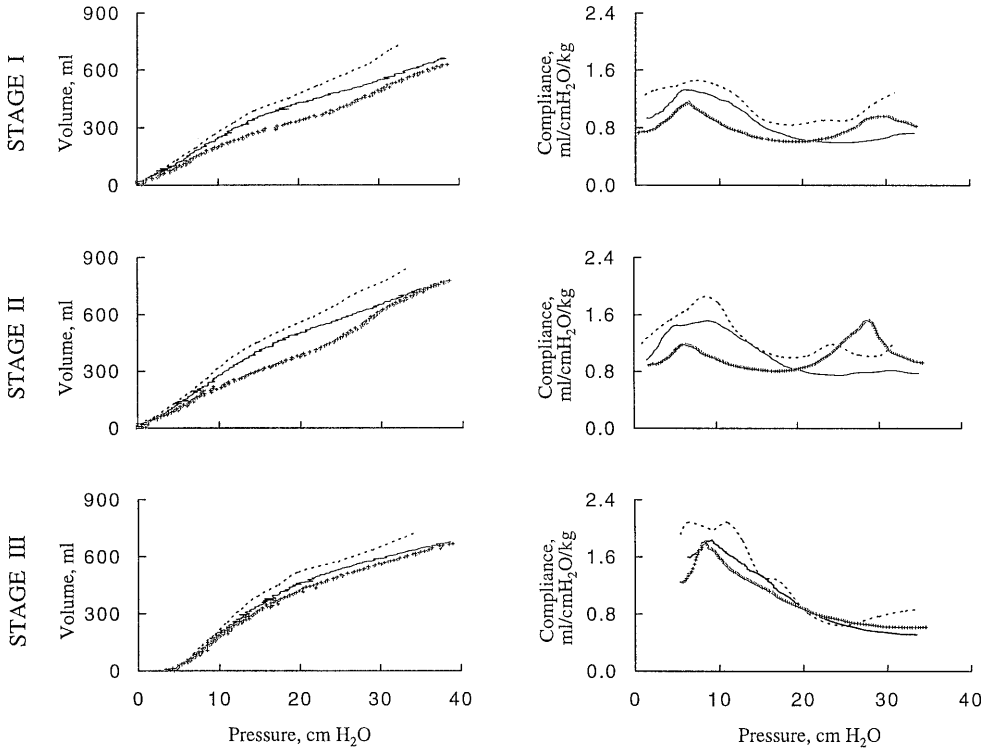

Fig. 2 +++ 1st P_{dyn}/V recording, — 2nd P_{dyn}/V recording, --- P_{st}/V recording. P/V curves (*left*) and P/C curves (*right*) from a pig at all stages. All pigs showed similar patterns

Table 2 Hemodynamics and arterial blood gases during the experimental period preceding P/V curves recordings

STAGE	HR (min^{-1})	mABP (mm Hg)	mPAP (mm Hg)	PaO_2 (kPa)	$PaCO_2$ (kPa)
Stage I	78.4 ± 10.6	88.0 ± 19.2	18.0 ± 2.2	12.7 ± 1.6	4.9 ± 0.6
Stage II	82.3 ± 7.7	80.9 ± 8.9	16.1 ± 3.9	12.9 ± 1.2	4.9 ± 0.5
Stage III	82.0 ± 8.2	81.2 ± 9.3	17.0 ± 2.8	12.8 ± 1.2	4.8 ± 0.2

Definition of abbreviations: Values are means ± SD; HR, heart rate; mABP, mean artery blood pressure; mPAP, mean pulmonary artery blood pressure; PaO_2, partial pressure of O_2 in arterial blood; $PaCO_2$, partial pressure of CO_2 in arterial blood

and then decreased to a nearly stable value (Fig 2, Table 3). Compared to the 1st P_{dyn}/V recording, in the 2nd one compliance was significantly higher up to a pressure of 20 cmH_2O and significantly lower at 25 and 30 cmH_2O. Compared to the 2nd P_{dyn}/V curve, the P_{st}/V curve showed similar features but a steeper slope corresponding to a higher compliance, (Fig. 2, Table 3).

At stage 2, i.e. in the lateral position at ZEEP, the findings were in principle similar to those in the supine position. In Fig. 3 the difference between the 1st and 2nd P/C_{dyn} curves is further clarified.

At stage 3, i.e. lateral position at PEEP, the 1st P_{dyn}/V did not show two peaks of compliance as observed at ZEEP in stages 1 and 2. At stage 3 all P/C recordings showed a steady fall in compliance towards higher P_{dyn} values (Fig. 2 stage 3, Table 3). The 2nd C_{dyn} in stage 3 was significantly higher than 1st C_{dyn} at low pressures and lower in the upper pressure range (Table 3). C_{st} was higher at PEEP than C_{dyn} from the 2nd P_{dyn}/V recording, as was the case at ZEEP.

The volume retained by 4 cmH_2O of PEEP measured during a prolonged expiration at ZEEP was 151 ± 20 ml.

Discussion

The methods employed in this study for the recording of P_{st}/V and P_{dyn}/V curves were based upon computer control of a standard ventilator that is the result of a stepwise development [4, 11, 12]. An important feature of the method is the precise control of the measurement procedure that exactly follows a defined protocol. This yields results with high reproducibility [12]. Errors in the determination of resistance will influence the calculated P_{dyn}/V curve. Inspiratory resistance varies little

Table 3 Compliance in relation to pressure at different conditions (ml/cmH_2O/kg)

	Recordings	DISTENDING PRESSURE, (cmH_2O)						
		5	10	15	20	25	30	35
Stage I	$1^{st}P_{dyn}$/V	1.08 ± 0.04**	1.15 ± 0.06**	1.07 ± 0.10**	0.84 ± 0.06*	0.89 ± 0.05**	1.28 ± 0.08**	1.10 ± 0.03
ZEEP	$2^{nd}P_{dyn}$/V	1.32 ± 0.06*	1.50 ± 0.08**	1.34 ± 0.11	0.94 ± 0.06**	0.79 ± 0.04**	0.91 ± 0.07*	0.94 ± 0.04
Supine	P_{st}/V	1.46 ± 0.07	1.68 ± 0.10	1.33 ± 0.10	1.08 ± 0.06	1.18 ± 0.11	1.13 ± 0.04	
Stage II	$1^{st}P_{dyn}$/V	1.11 ± 0.08**	1.12 ± 0.11**	1.05 ± 0.12**	0.97 ± 0.09	1.22 ± 0.10#*	1.43 ± 0.06**	1.14 ± 0.11**
ZEEP	$2^{nd}P_{dyn}$/V	1.34 ± 0.09**	1.61 ± 0.13**	1.38 ± 0.14	1.07 ± 0.08#	0.93 ± 0.04##*	1.00 ± 0.11	0.88 ± 0.07
Lateral	P_{st}/V	1.53 ± 0.11	1.90 ± 0.15#	1.53 ± 0.12##	1.21 ± 0.06#	1.17 ± 0.09	1.08 ± 0.07	
Stage III	$1^{st}P_{dyn}$/V		1.61 ± 0.07ðð**	1.35 ± 0.11ðð**	1.08 ± 0.09	0.84 ± 0.04ðð	0.80 ± 0.06ðð**	0.79 ± 0.06ðð**
PEEP	$2^{nd}P_{dyn}$/V		1.81 ± 0.09ð**	1.58 ± 0.12ð*	1.15 ± 0.06	0.80 ± 0.03ðð*	0.65 ± 0.03ðð	0.62 ± 0.04ðð
Lateral	P_{st}/V		2.01 ± 0.09	1.83 ± 0.10ð	1.19 ± 0.06	0.87 ± 0.05ð	0.80 ± 0.06ðð	

Definition of abbreviations: Values are means ± SE. Supine: supine position; Lateral: lateral position; $1^{st}P_{dyn}$/V, $2^{nd}P_{dyn}$/V: first and second dynamic recordings; P_{st}/V: static recording; ZEEP: zero end expiratory pressure; PEEP: positive end expiratory pressure. One symbol: $p < 0.05$; Two symbols: $p < 0.01$. *: differences between consecutive recordings; #: stage II compared to stage I; ð: stage III compared to stage II

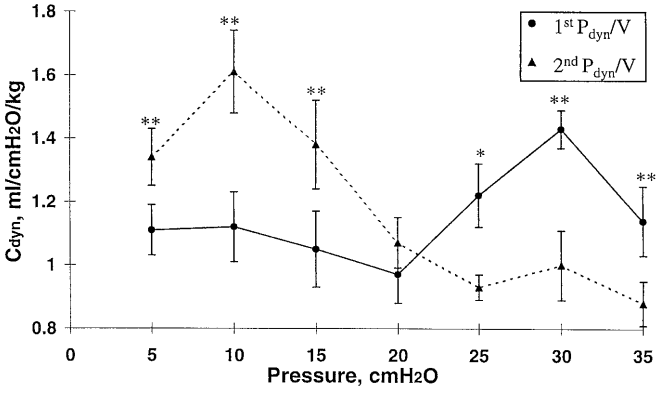

Fig. 3 Compliance from the 1st and 2nd P_{dyn}/V recordings in relation to P_{dyn}. Lateral position at ZEEP. Mean ± SE, *$p < 0.05$, **$p < 0.01$

with volume in the normal lungs of humans, cats and dogs [16, 17, 18]. The method for calculation of P_{dyn}/V curves on the basis of resistance measured over a full breath has recently been documented to introduce insignificant errors [12].

Elastic P/V curves of the respiratory system in various species are sigmoid. A lower segment with low compliance is followed by a middle linear segment with constant compliance and an upper segment with decreasing compliance [3, 4, 19, 20, 21]. In stage 3, at PEEP, our results comply with such an overall pattern previously observed in e. g. rabbits [20, 22], cats [23], and humans [21]. However, particularly the first dynamic curve recorded at ZEEP in the supine or lateral position deviated to a significant extent from previous results in that the compliance varied during the insufflation in a complex way. These unforeseen results merit a discussion of different causes for variation in compliance.

In principle, the slope of a P/V curve may vary for three reasons: (1) variation in the degree to which the lung is recruited, (2) true variations in distensibility of the lung parenchyma of recruited units and (3) non-linear P/V behaviour of the thoracic cage. The influence of continuing recruitment during the recording of a P/V curve has recently been analysed by Hickling [24] and Jonson et al. [25]. By definition compliance is volume change over pressure change:

$$C = \frac{\Delta V}{\Delta P} \qquad \text{Eq. 1}$$

Volume change can be caused by two phenomena:

1. Lung units which at a certain moment are open and subjected to the airway pressure will be further distended by an increase in pressure. The volume change caused by such distension, ΔV_{dist}, is a continuous process under an increasing pressure. The degree of distension will, however, be less at higher pressures because of stiffening of the lung [26].
2. Lung units which are collapsed open up when they are subjected to a sufficient airway pressure. This can be observed in operating theatres when a collapsed lung is re-aerated. More and more lung units literally "pop open" until the lung is completely expanded. The volume change related to the opening of collapsed lung units is denoted ΔV_{recr}. Accordingly:

$$C = \frac{\Delta V}{\Delta P} = \frac{\Delta V_{dist} + \Delta V_{recr}}{\Delta P} \qquad \text{Eq. 2}$$

Both ΔV_{dist} and ΔV_{recr} contribute to the value of compliance. Both factors therefore affect the shape of P/V curves, as will be discussed further.

Our data permit a partial analysis of the reasons behind the complexity of the observed P/V curves. The first segment, with a pressure from 0 to about

5–10 cmH_2O, showed an increasing compliance. This might reflect recruitment of collapsed lung units, in analogy with the concept of the lower inflection point [1, 3, 4, 12]. However, as discussed below, alveolar recruitment is probably occurring as a separate phenomenon at higher pressures. The initial increase in compliance may therefore represent the opening of closed airways. It may also be due to a non-constant thoracic compliance, as observed in man [27, 28]. The first and the second P_{dyn}/V curves as well as the P_{st}/V curve showed similar features over this first segment, which is compatible with either of these two explanations.

In the second P_{dyn}/V curve and the P_{st}/V curve the segment above 5–10 cmH_2O showed a mainly steadily decreasing compliance in both the supine and lateral positions at ZEEP as well as at PEEP. This observation is in line with the well-known stiffening of the lung at increasing distending pressure [26]. However, the uppermost segment of the second P_{dyn}/V curve and the P_{st}/V curve do not show a continuously decreasing compliance.

The 1st P_{dyn}/V recordings from ZEEP showed a distinctly different pattern. From a pressure of about 5 cmH_2O to about 15–20 cmH_2O compliance was lower than in the second recording (Fig. 3). This indicates that fewer lung units contributed to ΔV_{dist} because they were collapsed. Then, within the approximate pressure interval between 20 and 35 cmH_2O, compliance was higher during the first recording. Volume contribution related to recruitment, i.e. ΔV_{recr}, is the only conceivable cause for these higher values of compliance. Over the pressure interval from 25 to 35 cmH_2O, the volume deficit of the 1st P_{dyn}/V curve, compared to the 2nd one, combined with the higher compliance of the first curve indicate that recruitment is ongoing. Such high opening pressures imply that the finally recruited lung units were rather firmly collapsed. Similarly, high opening pressures have been reported by Rothen et al. [29] in healthy anaesthetised humans studied with a CT technique. P_{dyn}/V curves recorded in healthy anaesthetised humans before a recruitment manoeuvre displayed volume deficits and higher compliance values than curves recorded after the recruitment manoeuvre within a pressure range approximately 10–30 cmH_2O [21].

The pronounced fall in compliance between 30 and 35 cmH_2O, observed in the 1st P_{dyn}/V recording, reflects that the rate of recruitment is decreasing. This lends support to the theoretical analyses of Hickling [24] and Jonson et al. [25] suggesting that "the upper inflection point" should not be regarded uncritically as a sign of overdistension.

During the 5 min between the large recruitment manoeuvre and the first recording at stage 1, the lung had partly collapsed. At the end of the first recording from ZEEP the lung was, as discussed, reasonably well recruited. During the 20 s interval between the 1st and 2nd P_{dyn}/V recordings, a similar collapse did not occur. The time during which the collapse leads to the observed complex 1st P_{dyn}/V curve can accordingly be determined between 20 s and 5 min. One should be aware that recruitment caused by a single insufflation at a constant and limited flow is probably less efficient than that achieved with a static long-lasting pressure, which is applied at conventional recruitment manoeuvres. The observation that the 2nd P_{dyn}/V curve and the P_{st}/V curve did not show a continuously decreasing compliance at the highest pressures may be a sign that some recruitment occurred over this segment in spite of the volume history, which incorporated deep insufflations.

In principle, human and porcine lungs behave similarly with respect to collapse and recruitment under anaesthesia. However, the features reflecting lung collapse and, during a following insufflation, a recruitment that continues up to high pressures appear much more pronounced in pigs. The lungs of a pig are extensively lobulated and without collateral ventilation [7]. In children softness of the chest wall, which provides poor support to the underlying lung, leads to an increased tendency of airway closure and lung collapse [30, 31]. Further studies are needed to clarify whether differences between previously reported P_{dyn}/V curves in adult humans and our results in pigs reflect differences between species and/or the limited stage of development of the pigs.

Stages in the lateral position were made since pilot studies in the supine position, which is rather abnormal for a pig, showed that the P_{dyn}/V curves were complex, as was confirmed in this study. However, similar findings in the lateral position show that the complexity of the curves was not due to position.

At PEEP, stage 3, the 1st P_{dyn}/V curve in comparison to the 2nd curve showed that compliance was lower in the early phase of insufflation and higher in the late phase (Table 3). However, the differences were much less than at stages 1 and 2. Accordingly, a PEEP of 4 cmH_2O reduced, but did not completely eliminate, the tendency to lung collapse. This is in line with previous observations [1, 32].

At a given pressure the P_{st}/V recording deviated more and more towards higher volumes, compared to the 2nd P_{dyn}/V curve (Fig. 2). This corresponds to higher C_{st} values compared to C_{dyn} values (Table 3). The higher volumes and larger values of compliance of the P_{st}/V curve might be caused by repeated insufflations during the P_{st}/V recording procedure. In order to investigate this further we analysed a large insufflation, from which the last point of a P_{st}/V curve was measured, in the same way as the P_{dyn}/V curves. Then we obtained a P_{dyn}/V curve identical to the 2nd P_{dyn}/V curve. Accordingly, recruitment during the P_{st}/V recording did not cause the difference between the 2nd P_{dyn}/V curve and the P_{st}/V curve. A fundamental difference between dynamic and static P/V curves is that the former, but not the latter, is affected by a viscoelastic pressure component [16].

Non-linear viscoelastic behaviour has been observed [11, 14]. Accordingly, the viscoelastic pressure increases disproportionately at high lung volumes and distending pressures. Our observations are in line with the suggestions by Servillo et al. [4] that differences between P_{st}/V curves and P_{dyn}/V curves reflect viscoelastance [12]. However, it is also possible that repeated lung distension during the recording of the P_{st}/V curve might have led to a more complete recruitment than the single insufflation preceding the 2nd P_{dyn}/V curve.

In summary, young pigs showed a complex non-linear P/V behaviour of the respiratory system mainly reflecting a strong tendency to collapse. The application of PEEP provided only partial protection.

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