THE EFFECTS OF ADDING A POSITIVE EXPIRATORY PRESSURE PLATEAU (P.E.P.P.) WITH CONTROLLED VENTILATION WITH A BIRD MARK 7 OR MARK 8 VENTILATOR*

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INTRODUCTION

IN THE LAST FEW YEARS several workers[1-5] have demonstrated improved gas exchange during mechanical ventilation by adding a positive expiratory pressure plateau (P.E.P.P.) to the pattern of ventilation. Since that time P.E.P.P. has been used both as a means of oxygenating patients with large alveolar-arterial oxygen gradients and to ventilate patients with lower inspired oxygen tensions than would otherwise be possible, in an effort to minimize pulmonary oxygen toxicity.

However, many clinical situations are such that constant volume ventilators are not available and P.E.P.P. cannot be readily applied. In such circumstances it has been obviously tempting to incorporate P.E.P.P. to controlled ventilation with a Bird Mark 7 or Mark 7 ventilator. Before doing this we should consider the effects of P.E.P.P. on the performance of a constant pressure, time cycled ventilator. The following experiments were executed to determine these effects:

EXPERIMENTS AND METHOD

Bird Mark 7 and Mark 8 ventilators were set up to ventilate a 3-litre test lung, as shown in Figure 1, with and without P.E.P.P. in the expiratory circuit. Ventilation was controlled by appropriately setting the ventilator being tested.

The ventilators were driven by:

(i) oxygen, with the air-mix venturi open, and

(ii) compressed air with oxygen entrained through the ambient side of the ventilator.

Continuous pressure monitoring of the circuit pressure was recorded by a Statham pressure transducer. Flow was continuously monitored by a Vertek Digital Pneumotach VR 4000. Inspired nitrogen percentage (and, therefore, continuous oxygen percentage by deduction) was monitored by a Med Sciences Nitralyzer 505. All these parameters were recorded on a Beckman Type S-II Dynograph.

In all the experiments the Dynograph paper speed was 0.2 cm/sec.

The following samples represent the observations made and data recorded.

Mode I

This is representative of our experiments with Bird Mk 7 or Mk 8 ventilators with P.E.P.P. of 4 or 8 cm H_2O, driven by O_2, with the air-mix venturi open.

Figure 2 shows results with a Bird Mk 8, with a ventilating pressure of 20 cm

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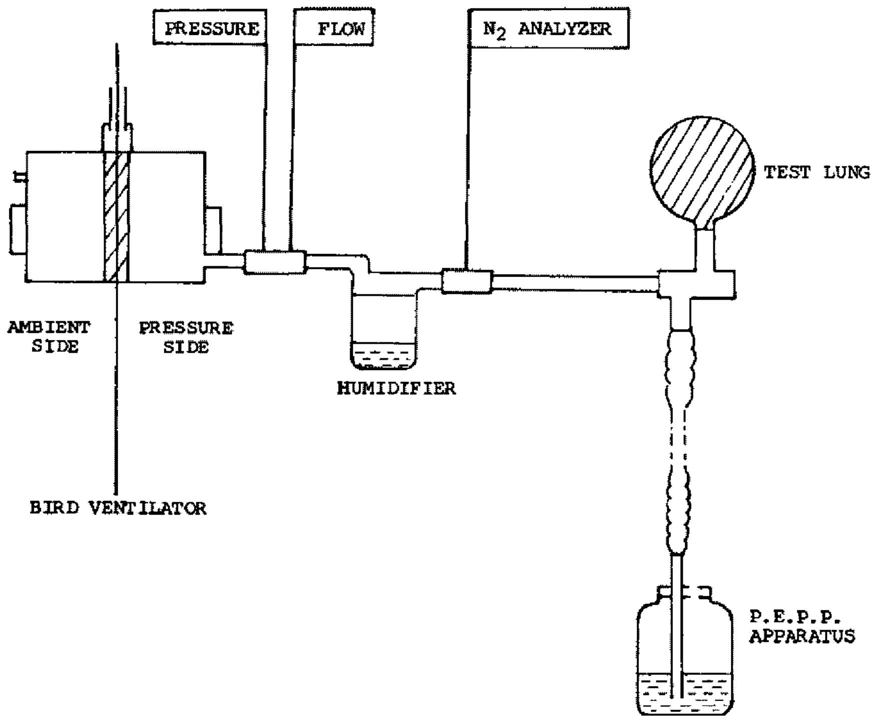

FIGURE 1. Diagramatic representation of test circuit and instrumentation.

H_2O, peak flow of 1.6 L/sec and a tidal volume of 650 ml, delivering 54 per cent oxygen.

After adding P.E.P.P. of 8 cm H_2O the immediate changes were:

1. The expiratory time increased from 3 to 18 seconds.
2. The inspiratory time decreased from 2.0 to 1.0 second.
3. The tidal volume decreased from 650 ml to 250 ml in 50 seconds and to 190 ml in 15 minutes.
4. The oxygen percentage increased from 54 per cent to 70 per cent in 50 seconds and to 95 per cent in 15 minutes.

Mode II

Figure 3 shows results from the same Bird Mk 8 ventilator driven by oxygen with air-mix venturi open and previously determined adjustments to the ventilator made at the moment when P.E.P.P. was added, so that the tidal volume of 650 ml was maintained. This required a ventilating pressure of 28 cm H_2O and a flow rate of 1 L/sec.

This caused:

1. An increase in inspiratory time to 5 seconds.
2. The shortest expiratory time achievable was 23 seconds.

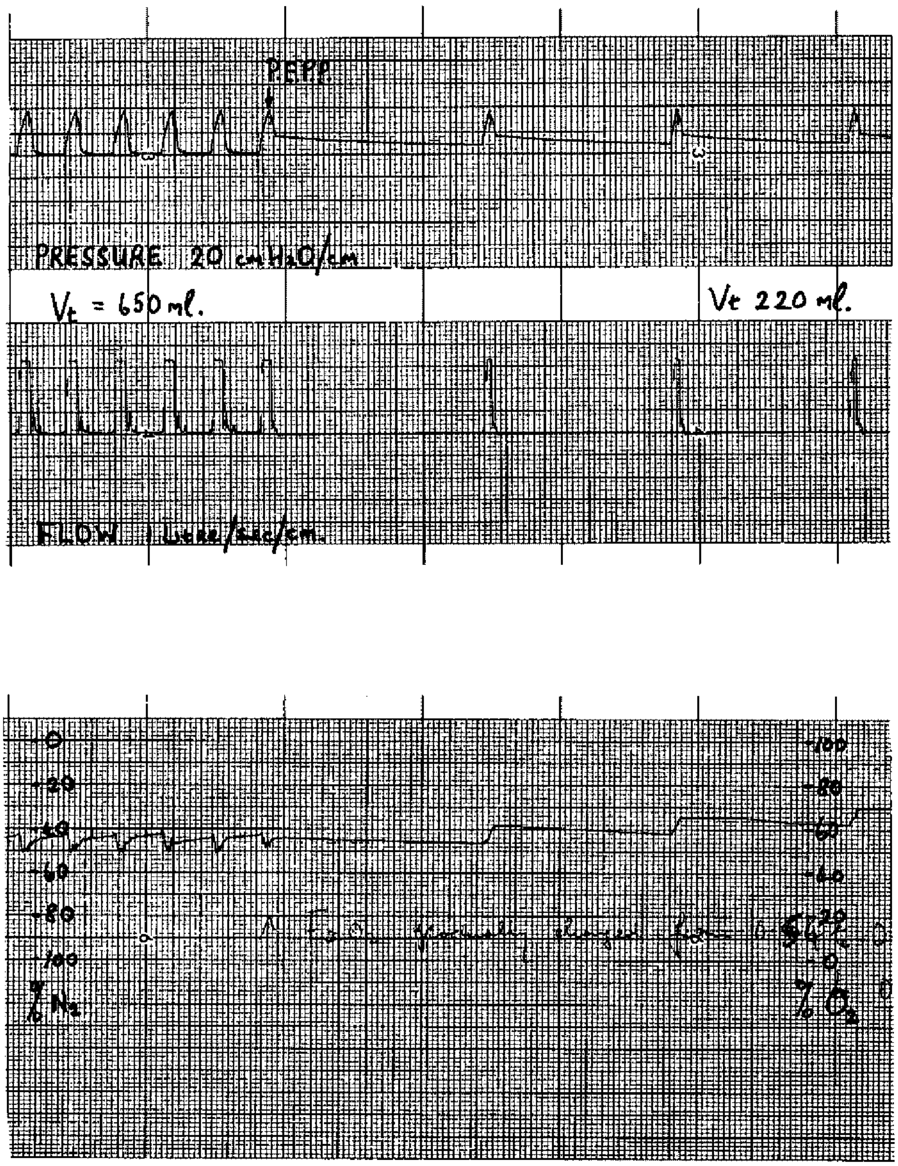

FIGURE 2. Results of P.E.P.P. of 8 cm H_2O with Bird Mark 8 ventilator, with a ventilating pressure of 20 cm H_2O, peak flow of 1.6 L/sec, tidal volume of 650 ml, delivering 54 percent oxygen.

3. The oxygen percentage rapidly increased from 58 per cent to 96 per cent in 4 minutes.

4. Flow characteristics were grossly changed.

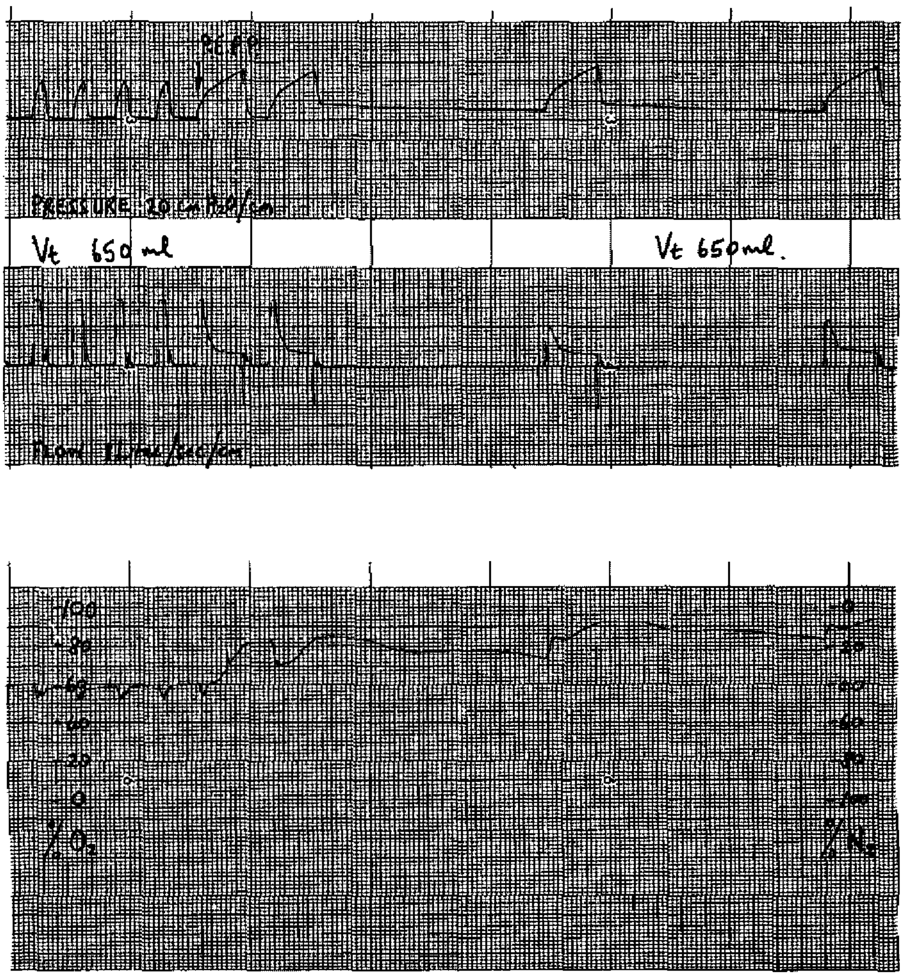

FIGURE 3. Results from same ventilator as Figure 2 driven by oxygen with air-mix venturi open and adjusted to maintain tidal volume of 650 ml.

Mode III

The data in Figure 4 is derived from a Mk 7 ventilator driven by air with 10 L of oxygen added to the ambient side of the ventilator to give 48 per cent oxygen.

The effects of adding P.E.P.P. of 8 cm H_2O are observed and are typical of the changes observed with a ventilator being so operated. These effects were:

1. Increase in expiratory time from 4 seconds to 20 seconds. After 4 ventilations the ventilator ceased to function and the system returned to room air in 65 seconds.
2. Inspiratory time decreased from 1.5 seconds to 0.5 second.

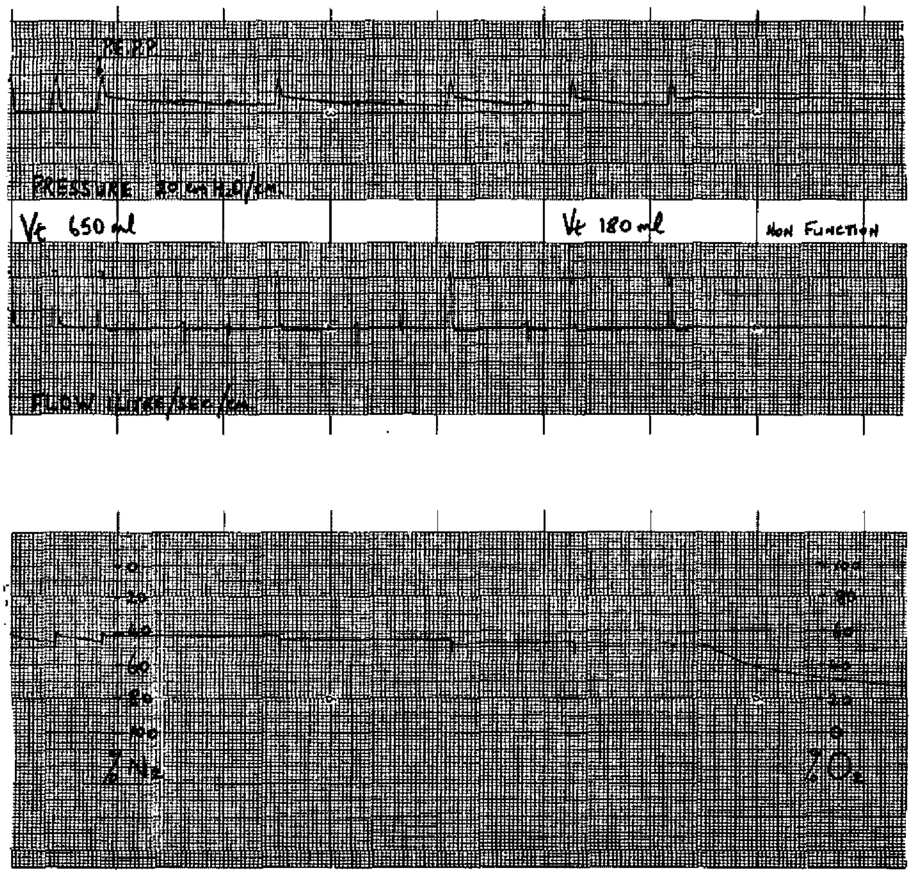

FIGURE 4. Data from Mark 7 Bird Ventilator driven by air with 10 l of oxygen added to the ambient side of the ventilator.

3. Tidal volume decreased from 650 ml to 180 ml before the ventilator ceased to function.

4. Altered flow characteristics.

The machine could be adjusted to function again by increasing ventilating pressure to 38 cm H_2O. However this still caused a decrease in tidal volume and the percentage of oxygen delivered dropped from 52 per cent to 24 per cent in 3 minutes.

Mode IV

These experiments were repeated using a Q circle and paediatric tidal volumes of 20 ml of oxygen were added to the humidifier to give 46 per cent oxygen.

Effects similar to those described for Mode III were observed (Figure 5) and frequently the ventilator was made non-functional, stopping in continuous expiration. If function could be regained by adjusting the machine the ventilatory pat-

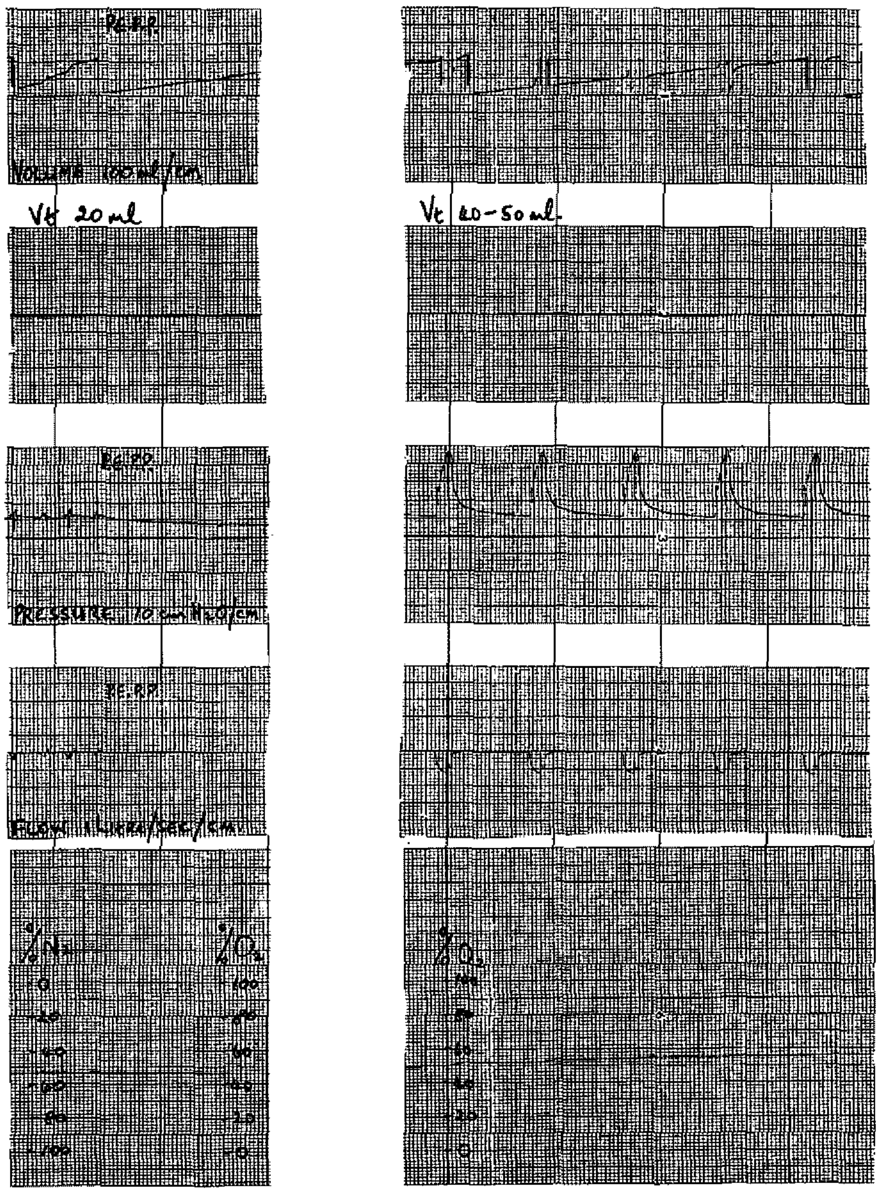

FIGURE 5. Effects using a Q circle with paediatric tidal volumes of 20 ml oxygen added.

tem was always completely unrealistic for infant ventilatory support. Oxygen percentage increased because the oxygen was added to the pressurized inspiratory limb.

Discussion

Fairley[6–7] has clearly shown that altering patient compliance readily affects the performance of the Bird Mk 7 and Mk 8 ventilators. The flow, volume and cycling performance is affected. When the ventilator is driven by oxygen with the air-mix venturi open the percentage of oxygen delivered varies markedly with changes in flow.

With controlled ventilation with a Bird Mk 7 or Mk 8 and adding P.E.P.P., with the air-mix venturi open, we have demonstrated:

1. Altered percentage of oxygen delivered.
2. Reduced tidal volume.
3. Increased expiratory time.
4. Altered flow characteristics.

With some ventilators it caused complete non-function. With all ventilators tested it altered the function of the time cycling mechanism, varying in degree from moderate increase of the expiratory time to complete non-function.

With consideration of the mode of action of the Bird ventilator and its venturi and expiratory time cycling mechanism, the effects observed on adding P.E.P.P. to controlled ventilation should have been predictable.

Let us consider the function of the Bird Mk 7 or Mk 8 with air-mix open and the effects of a continuous pressure on the pressure side of the ventilator which P.E.P.P. will bring about (Figure 6).

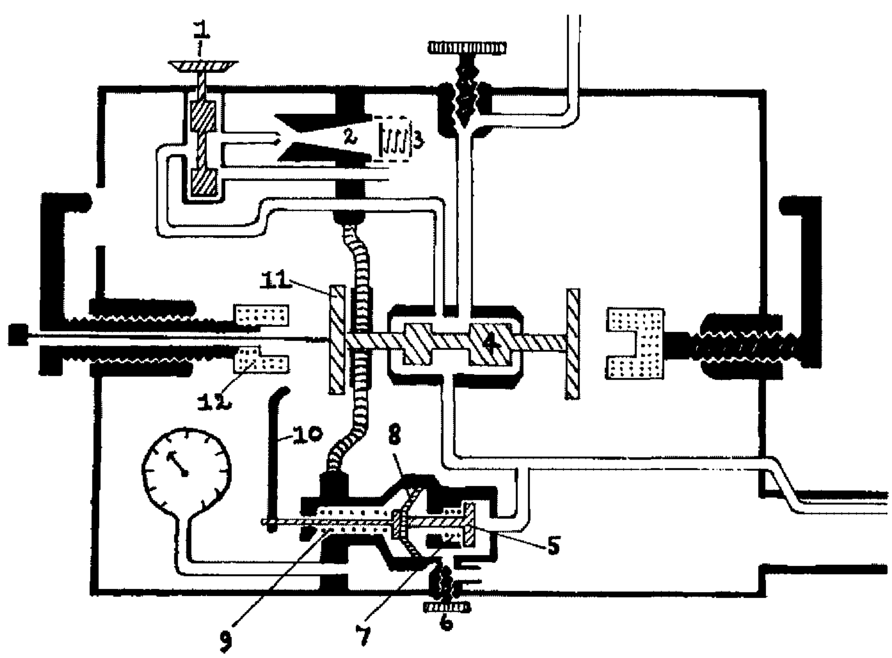

Figure 6. Schematic representation of Bird Mark 7 Ventilator.

1. Expiratory time cycling mechanism

The expiratory time cycling mechanism is controlled by the rate of bleed-off of pressure on the pressure side of the diaphragm (*8*) throughout expiration. This bleed-off of pressure is into the pressure side of the ventilator. This release of pressure occurs through the "air-mix" control (*1*) and the sliding valve (*4*). The piston (*5*) is returned to its resting position by the spring (*7*). The diaphragm (*8*) can only return to its resting position under the influence of the spring (*9*) at a rate which depends on the bleed off of pressure behind it through the expiratory time control (*6*), which once more is into the pressure side of the ventilator. It is evident that all avenues of pressure release for the expiratory time cycling mechanism will be opposed by the increased pressure in the pressure side of the ventilator imposed by adding P.E.P.P. The addition of a P.E.P.P. throughout expiration makes it increasingly difficult for this bleed-off of pressure to occur. Consequently, the expiratory phase will be increasingly prolonged, even to the point of non-function, depending on the characteristics of the particular ventilator and the amount of P.E.P.P. If the diaphragm of the expiratory valve is delayed or obstructed in its return to the resting position, then the movement of the arm (*10*) which knocks the plate (*11*) away from the ambient side magnet (*12*) will be similarly affected. Should the expiratory phase be indefinitely long, then inspiration will not be initiated. Consequently, the ventilator becomes non-functional.

2. The Venturi

Any resistance to the venturi will cause a decrease in the venturi gas flow per unit time. At the beginning of ventilation and of venturi flow, the pressure on both sides of the ventilator is normally atmospheric. Therefore, with P.E.P.P. in circuit at the beginning of ventilation the pressure side of the ventilator will have a pressure above atmospheric and the increase will be equal to the amount of P.E.P.P. applied. This offers resistance to the venturi flow and, therefore, will cause a decrease of total venturi flow through the diffuser (*2*).

If P.E.P.P. is of such magnitude as to resist the opening of the spring gate of the one way valve (*3*) then venturi flow will not occur.

Summary

The effects of adding a P.E.P.P. to controlled ventilation of a test lung with a Bird Mk 7 and Mk 8 ventilator, with the air-mix venturi in use, have been studied.

P.E.P.P. causes

(1) Increased resistance to the bleed-off pressure of the expiratory time cycling mechanism and

(2) Increased resistance to venturi flow.

These effects induce the following changes:

1. A gross change in percentage of oxygen delivered
2. A decrease in tidal volume
3. An increase in expiratory time
4. A decrease in inspiratory time
5. An alteration of flow characteristics.

The effects vary in magnitude with the amount of P.E.P.P. and the characteristics of the individual machine. The effects range from moderate disturbance of ventilator function to complete non-function. Even by making adjustments to the machine to produce the original tidal volume, the expiratory time effects and inspired gas percentage effects cannot be overcome.

Therefore, to use P.E.P.P. with controlled ventilation with a Bird Mk 7 or Mk 8, the ventilator must be driven with a pre-mixed gas of required oxygen concentration without use of the venturi. Even so, detrimental changes in the performance of the expiratory time cycling mechanism are to be anticipated.

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Résumé

Nous avons étudié les effets de l'application d'un plateau expiratoire positif au moyen du Bird Mark 7 et 8 sur un modèle pulmonaire. Le venturi provoquant le mélange d'air était dans le système.

Le plateau de pression positive expiratoire causait:

(1) une augmentation de la résistance pour l'interruption de la pause expiratoire.

(2) Une augmentation de la résistance pour le débit du Venturi. Ces changements provoquent les effets suivants:

– un changement important de l'oxygène débité.
– une diminution d l'air courant
– une augmentation du temps expiratoire
– une diminution du temps inspiratoire
– une modification des débits

Ces changements varient avec le degré de pression positive appliquée et les caractéristiques de chaque machine. Ils s'étendent de la modification légère à l'arrêt complet. Aucun ajustement des gaz inspirés ou du temps expiratoire ne peut rétablir le volume original d'air courant. C'est pourquoi si l'on veut appliquer un plateau de pression positive expiratoire avec un Bird Mark 7 ou 8, il faut pousser le respirateur avec des gaz préalablement mélangés à la concentration désirée sans l'aide du Venturi. Même ce faisant, il est à prévoir qu'on nuira quand même au mécanisme de la pause expiratoire.

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