Physiol. Res. 46: 271–278, 1997

Changes in Parameters of Mechanics of Breathing During High-Frequency Jet Ventilation: What is the Cause ?

A. ČALKOVSKÁ, K. JAVORKA, M. PETRÁŠKOVÁ, I. LAUČOKOVÁ-MIŠÍKOVÁ, A. DRGOVÁ[1], M. GÁL

Department of Physiology and [1]Department of Biochemistry, Jessenius Medical Faculty, Comenius University, Martin, Slovak Republic

Received July 3, 1996
Accepted February 2, 1997

Summary

In experiments on 51 healthy anaesthetized and paralyzed rabbits the changes in parameters of mechanics of breathing during high frequency jet ventilation (HFJV) were determined and the mechanisms responsible for these changes were investigated. In the first series of experiments with two groups of animals ventilated by HFJV with relative inspiratory time ti=0.5 and ti=0.7 airway resistance (Raw) after 5 h of HFJV in the ti=0.5 group increased from 1.14±0.05 to 2.31±0.09 kPa.l^{-1}.s (P≤0.001), in the ti=0.7 group from 1.22±0.04 to 1.78±0.08 kPa.l^{-1}.s (P≤0.01). Dynamic compliance (Cdyn) decreased in the ti=0.5 group from 0.041±0.004 to 0.017±0.001 l.kPa^{-1} (P≤0.01) and in the ti=0.7 group from 0.034±0.003 to 0.022±0.002 l.kPa^{-1} (P≤0.01). In the second series of experiments a group of animals was ventilated by HFJV after cervical vagotomy. The deterioration of Raw and Cdyn was significantly reduced in vagotomized rabbits in comparison to the controls without vagotomy. Finally, the study of phospholipid content in bronchoalveolar lavage fluid revealed no significant differences after 5 h of artificial ventilation or spontaneous breathing. These data indicate that HFJV results in changes in the parameters of mechanics of breathing in healthy lungs, which may be attenuated, but not fully eliminated, by bilateral cervical vagotomy. The decrease in Cdyn and increase in Raw are probably not due to changes in the pulmonary surfactant content.

Key words
High frequency jet ventilation – Mechanics of breathing – Vagotomy – Pulmonary surfactant

Introduction

Artificial ventilation may evoke changes in the mechanics of breathing and impair the exchange of the gases (Bos and Lachmann 1991). During high-frequency jet ventilation (HFJV), small tidal volumes are applied into the lungs at high kinetic energy and high frequency. HFJV is accompanied by dynamic positive end-expiratory pressure (PEEP) depending on mechanical properties of the respiratory system as well as on the parameters of ventilation. All these events together with others yet unknown, can evoke changes in the mechanics of breathing.

The response of mechanics of breathing to conventional (intermittent positive pressure) ventilation were studied mainly in patients with lung disorders, e.g. with adult respiratory distress syndrome (Putensen *et al.* 1991). Effects of HFJV on the mechanical properties of the respiratory system is difficult to estimate because of the typical features of HFJV as compared to conventional ventilation.

The present study was aimed to evaluate the changes in mechanics of breathing (airway resistance, Raw and dynamic compliance, Cdyn) during HFJV using a new computer-assisted method of lung function measurements based on a special algorithm for the calculation of parameters of pulmonary mechanics and for investigation of the mechanisms responsible for the development of these changes.

Since the vagus nerve represents the main afferent pathway from receptors in the airways and lungs and also supplies important motor inervation of

smooth muscles and mucous glands in the airways (Gabella,1989), we also searched for changes in mechanics of breathing during HFJV before and after bilateral vagotomy.

Information concerning the influence of artificial ventilation on pulmonary surfactant is controversial owing to the variety of subjects studied and the methods employed. Thus the question if the changes in Cdyn and Raw in healthy rabbits could be caused by changes in pulmonary surfactant due to adverse effects of HFJV is of considerable importance.

Material and Methods

General design of experiments

The study was arranged in three steps. In the first part, we evaluated the changes of Raw and Cdyn during HFJV using two different relative inspiratory times ti=0.5 and ti=0.7. The ti represents the relative duration of the inspiratory phase with regard to the length of each single respiratory cycle, which is considered to be 1. After that, we searched for the reflex mechanism of these changes by performing bilateral cervical vagotomy in a group of animals which were ventilated for 3 hours, since the most marked changes of Raw and Cdyn were seen during the first 180 minutes. Finally, the pulmonary content of phospholipids was assessed in bronchoalveolar lavage fluid of the HFJV groups (ti=0.5 and 0.7) and in a spontaneously breathing group (controls).

The experiments were carried out on 51 rabbits (chinchilla), mean body weight 2.84±0.06 kg, anaesthetized with Pentobarbital Spofa (induction dose 40 mg/kg i.v., maintenance dose 15 mg/kg/h) and paralyzed (with the exception of spontaneously breathing animals) with Arduan (Gedeon Richter A.G., Hungary, in a dose 0.3 mg/kg/30 min i.v) or Tricuran (Rodleben, Germany, in a dose 0.5 mg/kg/30 min i.v.). All animals were tracheotomized. Femoral arterial and venous catheters were introduced for monitoring of systemic blood pressure by means of an electromanometer LDP-102 (Tesla, Valašské Meziříčí), for withdrawal of arterial blood and for administering anaesthetics and muscle relaxants when necessary. Arterial PO_2, PCO_2 and pH were measured by a blood gas analyser BMS-3 (Radiometer, Copenhagen, Denmark) at 30 min intervals. In a group of 8 rabbits, bilateral cervical vagotomy was performed before the beginning of artificial ventilation.The controls were sham-operated with intact vagus nerves. All animals were ventilated with (or breathed spontaneously) humidified and warmed room air for 3 or 5 hours. Body temperature of the animals was maintained by a heating pad.

High-frequency ventilation (HFV)

Rabbits were ventilated by means of a high-frequency jet ventilator Beat-2 (Chirana, Stará Turá). The frequency of ventilation was 150/min, relative inspiratory time 0.5 or 0.7, respectively. The value of insufflation pressure (Pin) varied from 80 to 120 kPa and tidal volume (V_T) from 12 to 20 ml. Such a ventilatory mode was chosen to keep the value of $PaCO_2$ within the physiological range for anaesthetized rabbits (2.6–4.3 kPa) (Šmejkal and Paleček 1973).

Lung function measurements

Tracheal airflow was recorded with a heated Fleisch head connected to the pneumotachograph (ÚMMT SAV, Bratislava) in all artificially ventilated animals. Tracheal pressure in HFJ ventilated groups was registered *via* a pneumatic catheter (internal diameter 0.7 mm, external 1.1 mm) placed 0.5 cm below the distal tip of the tracheal tube. Its open passage was maintained by pneumatic air flushing during every other ventilatory cycle. Tracheal pressure and airflow values were delivered *via* a memory oscilloscope Tectronix 5223 (USA) and a double-channel A/D transducer to the PC AT computer. The use of software for continuous evaluation of 20 ventilatory parameters and parameters of mechanics of breathing during HFJV (Burle *et al.* 1991) made it possible to insert all measured and calculated parameters into the memory of the computer and their off-line assessment at the end of the experiment. The method of computing of ventilatory parameters and parameters of pulmonary mechanics during HFJV is based on the equation of the mean intratracheal pressure (P_T) and mean alveolar pressure (P_A). This fact can be explained as follows: inspiratory volume (V_{Ai}) in the cycle into the alveolar space is identical with the single expiratory volume (V_{Ae}).

Single volumes VAi and VAe can be expressed by means of total airway resistance (Raw) as

$$V_{Ai} = V_{Ae} = \frac{P_{Ti} - P_{Ai}}{Raw} T_i = \frac{P_{Ae} - P_{Te}}{Raw} T_e \quad (1),$$

where P_{Ti}, P_{Te} are the mean tracheal pressures on inspiration and expiration, P_{Ai}, P_{Ae} are the mean pressures in the alveolar space during inspiration and expiration, T_i, T_e are the inspiratory and expiratory times.

Supposing that the frequency of ventilation is higher than 100 min^{-1}, the dynamic courses of pressure in the alveolar space – which is in fact exponential – can be replaced by linear time courses. The mean alveolar inspiratory pressure (P_{Ai}) will thus equal mean alveolar expiratory pressure (P_{Ae}), i.e. $P_{Ai}=P_{Ae}=P_A$.

Substitution of the mean value of alveolar pressure P_A into the equation (1) can be expressed as the equation for the mean alveolar pressure

$$P_A = \frac{1}{T_i + T_e}.(T_iP_{Ti} + T_eP_{Te}) \quad (2),$$

which is identical with the equation for mean pressure in the tracheal space (P_T). Thus, $P_A = P_T$ expresses the equality of mean pressures in the tracheal and alveolar spaces during HFJV (Pérez Fontán *et al.* 1986).

This hypothesis has been based on the physical HFJ ventilator model and on a simplified lung model, where the circulating gas volumes are expressed as the product of the mean flows and the inspiratory and expiratory time phases. The mean flows are determined by means of the average pressure differences acting on the linear flow resistances in the model.

Airway resistance (Raw) and dynamic compliance ($Cdyn = \delta V/\delta P_A$) were evaluated in HFJ ventilated animals at the beginning of the experiment, in vagotomized animals 10 min after vagotomy and then every 30 min throughout the experiment.

Bronchoalveolar lavage (BAL)

In some animals, BAL was performed on the open chest after an overdose of anaesthetics. Saline (0.9 %) was instilled into the lungs *via* the tracheal cannula at room temperature in a volume of 28 ml/kg b.w. according to Pettenazzo *et al.* (1988). This volume was washed in and out three times and the procedure was then repeated four times. The total volume was recorded and the lavage fluid was stored at −20 °C before analysis. Lipids were extracted by the isolation method of Bligh and Dyer (1959).The total phospholipid content was determined in the lipid extract (Lowry and Lopez 1946).

Surface tension measurement

The surface tension was measured by a modified tensiometric method at 20 °C described by Du Nouy (1919).

Statistics

All data are given as the mean ± S.E.M. Student's t-test was used to assess the significance of differences.

Results

Values of body weight, pH and blood gases of all groups are summarized in Table 1.

Changes in mechanics of breathing during HFJV

The data were obtained in 12 rabbits. Animals ventilated by HFJV were divided into two groups – HFJV with ti = 0.5 and ti = 0.7 with 6 rabbits in each.

Insufflation pressure needed to keep normocapnia and normoxia was 68.8 ± 3.2 kPa in the ti = 0.5 group and 73.8 ± 4.7 kPa in the ti = 0.7 group (not significantly different).

Values of minimum (Pmin) and maximum (Pmax) tracheal pressures in ti = 0.5 and ti = 0.7 groups at the beginning (B) and at the end (E) of ventilation are given in Table 2.

Table 1. Body weight, partial arterial pressure of oxygen (PaO_2), carbon dioxide (PaO_2) and pH in all groups.

No	Group	n	Body weight (kg)	PaO_2 (kPa)	$PaCO_2$ (kPa)	pH
1	HFJV – 5 h ti = 0.5	6	2.78 ± 0.05	8.95 ± 0.42	3.52 ± 0.13	7.431 ± 0.026
2	HFJV – 5 h ti = 0.7	6	2.80 ± 0.18	8.70 ± 0.33	3.48 ± 0.05	7.462 ± 0.016
3	HFJV – 3 h No vagotomy	6	2.78 ± 0.05	9.23 ± 0.35	3.37 ± 0.09	7.422 ± 0.023
4	HFJV – 3 h Vagotomized	8	2.94 ± 0.24	8.73 ± 0.23	3.19 ± 0.14	7.417 ± 0.026
5	HFJV – 5 h ti = 0.5, BAL	14	2.90 ± 0.08	8.95 ± 0.32	3.22 ± 0.11	7.459 ± 0.019
6	HFJV – 5 h ti = 0.7, BAL	15	2.85 ± 0.08	9.18 ± 0.41	3.26 ± 0.10	7.458 ± 0.019
7	Spontaneous breathing – 5 hBAL	14	2.73 ± 0.15	9.14 ± 0.29	3.13 ± 0.10	7.462 ± 0.013

Values are means ± S.E.M., n – number of animals. No significant differences were present.

Table 2. Minimum (Pmin) and maximum (Pmax) tracheal pressures at the beginning (B) and at the end (E) of the experiment

Group	Pmin (B)	Pmin (E)	Pmax (B)	Pmax (E)
ti = 0.5	0.042±0.016	0.011±0.007	0.506±0.021	0.615±0.039[c]
ti = 0.7	0.157±0.019[a]	0.183±0.040[b]	0.542±0.038	0.808±0.073[d]

Values (in kPa) are given as means ± S.E.M. Significant differences: [a]Pmin(B): ti=0.5 vs. ti=0.7, P<0.01, [b]Pmin (E): ti=0.5 vs. ti=0.7, P<0.001, [c]Pmax (B) vs. Pmax (E) in ti=0.5 and ti=0.7, both P<0.02.

Pmin (dynamic PEEP) did not change significantly during 5 h ventilation neither in the ti=0.5 nor in the ti=0.7 group. However, Pmin in the ti=0.7 group reached higher values at the beginning as well as at the end of ventilation (both P≤0.01) compared to the ti=0.5 group.

Pmax at the end of the experiment was higher than Pmax at the beginning of ventilation in both groups (P≤0.02 and P≤0.05, respectively). The value of Pmax(E) was significantly higher in the ti=0.7 than in ti=0.5 group (P≤0.05).

Airway resistance (Raw)

Changes in Raw in both groups during the experiments are shown in Fig. 1.

Raw significantly increased in both groups, already 30 min after beginning of the experiment, and continuously increased during four hours of ventilation. There was a trend to a moderate decrease of Raw within 4.5 to 5 h in comparison to the previous values which was not statistically significant. The changes in Raw in the ti=0.7 group were not as prominent as in the ti=0.5 group. After 90 min of ventilation, Raw was significantly higher in the ti=0.5 group during the whole period of ventilation when compared to the values of the ti=0.7 group.

After 5 h ventilation, Raw in the ti=0.5 group increased from 1.14±0.05 to 2.31±0.09 kPa.l^{-1}.s (P≤0.001), in the ti=0.7 group from 1.22±0.04 to 1.78±0.08 kPa.l^{-1}.s (P≤0.01).

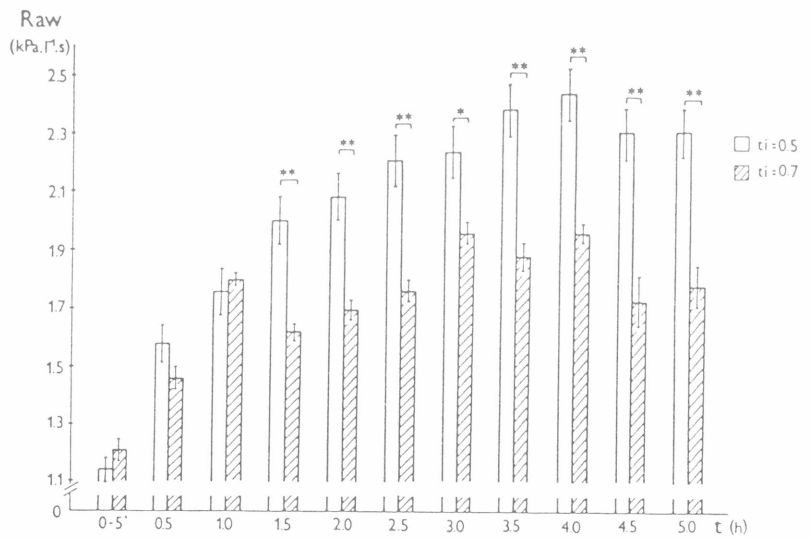

Fig. 1. *Values of airway resistance (Raw) during 5 h HFJV compared between ti=0.5 and ti=0.7 groups. * – P≤0.01, ** – P≤0.001.*

Dynamic compliance (Cdyn)

Changes of Cdyn in both groups during the experiment are shown in Figure 2.

There was a significant decrease in Cdyn already 30 min after the beginning of ventilation and this parameter reached lowest values in the ti=0.5 group during fourth hour of HFJV and did not decrease further. A significant decrease in Cdyn was also found in the ti=0.7 group. Statistically significant differences between Cdyn values in both groups were found after 1, 3, 4.5 and 5 h of ventilation.

After 5 h ventilation, Cdyn in the ti=0.5 group decreased from 0.041±0.004 to 0.017±0.001 l.kPa^{-1} (P≤0.01) and in the ti=0.7 group from 0.034±0.003 to 0.022±0.002 l.kPa^{-1} (P≤0.01).

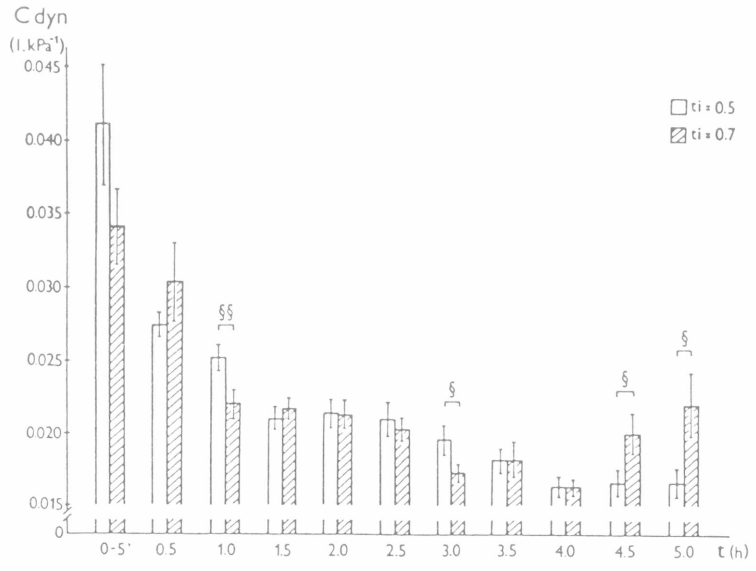

Fig. 2. *Values of dynamic compliance (Cdyn) during 5 h HFJV in ti = 0.5 and ti = 0.7 groups. § – P≤0.05, §§ – P≤0.02.*

Role of the vagus nerve in changes of breathing mechanics during HFJV

These experiments were performed on 14 rabbits. Eight rabbits were vagotomized and ventilated by HFJV for 3 h, six rabbits from previous experiments served as controls. The results were evaluated up to 3 h of ventilation.

Group without vagotomy (ti = 0.5)

Percentual changes of airway resistance (Raw) and dynamic compliance (Cdyn) at the beginning and at half-hours intervals are shown in Figures 3 and 4.

A significant increase in Raw and a decrease in Cdyn already occurred in the first 30 min on HFJV. The Raw gradually increased and Cdyn decreased till the end of the experiment. The most marked decrease in Cdyn was present during the first hour of ventilation. No further significant changes were noted subsequently.

Raw significantly increased from the initial value of 1.14 ± 0.05 to 2.24 ± 0.05 $kPa.l^{-1}.s$ at the end of 3 h ventilation, i.e. by 97.8 ± 14.4 % (P≤0.001). In the course of the experiment, Cdyn decreased from the initial value of 0.041 ± 0.004 to 0.020 ± 0.001 $l.kPa^{-1}$ (by 54.0 ± 5.2 %) (P≤0.001).

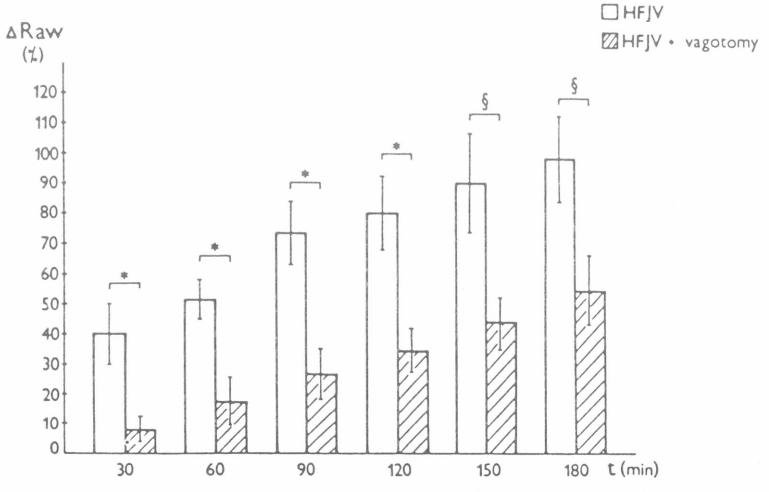

Fig. 3. *Percentage changes in airway resistance (δ Raw) during 3 h HFJV in groups with and without vagotomy. * – P≤0.01, § – P≤0.05.*

Group with vagotomy (ti = 0.5)

Percentual changes of Raw and Cdyn at various time intervals are shown in Figures 3 and 4.

Raw increased from 1.34 ± 0.05 to 1.92 ± 0.05 $kPa.l^{-1}.s$ (by 54.1 ± 11.5 %) (P≤0.001), while Cdyn decreased from 0.032 ± 0.002 to 0.020 ± 0.001 $l.kPa^{-1}$ (by 35.5 ± 5.0 %) (P≤0.001).

The deterioration of both parameters was significantly reduced in vagotomized rabbits in comparison to the controls (Figs 3 and 4).

Minimum (Pmin) and maximum (Pmax) tracheal pressure at the beginning (B) and at the end (E) of experiment

In the group without vagotomy Pmin(B) was 0.042±0.016 and Pmin(E) 0.018±0.002 kPa, Pmax(B) 0.506±0.021 and Pmax(E) 0.549±0.050 kPa. In the vagotomized group the corresponding value for Pmin(B) was 0.008±0.006, 0.003±0.002 kPa for Pmin(E), 0.549±0.028 for Pmax(B) and 0.628±0.018 kPa for Pmax(E). Pmin in the vagotomized group was significantly lower ($P \leq 0.05$) in comparison to the group without vagotomy.

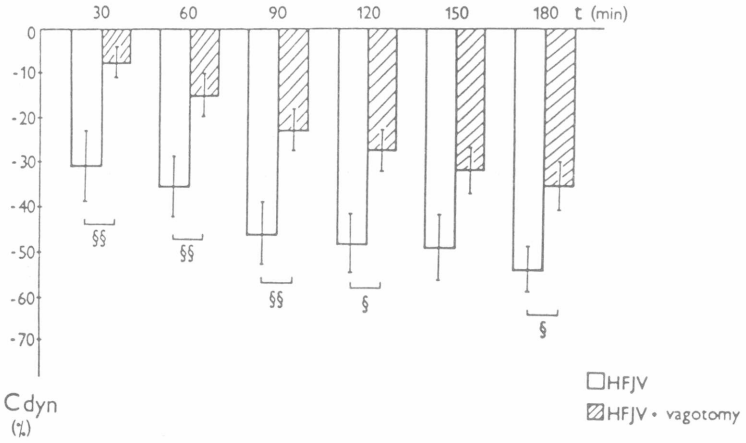

Fig. 4. *Percentage changes in dynamic compliance (δ Cdyn) during 3 h HFJV in group with and without vagotomy. §§ – P≤0.02, § – P≤0.05.*

Influence of HFJV on pulmonary phospholipids and surface tension of bronchoalveolar lavage fluid

Data were obtained from 43 rabbits in three groups: 1) HFJV, ti=0.5 (n=14), 2) HFJV, ti=0.7 (n=15), including the data on 12 rabbits (6+6) from pilot experiments and, 3) animals breathing spontaneously (n=14).

Phospholipid content and surface tension

The values of phospholipids and surface tension of the BAL fluid are shown in Table 3. No statistically significant differences were found either in the phospholipid content or in the surface activity of the BAL fluid.

Mechanics of breathing during HFJV in groups lavaged

As was to be expected from previous experiments, the mechanics of breathing also changed in the BAL groups during HFJV. Raw significantly increased after 5 h in the ti=0.5 group from 1.25±0.11 to 2.53±0.24 kPa.l^{-1}.s (by 103.4 %) ($P \leq 0.001$), while the increase in the ti=0.7 group from 1.53±0.10 to 1.87±0.09 kPa.l^{-1}.s (by 22.3 %) was not significant.

Cdyn significantly decreased in the ti=0.5 group from 0.03±0.003 to 0.015±0.001 l.kPa^{-1} (by 54.5 %) ($P \leq 0.001$) and from 0.023±0.002 to 0.015±0.001 in the ti=0.7 group (by 34.8 %) ($P \leq 0.02$).

In spontaneously breathing animals the parameters of mechanics of breathing were not investigated for technical reasons.

Table 3. Phospholipids content and surface tension of BAL fluid after HFJV with ti=0.5, ti=0.7 and after spontaneous breathing (control)

	HFJV (ti=0.5)	HFJV (ti=0.7)	Control
Phospholipids (μg/ml BAL)	65.8±3.7	53.0±4.5	57.2±2.9
Surface tension (mN/m)	50.3±0.8	51.5±0.8	49.7± 0.5

Values are given as means ± S.E.M. No significant differences were found between groups.

Discussion

The aim of this study was to investigate the changes in parameters of breathing mechanics (Raw and Cdyn) during high frequency jet ventilation (HFJV) in healthy rabbits, using a new method of computer-assisted lung function measurements. To analyse the mechanisms of possible changes, we

blocked the afferent and efferent vagal innervation by bilateral cervical vagotomy, and performed bronchoalveolar lavage (BAL) for surfactant phospholipid determination after 5 h HFJV.

The decrease in Cdyn and increase in Raw accompanying HFJV in healthy lungs are very likely the result of a complex mechanism. There is a lack of information in the literature concerning pulmonary mechanics during HFJV. Several authors showed a gradual decrease in lung compliance and concluded that the mechanisms of these changes remain unclear (Weinman *et al.* 1984, Wetzel and Gioia 1987).

The explanation should include a discussion on reflex mechanisms, alterations in the distribution of ventilation, in pulmonary circulation as well as on possible pulmonary surfactant changes.

More is known about changes in smooth muscle tone of the airways during high-frequency oscillatory ventilation (HFOV). Man *et al.* (1990) investigated the reflex changes in tracheal smooth muscle tension in anaesthetized dogs during HFOV and IPPV with or without PEEP. These authors reported relaxation of tracheal smooth musculature and a reduction of upper airway resistance (above the tracheostomy) during HFOV.

Not only slowly adapting pulmonary stretch receptors (SARs) but also receptors sensitive to rapid changes in lung volume – rapidly adapting irritant receptors (RARs) are stimulated by HFJV and HFOV (Wozniak *et al.* 1983, Kohl and Koller 1984). Davies *et al.* (1988) reported enhanced excitability of RARs in rabbits during high frequency ventilation. The increased activity of RARs could result in reflex bronchoconstriction as well as in facilitation of mucus production and in a gradual rise of airway resistance. Both the above mentioned mechanisms – reflex bronchoconstriction and enhanced mucus secretion from submucous glands of airways could have a deleterious effect on the parameters of breathing mechanics in healthy rabbits in our experiments.

In our study, HFJV was performed using two ventilatory modes differentiated only in their relative inspiratory time (ti). One group was ventilated by ti=0.5 – a neutral regime, second group by ti=0.7 – an expulsion regime. During the expulsion regime, there is a predominance of kinetic energy transporting mobile material in the direction from bronchoalveolar compartment (Brychta *et al.* 1985). The question is why the deterioration in parameters of the mechanics of breathing (mainly Raw) was more prominent in ti=0.5 group in comparison to ti=0.7 group during 5 h of HFJV. The ventilatory mode with a shorter expiratory time – ti=0.7 (Te=30 %) probably generates higher PEEP in the airways in comparison to the ti=0.5 group (Te=50 %). This may be inferred from the higher values of minimum tracheal pressure in ti=0.7 in comparison to ti=0.5 group ($P \leq 0.01$) (see Table 2) at comparable levels of insufflation pressure (Pin). This dynamic PEEP probably pneumaticaly stabilizes airways and reduces changes of their diameter in HFJV with ti=0.7.

A certain role in the decrease of Cdyn and increase of Raw may also be played by changes in the distribution of ventilation. From previous experiments, we know that the distribution of the suspension of silica particles in the lungs of rabbits after instillation by HFJV is not homogeneous. The results indicated the highest percentage of silica particles in the ventral part of the parahilar area and in the dorsal part, usualy on the left, which is in accordance with other authors (Yamada *et al.* 1989). Another physical feature of the suspension, in comparison with that of gas, does not allow us to make definite conclusions about the distribution of ventilation during HFJV, but our findings seem to support the hypothesis about the inhomogeneity of distribution of ventilation during HFJV.

The changes in pulmonary circulation may play a role in the decrease in Cdyn and the increase in Raw. However, they have not been investigated in our study. In general, HFV does not appear to alter regional lung perfusion significantly (Wetzel and Gioia 1987).

The mechanics of breathing were deteriorated during HFJV also in BAL study likewise in our pilot experiments. The dynamic compliance was significantly reduced after 5 h-lasting HFJV in spite of the fact that surface activity and phospholipids content in BAL fluid remained unchanged. This suggests that the changes of surfactant concentration do not play a significant role in Cdyn and Raw deterioration during HFJV. We found that the phospholipid content in BAL after HFJV at ti=0.7 did not differ from values after HFJV at ti=0.5 and in the controls. The results indicate that HFJV, even with its expulsion regime (see above), has no impact on the surfactant phospholipid content in the BAL fluid of healthy adult rabbits.

Our results are in agreement with the study of Frantz III. *et al.* (1982) in healthy cats ventilated at 12 Hz frequency and in adult rats ventilated by HF oscillations (Ward and Nicholas 1992) which contradict the results of Solimano *et al.* (1985). The latter authors found a decrease in surfactant secretion and stimulation of its reuptake in premature lambs. In this case, the difference between "adult" and "newborn or immature" surfactant metabolism could play a certain role.

The improvement of the mechanics of breathing after vagotomy supports the notion that the parasympathetic autonomic nervous system is partially responsible for this, however, not by interfering with surfactant metabolism.

We conclude that normocapnic 5 h-lasting HFJV has a deleterious effect upon the mechanics of breathing (Cdyn and Raw) in healthy lungs. The extent of these changes becomes differentiated owing to the

relative inspiratory time. Bilateral cervical vagotomy reduced but did not fully eliminate these changes and the parasympathetic autonomic nervous system therefore probably plays a role in the origin of these changes. HFJV at ti=0.5 and ti=0.7 did not cause changes either in surfactant phospholipid content or in surface tension of BAL fluid. Deterioration of Cdyn and Raw is probably not due to an impairment of the pulmonary surfactant system.

References

BLIGH E.G., DYER W.J.: A rapid method of total lipid extraction and purification. *Can. J. Biochem. Physiol.* **37:** 911–917, 1959.

BOS J., LACHMANN B.: Surfactant function: is it influenced by artificial ventilation? In: *The Surfactant System of the Lung.* E.V. COSMI, G.C. DI RENZO, M.M. ANCESCHI (eds), Houndmills, Macmillan Press, 1991, pp. 96–106.

BRYCHTA O., POKORNÝ J., ZABRODSKÝ V.: Expulsion effect of high-frequency jet ventilation. *Eur. J. Anesthesiol.* **2:** 2, 1985.

BURLE J., BRYCHTA O., JURČEK M., VRANKA V.: Computer assissted lung function measurement during high-frequency jet ventilation (HFJV). *Proc. 4th Int. Cong. "Fetal and Neonatal Physiological Measurements"*, Rotterdam, 1991.

DAVIES A., DUTIA M.B., PRICE R.F.: The effect of high-frequency ventilation on pattern of breathing of anaesthetized rabbits. *Q. J. Exp. Physiol.* **73:** 353–361, 1988.

DU NOUY P.L.: A new apparatus for measuring surface tension. *J. Gen. Physiol.* **1:** 521, 1919.

FRANTZ III. I.D., STARK A.R., DAVIS J.M., DAVIES P., KITZMILLER T.J.: High-frequency ventilation does not affect pulmonary surfactant, liquid, or morphologic features in normal cats. *Am. Rev. Resp. Dis.* **126:** 909–913, 1982.

GABELLA G.: Structure of airway smooth muscle and its innervation. In: *Airway Smooth Muscle in Health and Disease*, R.F. COBURN (ed.), New York, Plenum Press, 1989, pp. 1–16.

KOHL J., KOLLER E.A.: Breathing pattern and stretch receptor activity during high frequency ventilation. *Pflügers Arch.* **402:** 150–156, 1984.

LOWRY O.H., LOPEZ J.A.: The determination of inorganic phosphate in the presence of labile phosphate esters. *J. Biol. Chem.* **162:** 421–428, 1946.

MAN G.C.W., TEO K.K., KAPPAGODA C.T., MAN S.F.P.: Reflex changes in tracheal smooth muscle tone during high-frequency oscillation. *J. Appl. Physiol.* **68:** 714–719, 1990.

PERÉZ FONTÁN J.J., HELDT G.P., GREGORY G.A.: Mean airway pressure and mean alveolar pressure during high-frequency jet ventilation in rabbits. *J. Appl. Physiol.* **61:** 456–463, 1986.

PETTENAZZO A., IKEGAMI M., SEIDNER S., JOBE A.: Clearance of surfactant phosphatidylcholine from adult rabbits lungs. *J. Appl. Physiol.* **64:** 120–127, 1988.

PUTENSEN Ch., BAUM M., HORMAN Ch., LINGUAN W.: An automated determination of the pressure volume relation of the lungs as a guide for the respiratory adjustment during controlled mechanical ventilation. *Eur. Resp. J.* **14**(Suppl): p. 316. 1991.

SOLIMANO A., BRYAN C., JOBE A., IKEGAMI M., JACOBS H.: Effects of high-frequency and conventional ventilation on the premature lamb lung. *J. Appl. Physiol.* **59:** 1571–1577, 1985.

ŠMEJKAL V., PALEČEK F.: Values of blood gases in awake rabbits (in Czech), *Čs. Fysiol.* **22:** 339–343, 1973.

WARD H.E., NICHOLAS T.E.: Effect of artificial ventilation and anaesthesia on surfactant turnover in rats. *Respir. Physiol.* **87:** 115–129, 1992.

WEINMANN G.G., SIMON B.A., MITZNER W.: Lung compliance changes on high frequency ventilation in normal dogs. *J. Appl. Physiol.* **56:** 506–512, 1984.

WETZEL R.C., GIOIA F.R.: High frequency ventilation. *Pediat. Clin. N. Amer.* **34:** 15–38, 1987.

WOZNIAK J.A., DAVENPORT P.W., KOSCH P.C.: The response of pulmonary afferents to high frequency oscillatory ventilation. *Fed. Proc.* **42:** 4240, 1983.

YAMADA Y., BURNHAM C., HALES C.A., VENEGAS J.G.: Regional mapping of gas transport during high-frequency and conventional ventilation. *J. Appl. Physiol.* **66:** 1209–1218, 1989.

Reprint requests

A. Čalkovská, MD, PhD, Department of Physiology, Jessenius Medical Faculty, Comenius University, Malá Hora 4, 037 54 Martin, Slovak Republic.