

高頻度ジェットベンチレーション時に認められた特異な動脈 血炭酸ガス分圧の変化

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Specific Changes in the Partial Pressure of Arterial Blood Carbon Dioxide Observed During High-Frequency Jet Ventilation in Dogs

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High-frequency ventilation is a general term for artificial respiration with the ventilation rate much higher than in physiological respiration, which is conducted at tidal volumes equal to or less than the anatomical dead space. High-frequency jet ventilation (HFJV) is a method of high-frequency ventilation, which utilizes a high-frequency jet stream [3]. Although HFJV has already been applied to human medicine and detailed studies have been done [3, 7, 8], it has been seldom used in veterinary practice [2]. We have been examining the relationship between the driving pressure and ventilation rate in dogs to seek a possibility of clinical application of HFJV in small animal medicine. In the course of our studies we have observed that when driving pressures were extremely low, the relationship between ventilation rate and the partial pressure of carbon dioxide in arterial blood (PaCO_2) was different from that observed at high driving pressures, and this is the core of this report.

We performed our study using mongrel dogs weighing approximately 10 kg under pentobarbital anesthesia. Following endotracheal intubation, a T-tube was connected with a jet needle, to which was attached the endotracheal tube. Just before initiating artificial respiration, the animals were immobilized with pancuronium bromide and the experiment was conducted administering additional doses of pancuronium bromide when necessary.

We used an SAV-6 model jet ventilator (Silver Medical Co.) and conducted the experiment with (in Group A) and without (in Group B) a one-way valve attached on one side of the T-piece.

The high-pressure gas source used in this experiment was 100% oxygen. At a constant inspiratory/expiratory time ratio (I: E) of 1: 2, ventilation frequencies of 50, 100, 120 and 150/min and driving pressures of 0.3, 0.5, 1.0 and 1.5

kg/cm² were tested. Conditions outside the ranges described above were also tested, as it was considered to be necessary during the experiment. The ventilation procedure was as follows: after HFJV lasting for 10 minutes, some arterial blood was taken as a sample, and then artificial respiration was conducted for 5 minutes, so as to give a condition just as in natural respiration. Various combinations of ventilation frequencies and driving pressures were sequentially tested in the same procedure as described above.

In most cases there was an increase of PaCO_2 accompanied by an increase of ventilation frequency at driving pressures equal to or above 1.0 kg/cm². However, in Group A at a driving pressure of 0.5 kg/cm² as well as in Group B at driving pressure of 0.3 kg/cm² this tendency was obscure; i. e., there was little or no rise of the PaCO_2 or, a decline at a certain specific ventilation frequency. This change in the PaCO_2 was marked especially in dog No.6. In this animal this change was observed even at a driving pressure of 1.0 kg/cm². Although the ventilation frequency at which PaCO_2 declined varied among individual dogs, many showed a decrease at 120/min (Fig. 1).

During artificial respiration at a constant I: E ratio minute respiratory volume was constant and unrelated to ventilation frequency. Hence, the more frequent the ventilation was, the smaller the tidal volume became, thus raising PaCO_2 . This sort of change was observed in the authors' results as well and corresponds with observation in previous reports [3]. However, although a rise in PaCO_2 accompanying increases of frequency was observed at low driving pressures, at a certain specific ventilation frequency, PaCO_2 was found to decline. The fact that respiration improves at a specific ventilation frequency suggests a lowered airway resistance to the jet stream at this ventilation frequency, which leads to an expansion of the respiratory volume. At physiologic respiratory rates, the mechanical factors

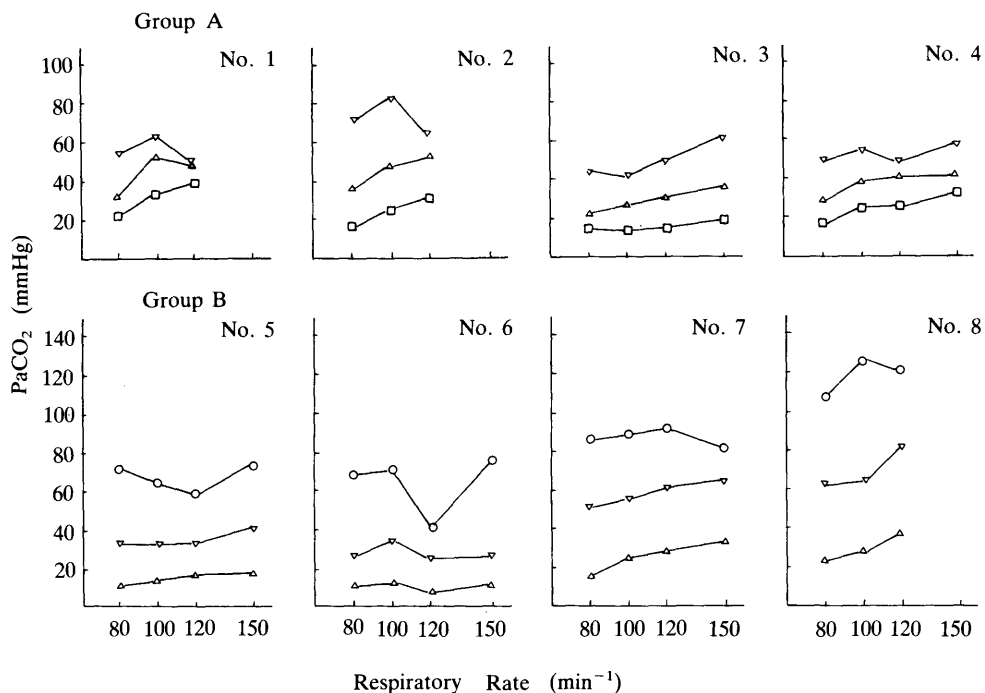


Fig. 1. PaCO₂ changes during HFJV. The jet was delivered via a T-piece with (Group A: Dog No. 1-4) and without (Group B: Dog No. 5-8) a one way valve attached on the side of a T-Piece. Driving pressures: 0.3 (○), 0.5 (▽), 1.0 (△), 1.5 (□) kg/cm². PaCO₂ decreased at 100/min in dog No. 3, 120/min in dogs Nos. 1, 2, 4, 5, 6 and 8, 150/min in dog No. 7.

limiting respiratory airflow are airway resistance and compliance [10]. However, when the respiratory rate begins to rise, the inertance of the thorax wall, diaphragm, liver and other abdominal viscera, which are moved by breathing movements, cannot be ignored. The inertance and compliance form an equivalent of a series resonance circuit [1, 5, 6]. Breathing appears to be performed with extremely little effort at certain ventilation rates that brings a harmony with the resonance cycle. Furthermore, it can be inferred that respiration in accordance with this resonance cycle is the most favorable ventilation rate because the rise in intra-alveolar pressure is extremely small and barotrauma is minimal. It may be that this resonance phenomenon plays some role in this phenomenon of improved respiratory efficiency at a specific ventilation rate observed in this experiment. However, the 120/min ventilation rate at which a decrease in PaCO₂ was observed in many of the dogs used in this experiment is below the rate which has been

believed to correspond to the resonance frequency of the dog [5], and more detailed studies would be needed.

Klain *et al.* [10] reported changes in PaCO₂ in the dog when they performed HFJV using a cannula. In the graph of PaCO₂ versus ventilation rate in their paper that PaCO₂ drops at 140/min. They simply state that PaCO₂ was in the range of 20-25 torr and do not refer to at all. Nevertheless, it would seem that whatever it might be that caused the decrease observed in their study, it could be identical to what was observed in our experiment.

With respect to the vagueness or loss of this phenomenon at high driving pressures, it may be that the volume of air delivered is unaffected by small rises and falls in airway resistance at such pressures; or, since PaCO₂ and respiratory volume are inversely proportional when the volume of carbon dioxide produced is constant, a small rise of respiratory volume may have no effect on PaCO₂ levels when respiratory volume

is sufficient. The reason why specific changes occurred in PaCO₂ in Group B at lower driving pressures than Group A is, as we suspect, that the air flowed in through the open end in keeping with the Venturi effect in Group B and the increase of respiratory volume was greater than in Group A, when compared at the same driving pressure.

In the present experiment using dogs, PaCO₂ was lowest at ventilation rates of approximately 120/min during HFJV at low driving pressures. This finding may be useful information for determination of the most suitable ventilation rate for HFJV.

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要 約

高頻度ジェットベンチレーション時に認められた特異な動脈血炭酸ガス分圧の変化(短報): 織間博光・野藤明仁・小泉 正・鷲巢 誠¹⁾・多川政弘²⁾・清水幹子・藤田道郎・手塚泰文(日本獣医畜産大学獣医放射線学教室, ¹⁾家畜病院, ²⁾獣医外科学教室)——麻酔下の犬に高頻度ジェットベンチレーションを実施し呼吸回数と動脈血炭酸ガス分圧(PaCO₂)の関係を検討した。その結果, 低駆動圧状態では従来から知られている, 呼吸回数の上昇に伴いPaCO₂が上昇するという傾向は不明瞭となり, 約120回/分の呼吸回数でPaCO₂が低下する傾向が認められた。この現象は高頻度人工呼吸法の犬での最適呼吸回数を設定する上で重要な知見であると考えられた。