Effect of High-Frequency Jet Ventilation on the Pulmonary and Systemic Circulation

N. V. Sanotskaya, M. A. Vyzhigina, D. D. Matsievskii, M. V. Luk'yanov, and S. O. Aleinikov

UDC 615.816.2.015.4:616.24-005].07

Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 116, № 9, pp. 239-241, September, 1993
Original article submitted February 19, 1993

Key Words: *high-frequency artificial lung ventilation; pulmonary circulation; systemic circulation, ultrasound*

At present, a new type of artificial lung ventilation, high-frequency jet ventilation (HFJV), is being successfully employed in anesthesiology and resuscitation. Despite a large body of clinical observations [1,2,4,6,14] and experimental studies [11,12] the mechanisms of the effect of HFJV on the cardiovascular system and the interrelations between the pulmonary and systemic circulation systems under these conditions are poorly understood. Investigations of the effect of HFJV on the pulmonary circulation are scant [5,15].

The purpose of the present study was to investigate the functioning of the right and left heart, pulmonary and systemic circulation, and lung microcirculation for the conversion from traditional artificial lung ventilation (ALV) to HFJV.

MATERIALS AND METHODS

In acute experiments on 22 male cats weighing 2.8-3.2 kg narcotized with nembutal (30-40 mg/kg intraperitoneally) the linear and volumetric blood flow rates in the ascending aorta and pulmonary conus were studied using ultrasound technique [8]. The balance between the right and left ventricular outputs was estimated with an analog computer as the ratio of the mean flow rate in the pulmonary conus to that in the ascending aorta. Blood pressure (BP) in the pulmonary and femoral arteries was measured with a micromanometer. The experiments were performed on the open chest. After the chest was opened in the 4th intercostal space, the animals were put on ALV, transducers were placed on the aorta and the common carotid artery, and measurements were carried out during 30 min, after which the animals were transferred to HFJV. Traditional ALV was effected with a DAM-EPN-2 apparatus for experimental animals, the inhaled oxygen fraction being 30-40% (F_i=0.3-0.4). The ventilation mode was as follows: 50-80 ml respiratory volume, 1.100-2.100 liters/min minute respiratory volume (MRV), and 15-21 min^{-1} breathing rate. HFJV was carried out with a Spiron-601 apparatus using the following operation mode: 100 min^{-1} breathing rate, 1:2 inspiration to expiration ratio, MRV=1.900-2.500 liters/min, and F_i=0.8-0.9. In both ventilation modes the pressure in the trachea was determined in mm H_2O with a needle manometer via a narrow catheter inserted in the trachea to the bifurcation. HFJV was adapted to the cat's MRV by adjusting the effective pressure in the Spiron-601 apparatus. The microcirculation in the lungs was studied using a modified biomicroscopic technique [7]. The capillary perfusion

Laboratory of Pathophysiology of Respiration and Laboratory of Bioengineering, Institute of General Pathology and Pathophysiology, Russian Academy of Medical Sciences. (Presented by M. I. Perel'man, Member of the Russian Academy of Medical Sciences)

0007-4888/93/0009-1059$12.50

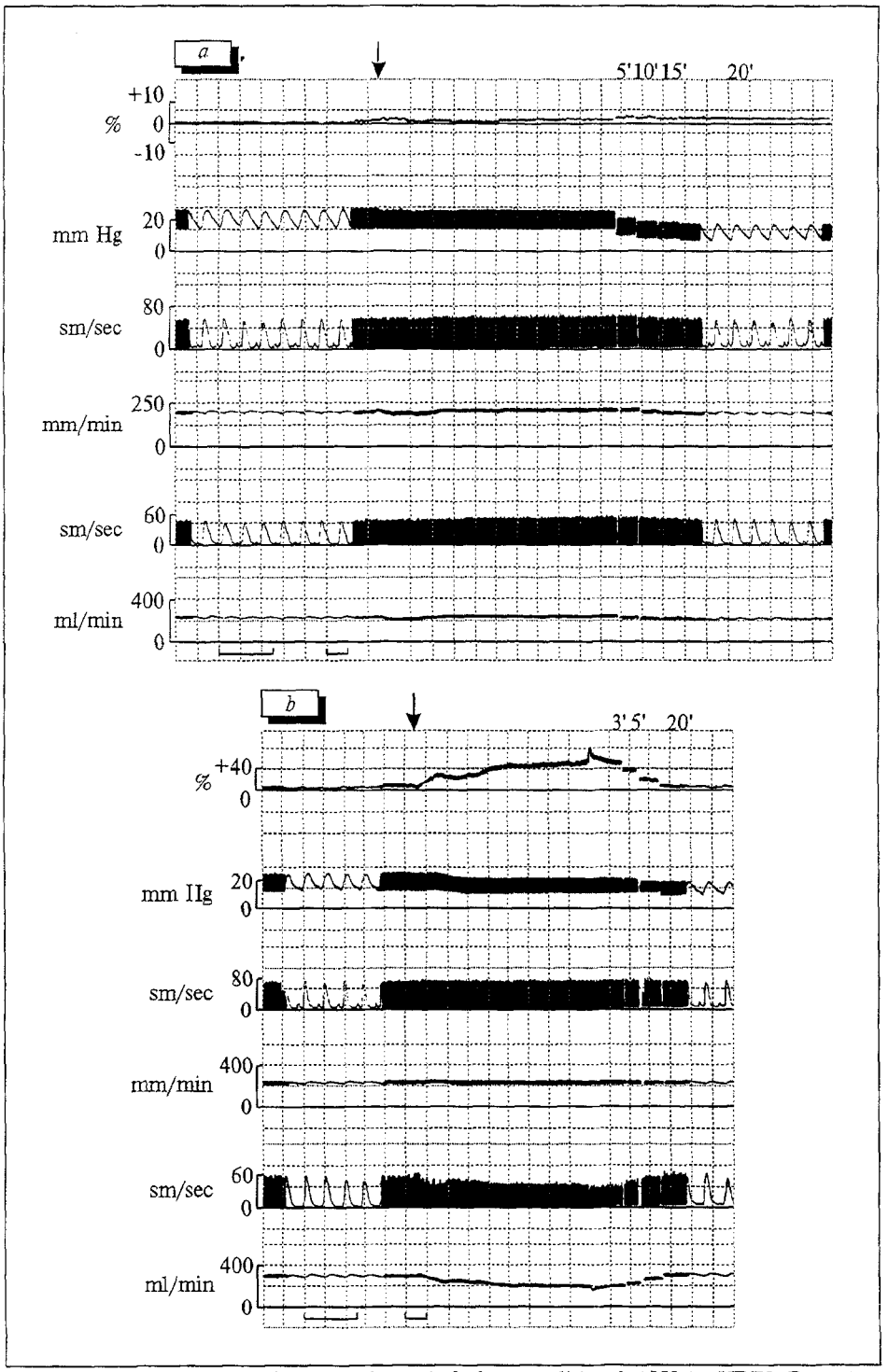

Fig. 1. Changes in hemodynamics for switch from traditional ALV to HFJV. From top down: balance between outputs of left and right ventricle, rel. units (curve rise corresponds to increase in ascending aorta vs. pulmonary conus); BP in pulmonary artery, mm Hg; linear blood flow rate in ascending aorta, cm/sec; volumetric blood flow rate in ascending aorta, ml/min; linear blood flow rate in pulmonary conus, cm/sec; volumetric blood flow rate in pulmonary conus, ml/min; thin lines under each curve show the baseline; arrow: switch from traditional ALV to HFJV; time scale: 1 and 10 sec; figures in upper part: time (min) from beginning of HFJV.

index (CPI) was calculated as the total length of blood-perfused alveolar capillaries per 10,000 μ^2 of lung area.

For evaluation of the parameters of the systemic circulation (stroke and cardiac indexes, stroke volume, left ventricular output, left-ventricle pumping coefficient, total peripheral resistance) the values of cardiac output to the aorta and the systemic BP were used and, respectively, cardiac output to the pulmonary artery and the pulmonary BP for evaluation of the parameters of the pulmonary circulation (stroke and cardiac indexes, stroke volume, total pulmonary resistance, arteriolar pulmonary resistance). The formula for calculating the microvascular pressure (MP), as well as the formulas for the pre- and postcapillary resistance were taken from the literature [3,10]. Statistical processing of the results was performed with a PDP 11/34 computer (USA) using the Student *t* test for paired populations.

RESULTS

After the animals went from traditional AVL to HFJV, a reliable 44% drop of BP ($p<0.05$) in the pulmonary artery was observed (Figs. 1 and 2, *a*). The MP also dropped by 46.34% in comparison with traditional ALV. The drop of BP in the pulmonary artery is largely due to a decrease of the total vascular resistance in the pulmonary circulation (Fig. 2, *b*). The vascular walls adjacent to alveoles are known to contribute approximately 50% to the total vascular resistance [13], their deformation being dependent on the peak pressure in the airways, which accounts for 1.8-2.5 cm H_2O and 9-10 cm H_2O during HFJV and traditional ALV, respectively. The drop of the total vascular resistance by 36.13%, of the pre- and postcapillary

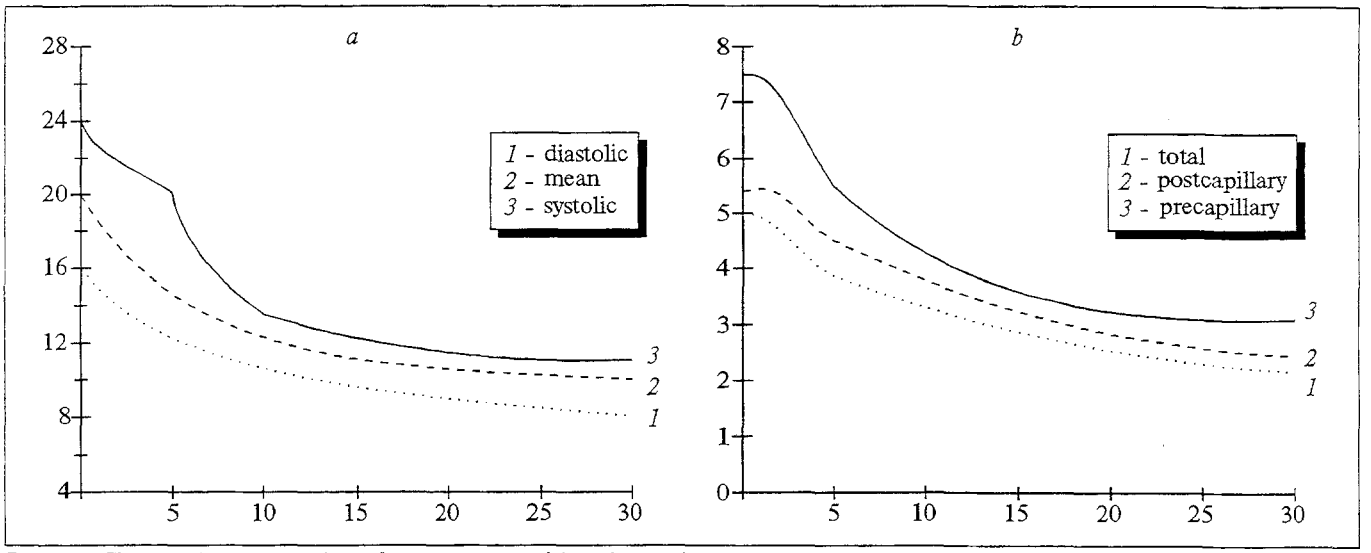

Fig. 2. Changes in pressure in pulmonary artery (*a*) and vascular resistance in system of pulmonary artery (*b*) for switch from traditional ALV to HFJV. Asterisk: $p<0.05$ in comparison with the initial value.

resistance by 28.88% and 31.2%, respectively, as well as the drop of BP in the pulmonary artery reduces the load on the right ventricle. The stroke work of the right ventricle under conditions of HFJV decreased from 0.41±0.2 to 0.19±0.001 kg×m/m^2, which constituted 46% of the initial value (traditional ALV) (Fig. 3, *a*). The decreased load on the right ventricle was due mainly to a drop of BP in the pulmonary artery. The reduced stroke work of the right ventricle led to a decreased volumetric blood flow in the pulmonary artery by 13.35% on average (Fig. 3, *b*), although the linear flow rate remained unchanged in the majority of the experiments. The 15% reduction of the stroke work of the left ventricle reflects a compensatory reaction of the systemic circulation directed toward the maintenance of the hemodynamic balance between the systemic and pulmonary circulation. In healthy animals the outputs of the right and left ventricle are balanced. Under traditional ALV we observed a slight redistribution of the blood flow to the pulmonary circulation by 0.4±0.08%, whereas under HFJV the flow redistribution, 1.8±0.04% on average, was directed to the systemic circulation. Although the degree and dynamics of these changes varied in different experiments, the above tendency was evident in all the animals (Fig. 1, *a*). It should be noted that in several experiments the efflux of blood to the systemic circulation was very pronounced but relatively transient, the balance between the outputs of the left and right ventricle being restored after 5-

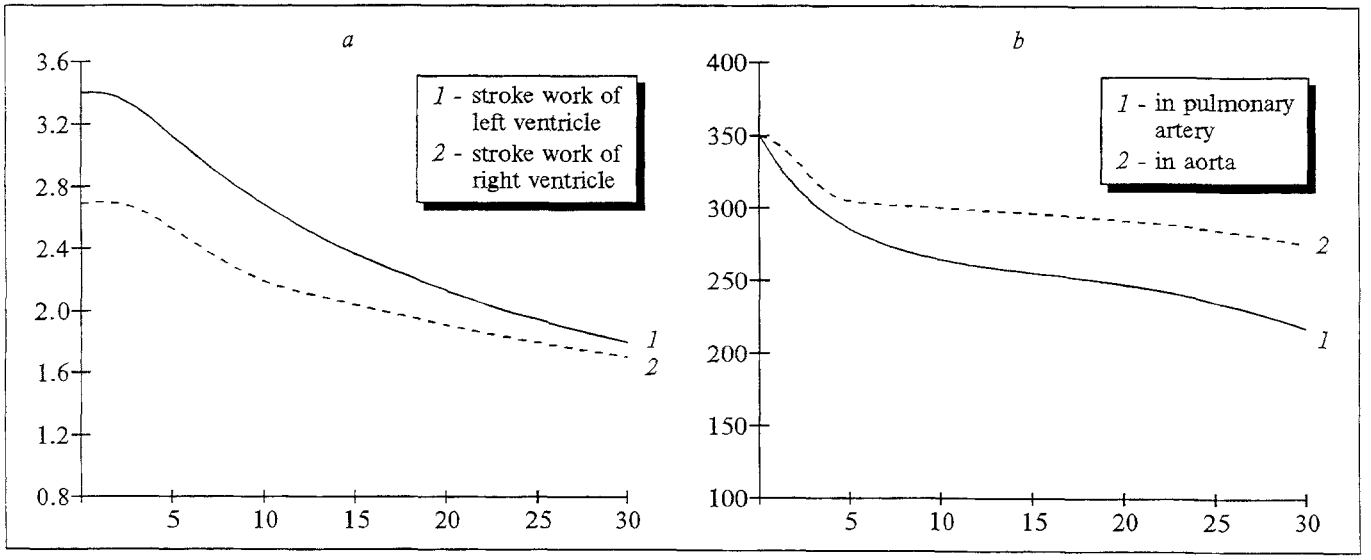

Fig. 3. Changes in stroke work of right and left ventricles (*a*) and volumetric blood flow rate in aorta and pulmonary artery (*b*) for switch from traditional ALV to HFJV. Asterisk: $p<0.05$ in comparison with the initial value.

7 min (Fig. 1, *b*). The left heart responds to this additional volume load by increasing the pumping coefficient of the left ventricle by 72% (from 1.05±0.05 to 1.81±0.166 g×m/mm/m).

Together with the dynamics of the parameters described above, the switch from traditional ALV to HFJV is characterized by a stability of the linear blood flow rate in the aorta as well as (in the majority of experiments) in the pulmonary artery, and by a stability of the systemic BP, total peripheral resistance, stroke volume, and stroke index in both the systemic and the pulmonary circulation ($p>0.05$), the heart rate being lowered from 184.6±2.8 to 165.4±1.96 beats/min during HFJV.

The structure of the lung microcirculatory bed (MCB) in health was studied earlier in our laboratory [7]. It should just be mentioned that the microvessels adjacent to the lung parenchyma undergo deformation during a cycle of spontaneous breathing. During traditional ALV under conditions of thoracotomy, the artificial inspiration leads to a straightening but simultaneously to a narrowing of the alveolar capillaries. Wide (interalveolar) capillaries also become narrowed. Thus, traditional ALV leads to a deformation of the MCB due to a relatively prolonged influence of high inspiration pressure and causes a rise of the microcirculatory (both pre- and postcapillary) and intracapillary resistance.

HFJV is characterized by a peculiar pattern of fluctuations in the respiratory changes in the MCB. In our case, the form of the alveolar capillaries is close to their physiological form during spontaneous breathing; with HFJV causing a higher rate of breathing and a reduced inspiration pressure, the form of the lung microvessels changes in a more limited range.

During HFJV there is a slight drop of the CPI, i.e., in the number of blood-perfused capillaries and, correspondingly, an increase in the number of plasmatic capillaries. As soon as after 10 minutes of HFJV the CPI drops reliably (by 9.09%) and then remains at this level. The dynamics of the CPI corresponds to that of the BP in the pulmonary artery. Our results are in conformity with the study reported previously [13], where a direct correlation was found between the BP in the pulmonary artery and the CPI under conditions of traditional ALV. A decreased blood volume in the pulmonary circulation, judging from the lower right ventricular output, also contributes to the CPI drop against the background of HFJV.

Stabilization of the main hemodynamic parameters under the new ventilation conditions occurs from the 10th to the 20th min. Changes in such parameters as minute volume, stroke volume, stroke index, and cardiac index in the systemic circulation occur 5 min after those in the pulmonary circulation, suggesting that HFJV affects the hemodynamics primarily in the pulmonary and only secondarily in the systemic circulation.

The data indicate that HFJV relieves the hemodynamic load on the pulmonary circulation, thus reducing the load on the right ventricle. It may be assumed that, in the given regime, HFJV may be effective in cases of hemodynamic overloading of the pulmonary circulation and right heart failure (pulmonary hypertension, pulmonary embolism, and lung edema after extensive resection of the pulmonary circulation).

REFERENCES

1. Sh. E. Atakhanov, *Anest. Reanimatol.*, № 4, 14 (1984).
2. M. A. Vyzhigina, B. F. Nazarov, M. V. Luk'yanov, *et al.*, *High-Frequency Ventilation,* Martin, Czechoslovakia (1989), p. 9.
3. D. P. Dvoretskii and B. I. Tkachenko, *Hemodynamics in the Lungs* [in Russian], Moscow (1987).
4. A. P. Zil'ber, *Respiratory Therapy in Everyday Practice* [in Russian], Tashkent (1986).
5. G. G. Ivanov and Sh. E. Atakhanov, cited in [6].
6. V. L. Kassil', *Artificial Lung Ventilation in Intensive Care* [in Russian], Moscow (1987).
7. A. M. Kulik, S. O. Aleinikov, and V. V. Zaretskii, *Byull. Eksp. Biol. Med*, **106**, № 8, 240 (1988).
8. D. D. Matsievskii, *Ibid.*, **76**, № 9, 119 (1973).
9. D. D. Matsievskii, *Ibid.*, **97**, № 3, 377 (1984).
10. A. J. Erdman, T. R. Vaughan, K. L. Brigham, *et al.*, *Circulat. Res.*, **37**, 271 (1975).
11. M. Klain and R. B. Smith, *Crit. Care Med.*, 5, № 6, 280 (1977).
12. P. P. Lunkenheimer, W. Raffenlenbenl, H. Keller, *et al.*, *Brit. J. Anaesth.*, **44**, № 6, 627 (1972).
13. V. Nagasaka, M. Matsuda, T. Noguchi, *et al.*, *Pulmon. Circulat. Res.*, 3, 11 (1990).
14. U. Sjostrand, *Crit. Care Med.*, **8**, № 3, 345 (1980).
15. R. D. Tallman, S. F. Peterson, and J. S. Donald, *Anesthesiology*, 59, Suppl. 3a, 144 (1983).