PEEP AND THE BAIN CIRCUIT

HERNANDO Y. ARANDIA AND PETER H. BYLES

ABSTRACT

The feasibility of applying positive end expiratory pressure within the Bain circuit using an Emerson PEEP valve was studied. It was determined that varying degrees of PEEP may be applied within the Bain circuit using an Emerson PEEP valve during either mechanically or manually controlled ventilation but not during spontaneous breathing. There was some loss of measured tidal volume with increasing PEEP, due primarily to compression gas losses but also from leakage throughout the system. The maximum gas loss was 100 ml per minute at PEEP 15 cm H₂O under test conditions.

PEEP may be applied between the Bain tubing and the manifold. However, one should then never allow the patient to breathe spontaneously as the PEEP valve presents an obstruction to inspiratory flow. With the PEEP valve relocated between the Bain manifold and the ventilator hose it was found that application of PEEP was possible without this disadvantage, but only during mechanical ventilation.

KEY WORDS: ANAESTHETIC TECHNIQUES, Bain Circuit, positive end expiratory pressure.

THE BAIN CIRCUIT¹ has become an accepted anaesthetic circuit presumably because of its constructional simplicity and the ease with which PaCO₂ can be controlled by manipulating fresh gas flows.² However hypoxaemia due to decreased FRC can occur in patients under anaesthesia³ and varying degrees of positive end expiratory pressure (PEEP), may be useful in such a situation.^{3,4} At first sight the application of PEEP to the Bain circuit appears difficult, since this circuit, unlike the circle system, does not fully segregate the inspiratory and expiratory gas flows. The following questions then arise, which this study seeks to answer: (1) How can PEEP be used with the Bain circuit? (2) Will its use affect the tidal volume delivered to the patient? (3) Is the Emerson PEEP device suitable, and where in the system is it best located? (4) Are there special limitations in its use?

METHODS

A test lung (Drager u Bungsthorax M13333) was ventilated a Bain Circuit using an Air Shields Ventimeter anaesthesia ventilator set to deliver a constant tidal volume (V_T of 500 ml). V_T was the expired volume measured directly from the test

lung using a Wright respirometer mounted between the test lung and the patient port of the Bain circuit. Inspiratory and expiratory pressures were recorded both at the test lung (distal pressure) and between the Bain tubing and Bain Circuit Manifold (proximal pressure), using Hewlett Packard transducers (model 12800 and a Hewlett Packard four channel recorder) (7754B). Fresh gas flows into the circuit were maintained at 3.5 litres per minute.

It was decided to use the Emerson water-column PEEP valve in these experiments. It consists of a vertical calibrated cylinder containing a column of water of the desired height, the weight of which presses the center of a rubber diaphragm against the open end of a gas port. The annular space under the diaphragm around this port is connected to a second port and the design is such that either port can function as the inlet or outlet, without changing the characteristic of the valve. It thus functions as a symmetrical threshold resistor and until the pressure difference across the valve exceeds the height of the water column no flow takes place. Thereafter flow proceeds virtually unimpeded, but with a constant pressure drop, for as long as the critical opening pressure differential is exceeded. Using the arrangement of Figure 1, one would expect an unchanged tidal volume to be delivered to the circuit during the inspiratory phase of ventilation with the Air-Shields ventilator, since this is a time-cycled constant-flow phase. The ventilation would thus

Hernando Y. Arandia, M.D., Assistant Professor; Peter H. Byles, M.D., Professor; Department of Anaesthesiology, State University of New York, Upstate Medical Center, 750 E. Adams Street, Syracuse, NY 13210, U.S.A.

FIGURE 1 Schematic diagram of the anaesthetic circuit used in the study. (A) Test lung; (B) Distal Pressure transducer; (C) Wright respirometer; (D) Bain circuit tubing; (E) Emerson PEEP valve; (F) Fresh gas port; (G) Proximal pressure transducer; (H) Bain manifold; (I) Ventilator.

automatically generate the additional pressure needed to hold the PEEP valve open. During expiration, exhaled gas flows freely back through the Emerson valve and the upper airway pressure falls until the PEEP pressure is reached, and is then held at that level until the next inspiration. The fact that this valve permits bi-directional gas flow makes it peculiarly suitable for use with the Bain circuit. It has the additional advantages of being self-calibrating, easily adjustable and of having a somewhat damped action which reduces flutter.

In the first series of measurements, the PEEP valve was incorporated in the system as shown in Figure 1, between the Bain circuit outer tubing and the proximal pressure transducer on the manifold. Throughout the experiments the manifold pressure release valve was closed. Without changing the ventilator settings and fresh gas flows, VT and peak inspiratory pressures were measured at PEEP levels of 0, 5, 10 and 15 cm H₂O.

In the second set of measurements, a semi-closed circle breathing circuit was connected to the same test lung, pressure transducers, ventilator and anaesthesia machine. The same Emerson PEEP valve was interposed between the expiratory limb of the SCBC hose and the expiratory valve. The same measurements were made at identical ventilator settings and fresh gas flows with and without a PEEP valve, and with incremental increases in PEEP.

Although the Emerson PEEP valve will open on the application of sufficient positive pressure to either of its parts, a negative pressure differential across it will cause it to close. It is thus not possible to take a spontaneous breath through the valve and, clearly, if this characteristic was not appreciated or was overlooked, the consequent

airway obstruction would be a grave hazard. One method of avoiding this would be to place the valve in the hose leading from the ventilator to the Bain manifold. Thus, on disconnecting the hose to attach the reservoir bag to the manifold for spontaneous ventilation, the PEEP valve would automatically be taken out of the circuit. Accordingly, a third set of readings were taken with the valve so located, again using the Bain circuit.

To test for compression gas losses and gas leaks from the Bain circuit, the patient port and respirator hose connected to the Bain manifold were occluded with tight fitting rubber stoppers coated with glue. A pressure transducer connected to the Bain circuit and a Hewlett Packard recorder were used to measure pressure changes within the circuit. Using a 1000 ml plastic syringe, 100 ml of air were injected into the Bain circuit and the resulting peak system pressure and the time interval between air injection and return of system pressure to baseline were noted and recorded.

RESULTS

Tidal volume changes with incremental increases in PEEP compared to controlled VT measurements without PEEP are presented in Figure 2. Peak inspiratory and end-expiratory pressures measured during ventilation with 500 ml VT without a PEEP valve, were identical at distal and proximal ports of the Bain circuit.

No increase in peak inspiratory and end-expiratory pressures, or change in VT were noted after the PEEP valve was incorporated in the circuit. There was a decrease in VT with increasing PEEP. At PEEP 10 cm H₂O, VT = 450 ml and at PEEP 15 cm H₂O, VT was 400 ml.

VT increased with decrements of PEEP until it returned to 500 ml when PEEP was zero.

FIGURE 2 PEEP recording with Bain Circuit and corresponding changes in tidal volume. Distal pressure—pressures measured in the test lung. Proximal pressure—pressures measured at the Bain manifold (A) No PEEP valve; (B) with PEEP valve; (C) PEEP 5 cm H₂O; (D) PEEP 10 cm H₂O; (E) PEEP 15 cm H₂O.

Figure 3 shows that the same changes in V_T were found on application of PEEP to a semi-closed breathing circuit, except that V_T was reduced from 500 ml to 400 ml at PEEP 12 cm H_2O .

The same changes in V_T occurred on application of incremental PEEP within the Bain circuit when the Emerson PEEP Valve was interposed between the Bain manifold and the ventilator hose. The test lung was as easily inflated and deflated by mechanical ventilation with the PEEP valve located at the ventilator hose, as when the PEEP valve was located between the Bain circuit and the Bain manifold.

Injection of 100 ml of air into the Bain circuit without the test lung and with the patient port and reservoir bag port occluded and the expiratory valve closed, resulted in an increase of system pressure to a peak of 25 cm of water from a baseline of zero. Compression factor was calculated as four ml per cm of water pressure. It took 21 seconds from the time of injection of 100 ml of air for the system pressure to return to atmospheric, representing a leak of about five ml per second. Leaks were noted in the connection between the Bain tubing and the manifold, the Bain manifold expiratory vent (closed position) and the connection between the ventilator hose and Bain manifold. These are locations where leaks may occur during clinical use of the Bain circuit.

DISCUSSION

This study shows that it is possible to apply varying degrees of PEEP in the Bain circuit by using the Emerson Water Column PEEP valve. A reduction of expired tidal volume was noted with varying degrees of PEEP in both the Bain circuit and the semi-closed breathing circuit. The reduc-

tion in tidal volume found in this study may be due to compression loss of gases as well as to some leak in the anaesthetic circuit. The compression loss was calculated to be four ml per cm water pressure. Since the tidal volume and peak inspiratory pressure were held constant before application of PEEP and since the ventilatory settings were not changed with incremental increases in PEEP level, the only increase in pressure within the system that can cause further compression gas losses is the addition of positive end-expiratory pressure. At a PEEP of 15 cm H_2O , with a compression factor of four ml per cm H_2O , compression losses can be as much as 60 ml per breath. With a leak of five ml per second, and a five second respiratory cycle, the gas loss by leakage during the respiratory cycle can be as much as 25 ml. Altogether, both compression losses and loss due to leak of gases at a PEEP of 15 cm H_2O can account for 85 ml of tidal volume loss. Since the usual anaesthetic circuit and anaesthetic machine are not completely airtight, both compression losses and subsequent gas leaks may account for 100 ml of tidal volume loss that was observed with a PEEP of 15 cm of water.

As described above, placing the PEEP valve between the Bain manifold and the patient does not permit spontaneous breathing. The advantage of placing the PEEP valve in front of the Bain manifold is that PEEP can be maintained at the same level whether the patient is being ventilated mechanically or manually, so long as ventilation is controlled. If the use of PEEP is indicated, we believe that it should be maintained whether the patient is ventilated mechanically or manually.

Recognizing the danger of allowing spontaneous ventilation with the PEEP valve located in the Bain circuit as previously described, we tested the possibility of connecting the PEEP valve through a respirator hose to the reservoir bag port of the Bain manifold. Such a location of the PEEP valve has been described by Erceg using a Boehringer PEEP valve with unidirectional Bird ventilator valves.⁵ The Emerson PEEP valve in such a location performs as well with controlled mechanical ventilation. Since the ventilator hose and the PEEP valve which is connected to it will have to be disconnected from the Bain circuit if one desires to ventilate the patient manually, or if one wishes the patient to breath spontaneously, the problem of being unable to get an adequate tidal volume on spontaneous ventilation with the PEEP valve can be circumvented. Obviously, no PEEP will be delivered if the patient breathes spontaneously or if

FIGURE 3 PEEP recording with semi-closed Circle System and corresponding changes in tidal volume. Distal - Pressures measured in test lung. Proximal - Pressures measured between PEEP valve and expiratory valve. (A) No PEEP valve; (B) with PEEP valve; (C) PEEP 5 cm H_2O ; (D) PEEP 10 cm H_2O ; (E) PEEP 12 cm H_2O .

the patient is ventilated manually when the PEEP valve is located between the Bain manifold and the ventilator hose.

In conclusion, PEEP can be applied satisfactorily within the Bain circuit using an Emerson Water Column PEEP valve. If one chooses to put the Emerson PEEP valve between the Bain tubing and the Bain manifold, then the patient's ventilation must be controlled continuously, either manually or mechanically. Spontaneous breathing when the PEEP valve is placed in such a location will provide an inadequate tidal volume, which may result in hypoxaemia and acute pulmonary oedema. To eliminate this danger, the PEEP valve may be placed instead between the Bain manifold and the ventilator hose. However, in such a location PEEP will no longer be obtainable for manually controlled or spontaneous ventilation.

There is some loss of tidal volume with the application of PEEP in the Bain circuit as in the

semi-closed breathing circuit. This loss of tidal volume is secondary to compression loss of gases as well as leakage of gas during the respiratory cycle.

REFERENCES

1. BAIN, J.A. & SPOEREL, W.E. A Streamlined Anaesthetic System. *Canad. Anaesth. Soc. J.* 19: 426-435 (1972).
2. CHU, Y.K., RAH, K.H. & BOYAN, C.P. Is the Bain Breathing Circuit the Future Anesthesia System? An evaluation. *Anesth. Analg.* 56: 84-87 (1977).
3. GARDINER, A.J.S. & PALMER, K.N.V. Effect of Premedication and General Anaesthesia on Arterial Blood Gases. *Brit. Med. J.* ii: 1433 (1964).
4. YAKAITIS, R.W., THOMAS, J.D. & MAHAFFEY, J.E. Effects of Intraoperative PEEP on Postoperative Arterial Oxygenation. *Anesth. Anal.* 54: 427-432 (1975).
5. ERCEG, G.W. PEEP for the Bain Breathing Circuit. *Anesthesiology* 50: 542-543 (1979).

RÉSUMÉ

La possibilité d'utiliser une pression positive de fin d'expiration avec le circuit de Bain, au moyen d'une valve à PEEP d'Emerson, a été étudiée à l'aide d'un montage, en laboratoire. On a trouvé que ceci était possible en ventilation contrôlée (manuelle ou mécanique) mais non en respiration spontanée. Une diminution de l'air courant parallèle à l'élévation de la PEEP a été observée. Cette diminution était causée par la compression des gaz et, à un degré moindre par des fuites dans le système. La diminution maximale observée dans les conditions de l'étude était de 100 ml avec une PEEP de 15 cm H₂O.

La valve à PEEP se place entre l'extrémité du tube de Bain et la pièce de raccord (manifold) permettant de relier le tube de Bain soit au ballon réservoir, soit au tube de sortie de l'appareil à ventilation mécanique. On ne devrait cependant jamais laisser le malade en respiration spontanée lorsque la valve à PEEP est dans cette position car elle crée une résistance à l'inspiration. Cet inconvénient peut être évité si la valve est placée entre la pièce de raccord et le tube de sortie du ventilateur, mais alors la PEEP n'est disponible que si on utilise le ventilateur.