High-Frequency Jet Ventilation During Radiofrequency Ablation: A Case Report

Paul E. Perkins, CRNA, MSN

High-frequency jet ventilation (HFJV) has been used in emergency airway scenarios and various surgical procedures. Although substantial literature is available regarding HFJV in these situations, there is only 1 publication to date concerning its use for cardiac radiofrequency ablation procedures.

The following case study describes a 49-year-old man undergoing radiofrequency ablation in which HFJV was used. This method has been used for these procedures for months in our institution with great success. Its effectiveness is attributed to the lack of significant heart movement as compared with conventional intermittent positive-pressure ventilation, which, in turn, has improved surgical conditions and resulted in decreased procedure times. In this case, a newly introduced in-line circuit filter was used. Impedance to passive exhalation was created after the filter became saturated from the high humidification.

This event, its management, and the following discussion on the mechanics of HFJV and its use in radiofrequency ablation procedures make this case an educational value to all anesthesia providers.

Keywords: High-frequency jet ventilation, radiofrequency ablation, peak inspiratory pressure.

Atrial fibrillation is the most common of all sustained cardiac arrhythmias.[1] Currently, radiofrequency catheter ablative procedures are accepted as primary therapy for patients with supraventricular tachycardia and several forms of ventricular tachycardia that are refractory to pharmacologic treatment.[2] Radiofrequency ablation is a relatively new procedure; the first was done in 1981.[3] With greater physiological understanding and technological advances, radiofrequency ablation procedures have increased in complexity and sophistication. Most institutions perform these procedures by using conscious sedation for patients, and the cardiologist relies solely on fluoroscopy for catheter guidance.

When the pulmonary veins were identified as major sources of atrial triggers (ectopic beats) by means of intracardiac mapping, the use of intracardiac ultrasound became necessary to prevent pulmonary venous stenosis due to the proximity of the catheter tip to the pulmonary venous ostium.[4] Due to the length of these procedures, which can be longer than 8 hours, and the need for the patient to be motionless, the use of general anesthesia to increase patient comfort and decrease procedure difficulty was inevitable. High-frequency jet ventilation (HFJV) was also used for these procedures in an attempt to minimize cardiac movement from the changing intrathoracic pressures associated with conventional ventilation.

A recent study by Goode et al[5] compared the use of HFJV with that of intermittent positive-pressure ventilation during cardiac radiofrequency ablation procedures. The principal finding of this study was that, relative to intermittent positive-pressure ventilation, HFJV produced less posterior left atrial motion, which facilitated catheter ablation.[5] The data that led to this conclusion were the significant decreases in left atrial volume, maximum change in left atrial pressure and pulmonary vein flow, motility of the left and right interpulmonary vein saddle sites, and number of radiofrequency applications initiated.[5] Last, and possibly most important from an anesthesia standpoint, were the significant decreases in ablation procedure time and total electrophysiology laboratory time.[5]

Case Summary

A 49-year-old man was admitted for bilateral atrial radiofrequency ablation due to a 15-year history of atrial fibrillation and atrial tachycardia accompanied by lightheadedness, fatigue, palpitations, and hypotension with episodes of rapid ventricular response. There was no response to medical treatment until 3 years ago, when oral amiodarone was prescribed. Since that time, there were no further occurrences of atrial fibrillation.

The patient's medical history was significant for obstructive sleep apnea, varicose veins, and benign thyroid nodules. His surgical history included 2 hernia repairs and a vasectomy without anesthetic complications.

His admission height and weight were 188 cm and 104 kg, respectively. Current medications included amiodarone and warfarin. His reported allergy was to quinidine. The airway was a Mallampati class II, and he was assigned an ASA physical status of II. He was a nonsmoker and stated he consumed one-half case of beer per week. Baseline vital signs were as follows: blood pressure (BP), 119/74 mm Hg; heart rate, 76/min; respirations, 18/min; and temperature, 34.7°C. The electrocardiogram revealed a normal sinus rhythm. An echocardiogram revealed an ejection fraction of 55%, a nondilated left ventricle with diffuse mild hypokinesia, low normal systolic function, thickened aortic valve with mild aortic regurgitation, and trace mitral regurgitation.

In the electrophysiology laboratory, a preoperative assessment was completed and consents for anesthesia and blood transfusion were obtained. Standard monitors were applied. Induction of anesthesia was performed with 2 mg of midazolam, 150 µg of fentanyl, 200 mg of propofol, and 100 mg of rocuronium through a preexisting 20-gauge peripheral intravenous (IV) line. An oral 8.0 endotracheal tube (ETT) was inserted without difficulty and confirmed with end-tidal carbon dioxide ($ETCO_2$) measurement and auscultation.

The patient was ventilated at a tidal volume of 800 mL, respirations of 10/min, and a fraction of inspired oxygen (FIO_2) of 0.6 with an initial peak inspiratory pressure (PIP) of 18 cm H_2O. General anesthesia was maintained with 0.45 to 0.6% end-tidal isoflurane with 50% oxygen and 50% air. The $ETCO_2$ was maintained between 33 and 36 mm Hg while the patient was conventionally ventilated. An esophageal stethoscope, oral gastric tube, and indwelling urinary catheter were inserted. Also, 2 additional peripheral IV lines were inserted, with one dedicated to the anticipated total IV anesthesia when HFJV was initiated.

Approximately 3 hours of general anesthesia was required for placement of 2 right femoral venous sheaths, 2 left femoral venous sheaths, and a right femoral arterial line. This time was also used for line preparation because extreme vigilance is required to ensure absence of IV air due to the creation of an atrial-septal defect by the cardiologist to gain access to the left atrium. During this time, IV volume, consisting of 500 mL of lactated Ringer's solution and 500 mL of 5% albumin, and a phenylephrine infusion were used to maintain a systolic BP of more than 100 mm Hg. Initial arterial blood gas (ABG) results during conventional ventilation were as follows: pH, 7.41; $PaCO_2$, 36 mm Hg; PaO_2, 178 mm Hg; HCO_3, 23 mEq/L; and base excess, –1.

When the cardiologist was prepared to begin the ablation component of the procedure, the anesthetic technique was changed from inhalation anesthesia to total IV anesthesia, with the administration of 50 mg of rocuronium, 150 µg of fentanyl, and 1 mg of midazolam, followed by IV infusions of mivacurium (7-8 µg/kg per minute), remifentanil (0.375-0.6 µg/kg per minute), and propofol (75 µg/kg per minute). Immediately before initiating thermal ablation, HFJV at settings of 100 cycles per minute, a driving pressure of 30 psi, a 30% inspiration/expiration ratio, 10% active humidification, and 0.6 FIO_2 was initiated. The jet ventilator alarm settings were set at a PIP of 40 cm H_2O and an end-expiratory pressure of 20 cm H_2O. The ETT jet connector was placed between the patient's 8.0 ETT and the anesthesia circuit. Adequate patient chest rise and fall was noted.

Thirty minutes after initiation of HFJV, the ABG results were as follows: pH, 7.31; $PaCO_2$, 48 mm Hg; PaO_2, 202 mm Hg; HCO_3, 23 mEq/L; and base excess, –3. At this time, the driving pressure was increased to 33 psi to improve ventilation and decrease $ETCO_2$. The cardiologist requested the patient's systolic BP be maintained between 100 and 110 mm Hg. The BP was labile (systolic, 80-144 mm Hg), which required multiple boluses of phenylephrine, 40 to 80 µg, in addition to the titrated baseline infusion (0.25-1.2 µg/kg per minute). The mean left atrial pressure, 7 mm Hg, was obtained via the intracardiac route by the cardiologist because of continued difficulty with maintaining BP in the requested range. A fluid bolus of 500 mL of lactated Ringer's solution was administered with little effect on the BP. The next ABG results (sample obtained 30 minutes after the last) were as follows: pH, 7.21; $PaCO_2$, 63 mm Hg; PAO_2, 228 mm Hg; HCO_3, 24 mEq/L; and base excess, –5. At this time, HFJV was discontinued and the following conventional ventilator settings were used: tidal volume, 800 mL; respirations, 16/min; and FIO_2, 0.6. The PIP at this time was 32 cm H_2O.

With continued problems maintaining the desired BP, an increase in PIP, and the increase in $ETCO_2$, fluoroscopy was used to confirm proper ETT placement. Breath sounds remained equal. The left atrial pressure was 9 mm Hg after a second 500-mL IV bolus of lactated Ringer's solution. After 15 minutes of conventional ventilation, the $ETCO_2$ was 45 mm Hg. Another blood sample was obtained for ABG measurement, and results were as follows: pH, 7.33; $PaCO_2$, 43 mm Hg; PaO_2, 207 mm Hg; HCO_3, 22 mEq/L; and base excess, –3.

To complete the ablation procedure, HFJV was reinstituted with the driving pressure increased to 35 psi and the other settings unchanged. After the return to HFJV, an episode of severe hypotension occurred (systolic BP, 44 mm Hg), which was treated successfully with phenylephrine boluses and a return to conventional ventilation. At that time, it was determined that the in-line circuit filter, which was recently introduced at this facility, was saturated with fluid. The filter was removed and the PIP instantly dropped from 32 cm H_2O to the baseline of 18 cm H_2O.

The cardiologist finished the ablation while conventional ventilation was used for the patient. The patient received a total of 3,200 mL of crystalloid, 500 mL of colloids, 300 µg of fentanyl, 3 mg of midazolam, 250 mg of rocuronium, 10 mg of remifentanil, 190 mg of mivacurium, and 30 mg of IV ketorolac. The total urinary output was 1,400 mL.

The patient was weaned off phenylephrine in the electrophysiology laboratory after all anesthetic agents were discontinued, and the patient was transported, breathing spontaneously, to the postanesthesia care unit with a T-piece and oxygen at 10 L/min. The vital signs on admission to the postanesthesia care unit were as follows: BP, 112/52 mm Hg; heart rate, 96/min; respirations, 10/min; and oxygen saturation, 98% with an FIO_2 of 0.4. The patient's postoperative course was uneventful.

Discussion

The use of high-frequency ventilation in humans was first reported in 1972. High-frequency ventilation is defined as a mode of ventilation at respiratory rates more than 1 Hz (>60 cycles per minute) and at tidal volumes less than dead space. High-frequency jet ventilation is a special type of high-frequency ventilation in which small amounts of gas are introduced into the patient's airways under high pressure through a noncompliant catheter or cannula at frequencies between 60 and 600 cycles per minute.[6] Oxygenation and ventilation are not accomplished by bulk gas flow but by coaxial flow in the larger airways.[7] This is explained as asymmetric velocity profiles that induce an inward central movement of oxygen and an outward movement of carbon dioxide along the periphery of the airways. High velocity jets of gas and branching of the bronchial tree cause turbulence to arise that is responsible for enhanced mixing of molecules and facilitating diffusion processes.[6]

The key mechanics of HFJV include driving pressure, inspiration/expiration ratio, jet catheter size, rate, FIO_2, and humidity. Minute ventilation is most dependent on driving pressure and the inspiration/expiration ratio. It is independent of the rate unless the rate is less than 60 cycles per minute or greater than 600 cycles per minute. Finally, active humidification is required due to the higher minute ventilation.

High-frequency jet ventilation can be used in a variety of settings: operating rooms, intensive care units, and any time emergency airway ventilation is needed when other airway maneuvers have failed. Often its use is indicated when a quiet surgical field is preferred because HFJV uses very small tidal volumes. Intraoperative cases that may use HFJV include otolaryngology procedures, microlaryngeal procedures, thoracotomies, oral procedures, upper abdominal surgeries, and, more recently, radiofrequency ablation. High-frequency jet ventilation is useful for patients with barotrauma to prevent hypoxemia during suctioning; during weaning, because it does not interfere with spontaneous breathing; and during ETT changes.[7]

The use of HFJV is not without potential complications.[7] With frequencies greater than 6 Hz, carbon dioxide retention can become a problem. A decreased temperature can occur in children if respiratory gases are not heated. Excess or insufficient humidification can cause airway damage. If minute ventilation is excessive, hypotension can occur. Impaired exhalation can lead to end-expiratory pressure buildup. Barotrauma can occur if the catheter is introduced beyond the carina.

In the present case, exhalation was impaired due to the saturation of the airway filter with water from active humidification. This type of filter, which incorporates the mass spectrometer sampling line port, was recently introduced for use at this facility. The impedance of passive exhalation explains the carbon dioxide retention during HFJV and the ineffectiveness of increased driving pressure to reduce the carbon dioxide levels. The impedance present in the filter was significant enough to affect carbon dioxide elimination but did not completely block exhalation, which would have significantly increased end-expiratory pressure, causing the jet ventilator alarm to sound and the jet ventilator to automatically shut off. When conventional ventilation was reinstituted, the peak inspiratory pressure was noted to have increased from 18 to 32 cm H_2O. It was immediately determined that the filter was saturated with water, creating the impedance to inspiratory flow. When the filter was removed, the PIP returned to normal.

Significant hypotension occurred in this case that could be related to a variety of causes. Hypovolemia was ruled out because there was essentially no blood loss, appropriate fluid administration was calculated and administered, the left atrial pressure was normal, and there was never any tachycardia. A tension pneumothorax was ruled out because equal chest rise and bilateral breath sounds were present and the end-expiratory pressure within normal limits. During the ablation, the use of vasoactive infusions is common to supplement the BP due to the cardiac depressant effects of propofol, histamine release associated with mivacurium, and high doses remifentanil. Although this is not fully understood, even in a deeply anesthetized patient, frequently the cardiologist is able to detect erratic cardiac movement during ablation, which has been found to be blunted by the administration of high-dose remifentanil.

Summary

Radiofrequency ablation is a complex procedure that requires multiple anesthetic management techniques. The use of HFJV has proven to be very beneficial in these cases because it can decrease the technical difficulty for the cardiologist, which, in turn, decreases the anesthetic time for the patient. When using HFJV, strict attention must be given to evaluating proper ventilation. As proven with this case, even mild impedance of expiratory flow can cause significant carbon dioxide retention. Due to the need for active humidification, future use of in-line circuit filters with HFJV may not be feasible. Last, the use of frequent ABG analysis is necessary for evaluation of adequate ventilation.

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AUTHOR

Paul E. Perkins, CRNA, MSN, is a nurse anesthetist with Maryville Anesthesia, P.C., Maryville, Tennessee. He was a senior student in the University of Pittsburgh Nurse Anesthesia Program, Pittsburgh, Pennsylvania, when this article was written. He won the 2005 AANA Student Writing Contest with this submission. Email: pperk@mac.com.