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Case reports

Positive end expiratory pressure and critical oxygenation during transport in ventilated patients

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Abstract. Transportation of patients critically dependent on positive end expiratory pressure (PEEP) can be problematic, as a patient of ours with adult respiratory distress syndrome (ARDS) and bilateral broncho-pleural fistulae demonstrated. He required intermittent positive pressure ventilation (IPPV) (Siemens 900C) with 100% O_2 and PEEP of 2 kPa to maintain his arterial O_2 saturation (SaO_2) >90%. Severe hypoxemia (SaO_2 <75%) occurred on change to a portable ventilator (Oxylog, Dräger) with a PEEP valve (Ambu 20) at its expiratory port, despite adjusting the valve to 2 kPa, continuing use of 100% O_2, and varying the ventilatory pattern. The problem appeared due to loss of PEEP because of gas leak from the lungs via his intercostal catheters. It was solved by introducing a continuous O_2 flow of 5 l/min into the circuit between the Oxylog non-rebreathing valve and endotracheal tube. We used a model lung to investigate the effect of a gas leak from the lungs or circuit on the performance of the Oxylog IPPV/PEEP system. Lung compliance and ventilatory pattern were adjusted so that tidal volume (V_T) = 0.6 l, peak inspiratory Airway pressure (PIP) = 5 kPa, PEEP = 1.5 kPa, and respiratory rate = 10/min. A small leak was introduced from the lung resulting in a decrease in PIP, V_T, and PEEP. Adjustment of ventilator minute volume to restore PIP to 5 kPa failed to restore PEEP, airway pressure continuing to fall throughout the expiratory pause. PEEP was restored by providing a compensatory flow of O_2 of 5 l/min to the system between the Oxylog non-rebreathing valve and the lung. We conclude that significant loss of PEEP can occur in patients with gas leaks from the lung when ventilators, such as the Oxylog, are used that do not provide a compensatory flow of gas into the lung during expiration and the expiratory pause. If the patient is critically dependent on PEEP this loss will result in severe hypoxemia.

Key words: PEEP – Oxygenation – Transport – Ventilator – Bronchopleural fistula

The transportation of patients with severe disorders of gas exchange, critically dependent on positive end expiratory pressure (PEEP), can be problematic. Simple ventilators are often used for the purpose and unforeseen changes in ventilatory parameters may take place that put the patient at risk of hypoxemia.

Where there is a leak of gas from the lung or ventilator breathing circuit, alveolar hypoventilation and/or loss of PEEP may occur. During the inspiratory phase of intermittent positive pressure ventilation (IPPV) a component of tidal volume is lost through the leakage pathway. This may be compensated for by increasing the tidal volume delivered by the ventilator. However, an increase in inspiratory gas flow would not be expected to compensate for the continuing loss of gas through the leak during expiration. The magnitude of this loss would depend on the level of PEEP, the size and resistance of the leakage pathway, the elastic recoil of the lung and chest wall, and the length of expiration. If uncompensated, the leak would result in a progressive decline in airway pressure throughout expiration and the expiratory pause, with a decrease in the level of PEEP and in lung volume. Should the patient be critically dependent on PEEP, significant hypoxemia would be expected [1].

The loss of PEEP could be avoided by delivering a continuous flow of gas into the breathing circuit so as to compensate for the continuing leak of gas during the expiratory pause. This characteristic, or the more sophisticated inspiratory/expiratory valve systems used to maintain PEEP in many ventilators in common use in intensive care units (ICU), is not provided by portable ventilators such as the Dräger Oxylog. These simple ventilators are often used in transferring patients between ICU and other destinations, such as the operating theatre.

We report the case of a patient with adult respiratory distress syndrome (ARDS) and bilateral bronchopleural fistulae who was critically dependent on PEEP and presented just such a problem. We describe how hypoxemia was avoided during transport by simple modification of the breathing circuit of his portable ventilator. The mechanisms underlying our modification were subsequently investigated in the laboratory using a model lung.

Case report

A 17-year-old youth sustained a closed head injury and major blunt trauma to the chest in a motor vehicle accident. He remained intubated and ventilated throughout his ICU admission.

Several ribs were fractured in each hemithorax, the lungs were severely contused, and he developed bilateral pneumothoraces requiring placement of intercostal catheters. One week after admission he developed a staphylococcal septicaemia, followed by adult respiratory distress syndrome (ARDS), persistent bronchopleural fistulae and gross surgical emphysema. He developed renal failure and disseminated intravascular coagulation (DIC) with purpura fulminans. The right arm became cold and gangrenous. Oxygenation became critical, and a saturation of 90% or more was achieved only with a fractional inspired oxygen concentration (F_iO_2) of 1.0 and PEEP of 2 kPa (20 cmH_2O). Any reduction in these parameters produced immediate hypoxemia and bradycardia. He was ventilated with a Servo 900C ventilator.

The sepsis, multiple organ failure and critical oxygenation persisted in spite of conservative treatment and two factors were considered to be potentially contributing to or perpetuating his critical state: firstly, the gangrenous right arm, and secondly, the possibility of ischaemic bowel. He was eventually to undergo two separate surgical procedures which required transportation to the operating theatre, amputation of the right arm and a laparotomy, before he died 21 days after admission.

Transport to the operating theatre presented a major problem because of his critical oxygenation. Changeover from the Servo 900C ventilator to a Dräger Oxylog ventilator with continued use of an F_iO_2 of 1.0, the same respiratory rate and minute volume, and with an Ambu 20 PEEP valve set at 2 kPa (20 cm H_2O) at its expiratory port resulted in immediate progressive hypoxemia. Arterial oxygen saturation (SaO_2) decreased rapidly from >90% to <75% on each occasion that it was attempted. The decline in SaO_2 was only arrested by changing back to the Servo 900C.

We hypothesized that: (1) loss of PEEP occurred using the Dräger Oxylog and Ambu 20 PEEP valve because of an uncompensated continuous leak of gas from the lungs via the bronchopleural fistulae during expiration and the expiratory pause, resulting in a progressive fall in functional residual capacity (FRC) and increasing hypoxaemia; (2) this leak would be compensated for by provision of a compensatory oxygen flow, delivered to the ventilator circuit adjacent to the endotracheal tube via a T connector.

On this basis we inserted a simple T connector between the non-rebreathing valve of the Oxylog breathing circuit and the catheter-mount that connected the breathing circuit to the endotracheal tube (Fig. 1). An oxygen flow of 5 l/min to the T connector proved highly effective in maintaining oxygenation with SaO_2 being preserved at greater than 90% on the Oxylog ventilator, allowing successful transfer to the operating theatre on both occasions.

As we had no immediately available device to measure and record PEEP in the Oxylog cicruit, we subsequently investigated our hypotheses in the laboratory, using a model lung.

Laboratory investigation: method and results

A model lung was used to investigate the effect of a gas leak from the lungs or ventilator breathing circuit on the performance of the Dräger Oxylog IPPV/PEEP system.

The model lung consisted of a 2-l antistatic rubber bag mounted between hinged boards between which springs where stretched, the length and spring constant of which were chosen to simulate the low compliance of our patient with ARDS (Fig. 2). Leakage from a breathing circuit or bronchopleural fistula was simulated by creating a defect in the tail of the bag. The magnitude of this leak could be controlled using a gate clamp.

The model lung was ventilated using the Dräger Oxylog ventilator, with an Ambu 20 PEEP valve placed in the usual position at the expiratory port of the non-rebreathing valve in the Oxylog circuit. A compensatory oxygen flow could be introduced via a T connector positioned at the neck of the 2-l bag, equivalent to the position of the endotracheal tube. A pneumotachograph (Fleisch No. 2) was placed between the T connector and the bag to measure tidal volume (V_T). Airway pressure (Paw) was measured at the T connector using a pressure transducer (PM131, Statham, Oxnard, CA). These parameters were recorded on a direct writing polygraph (Model VII, Watanabe, Tokyo, Japan).

The compliance of the model lung and the ventilatory pattern were adjusted so that the following parameters were established at the start of the experiment: a V_T of 0.6 l; a respiratory rate of 10/min; a peak inspiratory pressure (PIP) of 5 kPa (50 cmH_2O); and a PEEP of 1.5 kPa (15 cmH_2O).

After a control period (Fig. 3a), the leakage pathway was opened, resulting in an immediate decrease in PIP and decrease in PEEP. The ventilator minute volume was increased, by increasing V_T, so as to restore PIP to 50 cmH_2O. While this adjustment compensated for the loss of inspiratory gas flow via the leak, it failed to correct the progressive decline in airway pressure throughout expiration and the expiratory pause with its attendant de-

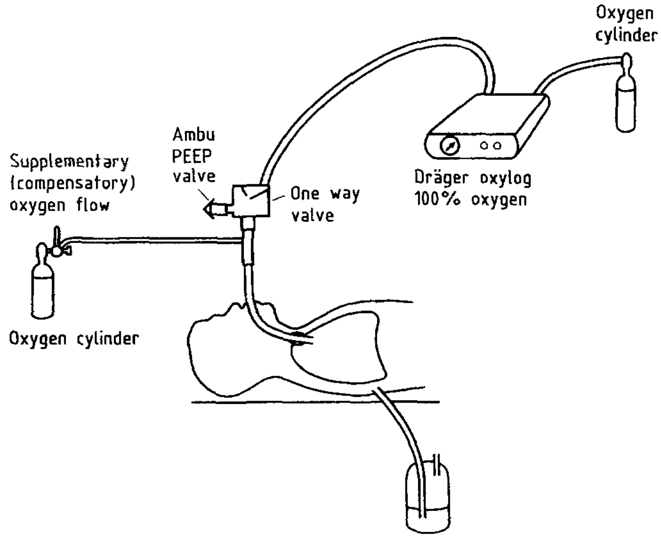

Fig. 1. Diagramatic representation of the modified Dräger Oxylog IPPV/PEEP breathing circuit used to transport our patient, showing the provision of a compensatory continuous oxygen flow into the circuit

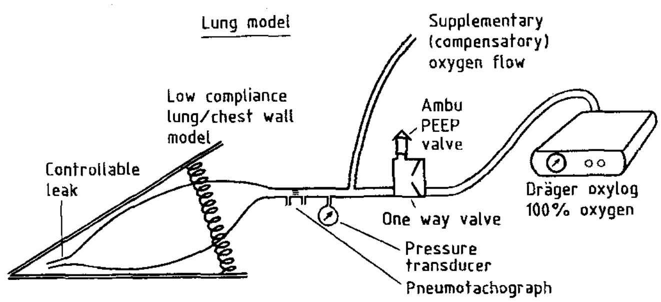

Fig. 2. Diagramatic representation of the model lung used to investigate the effect of a gas leak on the performance of the modified Dräger Oxylog IPPV/PEEP breathing circuit. For further details see text

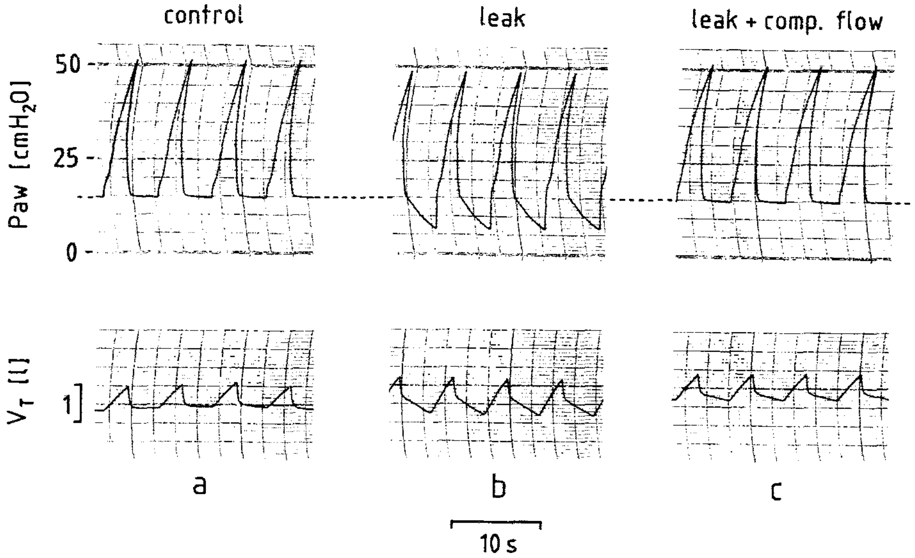

Fig. 3a–c. Airway pressure (*Paw*) and tidal volume (V_T) measured in the model lung under the various experimental conditions: **a** Control period: no leak. **b** Leak from lung introduced and ventilator minute volume adjusted to restore peak inspiratory Paw (PIP) towards 5 kPa (50 cmH_2O). Note continuing decline in Paw throughout expiration. **c** Continuing leak with compensatory continuous flow of oxygen of 5 l/min now introduced into the circuit. Note the restoration of PEEP to control levels. For further explanation see text

crease in the level of PEEP (Fig. 3b). A compensatory continuous flow of oxygen of 5 l/min was then added via the T connector in an attempt to compensate for the leak of gas from the model lung during expiration and the expiratory pause. This immediately restored the PEEP to a stable level of 1.5 kPa (15 cmH_2O), as it was under control conditions. PIP also increased because, in addition to its effects in expiration, the 5 l/min continuous gas flow partially compensated for loss of gas from the lung during inspiration. The ventilator minute volume was then reduced to restore a PIP of 5 kPa (50 cmH_2O); PEEP remained stable at 1.5 kPa (15 cmH_2O) following this adjustment (Fig. 3c).

V_T was measured at the neck of the 2-l bag. Introduction of the leak caused inspiratory V_T to exceed expiratory V_T by the volume of gas escaping through the leak. Increasing ventilator minute volume increased inspiratory V_T. In Fig. 3b the V_T signal from the pneumotachograph has been offset to return it to a constant baseline for the start of each inspiration. Without the offset there would have been a progressive rise in the baseline with each respiratory cycle. This technical adjustment accounts for the apparent ongoing "expiration" seen during the expiratory pause in the figure despite the absence of flow across the neck of the bag during that time, all the ongoing loss of gas from the lung occurring via the leakage pathway. Allowing for the offset, the figure demonstrates the difference in inspiratory and expiratory V_T when a leak is introduced. In Fig. 3c the influence of the compensatory continuous oxygen flow and the reduction of ventilator minute volume (see above) is seen. Inspiratory V_T is less and the offset during the expiratory pause appears less because of the changed proportion of inspiratory V_T to expiratory V_T and the presence of the small continuous oxygen flow into the lung throughout the expiratory pause.

Discussion

PEEP implies the use of positive pressure in the airway at the end of expiration. When the preset expiratory pressure is reached further expiration is stopped by a pressure-sensitive valve at the expiratory port of the ventilator breathing circuit [2]. This signifies the end of expiration and the commencement of the expiratory pause. If there is loss of gas from the lung via a bronchopleural fistula or from elsewhere in the breathing circuit, the pressure in the circuit and airway will continue to decline below this preset expiratory pressure if a flow of gas into the circuit is not provided to compensate for the leak. This can be achieved by sophisticated inspiratory/expiratory valve systems, as in the Siemens Servo 900C ventilator [3], or, in less complex ventilators, by a continuous flow of gas into the breathing circuit as we have demonstrated. Our report illustrates that this can be simply provided via a T connector to the breathing circuit near the endotracheal tube.

While we have studied the Dräger Oxylog, the underlying principle is broadly applicable. It should be noted that a further relevant limitation of the Dräger Oxylog is that the pressure gauge on the ventilator monitors circuit pressure proximal to the non-rebreathing valve assembly. As the PEEP valve is mounted distal to this point, the gauge does not register the PEEP levels [4], hence any loss of PEEP can be easily overlooked. Our report highlights the necessity to adequately monitor the level of PEEP within the circuit.

These considerations are of great importance where the patient with a bronchopleural fistula is critically dependent on PEEP, as any loss of PEEP will be accompanied by severe hypoxemia. The modification we describe allows a simple ventilator such as the Dräger Oxylog to be used in the transport of such patients. Where available a sophisticated ventilator, such as the Siemens 900C, organized for patient transport, is a useful alternative, although more bulky and cumbersome. Whatever the choice of ventilator, basic requirements are to ensure adequate PEEP and gas exchange, besides appropriate oxygen content and humidification of the inspired gas.

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