A New Device That Allows Synchronous Intermittent Inspiratory Chest Tube Occlusion with any Mechanical Ventilator*


Controlling a massively leaking bronchopleural fistula (BPF) can prove difficult. In combination with acute respiratory failure (ARF), BPF results in a mortality of 81 percent. Intermittent inspiratory chest tube occlusion (IICTO) is recognized as effective in controlling even the largest BPF; however, IICTO, as previously described, is difficult to use for a variety of reasons. We report two cases of BPF in association with ARF managed with a simple new device that allows the application of IICTO with virtually any mechanical ventilator. The effectiveness of the device and associated technique in controlling BPF leaks is clearly demonstrated and may have played a role in the eventual recovery of a patient with BPF. Further study of the technique is warranted.

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BPF = bronchopleural fistula; ARF = acute respiratory failure; PIP = peak inflation pressure; HFJV = high-frequency jet ventilation; ILV = independent lung ventilation; ILV/UHFW = independent lung ventilation/unilateral high-frequency jet ventilation; CTP = chest tube pressurization; IICTO = intermittent inspiratory chest tube occlusion; Ppl = pleural pressure; Paw = airway pressure; SIMV = synchronized intermittent mandatory ventilation; CPAP = continuous positive airway pressure; PCV = pressure control ventilation

The combination of bronchopleural fistula (BPF) and acute respiratory failure (ARF) carries a mortality rate of 81 percent. Mechanical ventilation, required in the treatment of ARF, often exacerbates the BPF and, thus, gradually increases the leak. Unless the leak is controlled, the expanding BPF may lead to contamination and infection of the pleural space, mismatching of ventilation and perfusion, persistent pneumothorax, inability to provide alveolar ventilation, and progressive deterioration of the patient's condition. Reducing the leak through a BPF can prove difficult, and substantial leaks frequently persist despite the use of ventilatory techniques aimed at lowering mean airway pressure or peak inflation pressures (PIP).

A number of experimental methods have been used in attempts to control a persistent, seriously leaking BPF. Reports have detailed the use of high-frequency jet ventilation (HFJV),1-5 independent lung ventilation (ILV),6-8 independent lung ventilation/unilateral high-frequency jet ventilation (ILV/UHFJV),9 chest tube pressurization (CTP),9,10 and intermittent inspiratory chest tube occlusion (IICTO).11-13 These methods, however, require specialized techniques, modified equipment, or ventilators that are not commonly available. Besides technologic problems, each modality also presents significant physiologic problems. For example, HFJV is unlikely to control a large BPF in patients with ARF.5,6 Further, HFJV does not adequately humidify inhaled gases, and long-term use may lead to inspissation of airway secretions and other related problems.14 Both ILV and ILV/UHFJV require reintubation with a double-lumen endotracheal tube, a procedure that entails some risk in a critically ill patient.15 With CTP, the ambient outlet of a water-seal bottle is connected to the ventilator circuit to equalize pleural pressure (Ppl) and airway pressure (Paw) by simultaneous exposure to pressure generated within the ventilator circuit. Lung collapse and pneumothorax have been reported with this system, and it must be used with caution when spontaneous breathing does not reduce Ppl enough to maintain lung expansion.11 An additional concern is increased airway resistance during mechanical inspiration; increased resistance can delay pressure equilibration between the ventilator circuit and the lungs, but not between the circuit and water-seal (Ppl). When Ppl exceeds Paw, even momentarily, the lung is liable to collapse.

However, IICTO, has been reported to be effective in controlling even the largest BPFs.11-13 Unfortunately, IICTO is difficult to use, primarily because it was initially accomplished with a ventilator (Bird Mark 2/6) that is no longer available commercially. Furthermore, even though a modification of that system had allowed it to be used for IICTO with any ventilator that had an external, pneumatically powered exhalation valve,13 this type of valve is not available on

*From the Departments of Anesthesiology and Medicine, University of Florida College of Medicine, and Respiratory Care Service, Shands Hospital at the University of Florida, Gainesville.
†Equipment Supervisor.
‡Assistant Respiratory Therapist.
§Assistant Professor of Anesthesiology and Medicine.
Manuscript received August 28; revision accepted December 1. Reprint requests: Dr. Layon, Anesthesiology, J.H. Miller Health Center, Box J-254, Gainesville, Florida 32610

1426 Synchronous Intermittent Inspiratory Chest Tube Occlusion (Blanch, Koens, Layon)
today's commonly used ventilators (eg, Siemens 900C, Hamilton Veolar, Bird 6400ST, Ohmeda CPU-1, Puritan-Bennett 7200a, Engstrom Erica, Bear 5).

We have developed a simple, new device (Fig 1) that allows the application of IICTO with virtually any mechanical ventilator and with most modes of ventilation. The device is flexible in that IICTO can be applied during any mechanical inspiration or, by an adjustment, only during volume-controlled, synchronized intermittent mandatory ventilation (SIMV) breaths when SIMV and PS are used concurrently. We describe two cases in which our device had clinical utility.

CASE REPORTS

CASE 1

A previously healthy 33-year-old man was transferred to our institution 19 days after a motor vehicle accident. He had developed bilateral Pseudomonas pneumonia and a persistent left thoracic air leak, which resulted in the need for progressively increasing ventilator support.

When the patient arrived in our surgical intensive care unit (SICU), ventilator settings were frequency of 30 breaths/min, tidal volume (VT) of 850 ml, PIP of 80 cm H_{2}O, continuous positive airway pressure (CPAP) of 5 cm H_{2}O, and an inspired fraction of oxygen (FiO_{2}) of 0.7. The patient was treated with appropriate antibiotics and underwent multiple ventilatory manipulations, including pressure control ventilation (PCV), which decreased PIP to 60 cm H_{2}O, in an effort to improve ventilation and oxygenation. However, the pneumonia and BPF persisted and the patient's condition slowly deteriorated. On the 25th day after injury, the left chest tube leak had increased to 750 ml with each mechanical breath.

Initiation of IICTO provided immediate control of the leak and reduced it to 75 ml with each breath. No improvements in the patient's ventilatory status were noted after 24 hours, so IICTO was discontinued. At that point, the left chest tube leak was 375 ml per breath, but within one hour of discontinuing IICTO, the leak had progressively increased to nearly 500 ml per breath, and IICTO was therefore reinitiated. Control of the BPF was regained, but the patient died the following day of uncontrolled sepsis.

CASE 2

A 21-year-old man sustained multiple injuries in an automobile accident. He was admitted to a local hospital and was initially treated with CPAP up to 28 cm H_{2}O and SIMV. On day 2, bilateral pneumothoraces developed and were treated by chest tube placement. The patient's condition slowly deteriorated and bilateral BPFs with volume losses as high as 500 ml per breath developed.

The patient was transferred to our institution on posttrauma day 20. At the time of transfer, ventilator settings were frequency of 22 breaths/min, CPAP of 10 cm H_{2}O, FiO_{2} of 1.0, and PIP of 110 cm H_{2}O; arterial blood gases were a pH of 7.34, Po_{2} of 67 mm Hg, and Pa_{4} of 187 mm Hg. The patient was ventilated in the PCV mode with a Siemens 900C, and inspiratory pressure was reduced to 80 cm H_{2}O. Despite the reduction in PIP noted after institution of PCV, hypercarbia and continuous leaking from the BPFs prompted the placement of an IICTO valve onto each of the four leaking water-seal bottles. The total leak after initiation of IICTO was approximately 150 ml per breath.

With control of the BPFs established, the patient's pulmonary status remained relatively stable and his overall condition began to improve slowly. By posttrauma day 31, IICTO was discontinued.
from the two left chest tubes. Ventilator settings at the time were f of 8 breaths/min (spontaneous f of 17 breaths/min), inspiratory pressure limitation of 64 cm H₂O, CPAP of 8 cm H₂O, and an FIO₂ of 0.4. On posttrauma day 37, with no evidence of leakage, IICTO was discontinued from the remaining two chest tubes; the ventilator settings had been unchanged for the previous six days. The patient continued to improve slowly and was successfully weaned from mechanical ventilation, had no recurrence of BPF, and was ultimately discharged to a rehabilitation unit.

**DISCUSSION**

The device we constructed and used consisted of a pressure-amplifying valve (Clippard 2010) designed to be connected between a supply of gas (50 psi) and, in this case, an exhalation valve (Bird 4230), which functioned as the dynamic component of the IICTO system (Fig 1). This pressure-amplifying valve is considered to be “normally closed,” which implies that a “trigger” or signal pressure is required to open the device to actuate the exhalation valve. The triggering pressure is 3 cm H₂O. Loss of this pressure results in closure of the pressure amplifier and depressurization of the exhalation valve through an exhaust port located in the former valve (Fig 2 and 3).

The triggering is provided by attaching a line containing an overpressure relief valve into the inspiratory limb of the ventilator breathing circuit, proximal to the humidifier. The overpressure relief valve is adjusted to relieve pressure at approximately 5 cm H₂O above the level of CPAP or to any pressure at which valve actuation is desired. Initiation of mechanical inhalation increases airway pressure, opens the overpressure governor, triggers the pressure amplifier “on,” and, in turn, closes the exhalation valve to occlude the chest tube. An appropriately adjusted needle valve acts to dissipate the triggering pressure during the expiratory phase. The needle aperture is adjusted by completely opening it and then slowly closing it until the exhalation valve opens and closes synchronously with each ventilator cycle. In practice, little adjustment of the needle valve is required.

The device we describe is extremely versatile and can provide IICTO with most ventilators. The output pressure and exhaust capability provided by this device are sufficient to simultaneously open and close four or more exhalation valves, an advantage not always provided by other techniques. The device also functions well with the IICTO valve placed into the
Figure 3. During the exhalation phase, airway pressure decreases, which causes the overpressure relief valve to close. The pressure loading the diaphragm (A) in the amplifier valve dissipates via a needle valve, which closes the amplifier valve. Thus, the exhalation valve opens and allows the chest tube and the underwater seal apparatus to function in the normal manner.

Thoracostomy tube or on the ambient outlet of a water-seal bottle (Fig 2 and 3). Safety is enhanced by applying IICTO to the ambient outlet and thereby preventing the risks of infection, valve contamination, and disconnection associated with the placement of an exhalation valve into a thoracostomy tube. A further advantage is provided by the compressible volume within the bottle. A small amount of gas continues to flow through the BPF during the inspiratory phase and compresses the bottle. This ensures the preservation of the Paw-Ppl gradient and reduces the risk of lung collapse. Adjustment of the compressible volume by changing the water-seal bottle size allows the magnitude of the leak to be manipulated, although the leak will be substantially reduced regardless of the bottle size.

Although the value of IICTO in restoring pulmonary gas exchange is clearly established,11-13 most cases of BPF are adequately managed by conventional ventilator adjustment.1 Furthermore, controlling a leaking BPF does not ensure immediate improvements in gas exchange.1,3 Nevertheless, we contend that IICTO should be considered whenever a persistently leaking BPF develops in association with ARF. Reducing the magnitude of a BPF leak is considered a primary goal of therapy, because complications are minimized and healing is promoted,15 even in the face of high PIP, as evidenced in both cases reported herein. In fact, four BPFs healed in our second patient while he was mechanically ventilated at a PIP in excess of 60 cm H₂O.

Both our patients fulfilled criteria that should have resulted in death—late onset of BPF and leak of more than 500 ml per breath.1 Patient 1 did die, but from overwhelming sepsis rather than inability to oxygenate and ventilate; in patient 2, however, we believe IICTO played a role in preventing death. Further studies of this system and the technique of IICTO need to be undertaken to ensure its safe utilization. If the technique is shown to be without serious risks, we think it is reasonable to recommend its use in cases such as the two we have described.

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