High frequency ventilation is a new ventilation technique whose clinical application is being investigated extensively. This article describes three types of high frequency ventilation techniques, defines each technique, lists the possible clinical indications for high frequency ventilation, and presents a case study on the use of high frequency ventilation on a patient in whom conventional ventilation had failed.

High frequency ventilation (HFV) was introduced by Sjostrand nearly 15 years ago. Its recent use for patients in respiratory failure has led to the intensive investigation of the physiological mechanisms of respiratory gas exchange in HFV. For these reasons the nurse anesthetist should become familiar with the physiological concepts of HFV and possible clinical applications.

HFV systems are classified into three categories, according to the mechanisms of respiratory gas exchange, each producing different physiological effects: (1) high frequency positive pressure ventilation (HFPPV); (2) high frequency oscillation (HFO); and (3) high frequency jet ventilation (HFJV). HFPPV uses frequencies from 60 to 150 breaths per minute with tidal volumes that are less than normal physiological tidal volume but greater than the physiological dead space volume. HFO produces cyclical movement of the same volume of gas in and out of the airway with little bulk delivery of gases into the alveoli. HFJV delivers gas through a narrowed orifice such as a 14 gauge needle to produce a high velocity low pressure "jet" effect. HFO and HFJV both produce improved respiratory gas exchange at lowered peak airway pressures.

The lowered peak airway pressures and improved gas transport provided by these ventilatory systems result in several distinct advantages, including: (1) less impairment of venous return and right ventricular afterload, resulting in improved cardiac function; (2) diminished pulmonary barotrauma due to decreased airway pressure; and (3) decreased lung motion and changes in intracranial pressures due to ventilation. Because of these advantages, HFV may be useful in the following conditions: (1) adult respiratory distress syndrome (ARDS); (2) bronchopleural fistula (BPF); (3) thoracic pulmonary surgery; and (4) neurosurgery. Since HFJV and HFO possess similar advantages but act via different mechanisms, it is possible that their use in combination might prove even more effective for treatment of these conditions.

The purpose of this article is to review the physiological mechanisms and effects of HFO and HFJV, describe the rationale of these two systems and describe the use of HFV for a patient with ARDS.
High frequency oscillation

With conventional ventilation, gas exchange between the trachea and the small airways is produced by convective flow. However, the movement of gas in the terminal airways occurs primarily via diffusion. In respiratory diseases such as ARDS, where there is destruction of the architecture of the terminal airway units, the diffusion distances are significantly increased. A conventional ventilator does not substantially enhance diffusion of gas molecules in the terminal airways, and may only damage these terminal respiratory units further because of barotrauma. In the ARDS patient this barotrauma may produce bronchopleural fistulas and subcutaneous emphysema.

In patients with severe pulmonary disease, Butler et al.\(^3\) showed that oscillatory flow can maintain adequate gas transport with minimal bulk gas flow. HFO was used at a frequency of 15 Hz, fresh gas flow of 12-15 L/minute, and tidal volumes of 100-150 ml. Satisfactory ventilation was obtained in all patients. In addition, the calculated pulmonary shunt fraction \((Q_s/Q_t)\) was found to be less than that found with conventional ventilation. Neither airway pressures nor hemodynamic variables were measured in this study. Because HFO maintains adequate gas transport with lowered peak airway pressures, its use may lead to a reduced incidence of pulmonary barotrauma. For this reason, HFO may be clinically useful in patients with ARDS who require high peak airway pressures with conventional ventilation. Another advantage of HFO is the rapid vibrational motion of the thorax and lungs, which enhances the removal of airway secretions and further improves gas transport.

High frequency jet ventilation

In 1967, Saunders first introduced this method of ventilation when he ventilated paralyzed patients through an open bronchoscope using an intermittent jet of oxygen under high pressure through a small (14 gauge) cannula to the trachea. He described a "jet effect" type of ventilation, which caused air entrainment based on the venturi principle.\(^4\) The venturi principle states that as the velocity of flow of a gas increases, the pressure in the constricted part of the gas decreases, producing a suction effect.\(^5\) Because this venturi mechanism causes a decreased pressure at the outflow of the HFJV, gas will be entrained and tidal volume increased. Gas entrainment not only enhances the tidal volume but adds humidified room air to the dry gas. The disadvantages of HFJV are that a high pressure gas source (50 PSI) is needed, and inspired oxygen concentrations may be diminished due to the entrainment of room air. The principle of HFJV is not rate dependent, and respiratory rates may vary but are usually greater than 60 cycles per minute.

High frequency jet ventilation is achieved through the lumen of a triple port portex endotracheal tube, which is connected to the patient’s tracheostomy tube. The inspired air is also humidified by a saline infusion at 1 cc/minute through the third port on the endotracheal tube. Because of the large diameter of the gas flow port on the endotracheal tube, there was less of an increase in velocity of gas flow, less decrease in pressure, and therefore less air entrainment in this system.

Case study—Use of HFO augmented with HFJV

The patient was a 62-year-old male with chronic obstructive pulmonary disease who underwent coronary artery bypass surgery for intractable angina. During the postoperative course he developed ARDS and required mechanical ventilation using peak inspiratory airway pressures of 70-80 cm H\(_2\)O, positive end expiratory pressures of 27 cm H\(_2\)O, and an F\(_{1O_2}\) of 0.90. He had developed bilateral bronchopleural fistulas and total body subcutaneous emphysema. Epinephrine and dopamine were required intravenously to maintain the patient’s cardiovascular function. His weight increased from 90.7 kg on the first postoperative day to 100.3 kg on the eighth postoperative day. He developed acute renal failure postoperatively, and on the eleventh postoperative day renal dialysis was initiated.

On the eighth postoperative day, after institu-
tional approval and informed consent from the patient's family, HFO and HFJV were instituted in an attempt to improve the patient's respiratory gas exchange status. Over the next eight days, the patient was ventilated with HFO and HFJV for increasing periods of time each day. At the beginning of each HFO and HFJV period, copious amounts of airway secretions were aspirated. (Figure 1.)

During the period of HFO and HFJV ventilation, the patient's arterial blood gases were maintained and/or slightly improved at lowered airway pressures compared to those observed with conventional ventilation. With the decrease in airway pressure the air leaks noted in the chest tubes due to the bronchopleural fistula were markedly decreased. In spite of the short-term improvement in the patient's pulmonary status, the primary disease process was not reversed.

Conclusion

This article has defined the terms generally used with HFV and explained briefly the physiological concepts used to currently support HFV. Some of the possible applications of HFV and an example of such applications have been presented. The advantages of HFV in contrast to conventional ventilation have been shown. They include:

1. The opportunity to ventilate a patient with lowered peak airway pressures, allowing for lung healing.
2. Lowered intrathoracic pressure, allowing improvement in venous return with subsequent hemodynamic stabilization.
3. Loosened airway secretions, with improved pulmonary toilet.
4. Decreased calculated pulmonary shunt fraction (Qe/Qt) with improvement in arterial oxygenation.

At present the realm of complications resulting from HFV is still not completely known. The major known complication is pulmonary air entrapment, which is caused by a prolonged inspiratory time.

The role of HFV and its clinical applications have not been fully explored. With further research and refinement of HFV techniques the possibility of HFV becoming the “ventilatory technique of choice” may soon be realized.

REFERENCES


ACKNOWLEDGMENT

The author wishes to thank Drs. S.M. Muldoon and J. Langston for their assistance in the review of the manuscript, and Hortence Koller and Sandra Winer for secretarial assistance.