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Case Report

A new method of securing the airway for differential lung ventilation in intensive care

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Differential lung ventilation to achieve optimised ventilation for each lung is a procedure rarely used in the intensive care unit, to treat select cases of severe unilateral lung disease in intensive care. However, existing techniques both for securing the airway and ventilating the lungs are challenging and have complications. We present the use of differential lung ventilation in the intensive care setting, securing the airway with a technique not previously described, using endotracheal tubes inserted through a tracheotomy and orally. In the course of 1 month, we treated three patients with unilateral atelectatic and consolidated lungs by differential lung ventilation. The left lung was ventilated through an endotracheal tube inserted into the left main stem bronchus through a tracheotomy. The right lung was ventilated through an endotracheal tube with the cuff positioned immediately under the vocal cord. In patient 1, the diseased lung remained consolidated after 24 h of differential lung ventilation. In the two other patients, the diseased lungs responded to differential lung ventilation by increased compliance and radiographic increased aeration. Differential ventilation of the lungs with this novel technique is feasible and may increase the likelihood of successful treatment of atelectatic lungs refractory to conventional ventilator strategies.

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Differential lung ventilation (DLV), and especially single lung ventilation, is frequently used in anaesthesia for thoracic surgery. DLV in intensive care has been used more rarely and in selected cases. The indication is often to treat severe unilateral lung disease following trauma,[1–3] or lung disease with an asymmetrical distribution, such as pneumonia, unilateral lung oedema, aspiration and bronchopleural fistula.[1,2]

Air or any other gas will flow down the path of least resistance and highest compliance, creating a dilemma in the treatment of unilateral or asymmetric lung disease resulting in different airway resistance and lung compliance. The airway pressures needed to expand and keep the diseased lung open are often harmful to the healthy lung and can also influence cardiac function negatively.[4] The advantages of independent lung ventilation in unilateral lung disease are the possibilities of applying different levels of positive end-expiratory pressure (PEEP), inspiratory pressure and volumes, inspiratory to expiratory ratio, and even different gas mixtures to the two lungs. Thus, sparing the healthier and more compliant lung and the circulation from the harmful effects of the pressures needed to recruit and ventilate the diseased lung.

The use of DLV has been described since 1931 in anesthesia and since 1976 in intensive care.[5] There are several airway devices to enable DLV, including bronchial blockers, double-lumen endotracheal tubes, double-lumen tracheotomy tubes and two single-lumen tubes through a tracheotomy.[1,3,6,7] However, these techniques have potential pitfalls.[1] Specific to double-lumen tubes, complications like vocal cord trauma, airway ischaemia and stenosis, pneumothorax, pneumomediastinum, subcutaneous emphysema, and displacement have been

Authors' contributions: Both authors contributed equally to this paper. GWS drafted the manuscript and participated in treatment of the patients described in this case study. KD developed the DLV technique described in this paper, participated in treatment of the patients, conceived the study and its design, took photos, and helped to draft the manuscript

Table 1

Patient demographics.

Patient no:	Age	SAPS-II score	Diagnosis	Length of mechanical ventilation prior to DLV (days)	Length of DLV (h)	Length of mechanical ventilation after DLV (days)	Total length of stay in ICU (days)	Outcome
1	73	27	Pneumonia, COPD	18	24	1	23	Died
2	60	45	Foreign body, pneumonia	1	24	13	22	Survived
2	79	37	Legionella pneumonia	17	24	8	34	Survived

DLV, differential lung ventilation; ICU, intensive care unit; SAPS-II, Simplified Acute Physiology Score II.

reported.[7–9] Other airway devices are likely to have some of the same risks. The aim of this article is to present a technique not previously described combining two endotracheal tubes, one through a tracheotomy and one inserted orally, for DLV.

Materials and methods

The Norwegian Social Science Data Services approved the study. Consent for publication was obtained. In the course of 1 month, we treated three adult patients with unilateral atelectatic and consolidated lungs, which had not responded to conventional recruitment and ventilation strategies, by DLV. Different PEEP levels, bronchoscopy and recruitment manoeuvres had been attempted. Demographic data for our patients are presented in Table 1. The patients differed in that patient 1 had longstanding severe lung disease, affecting the left lung disproportionately. The remaining two patients had acute lung disease of shorter duration. In patients 2 and 3, the left and right lungs were consolidated, respectively (Table 2).

Technique

In all three patients, the left lung was ventilated through an endotracheal tube (6.0 mm inner diameter) with the inflated cuff in the left main stem bronchus placed through a tracheotomy between the second and third tracheal cartilage ring. The right lung was ventilated through an endotracheal tube (8.0 mm inner diameter) inserted orally (Fig. 1). This tube was fixed to the skin using adhesive tape to keep the cuff just distal to the vocal cords and the distal tube end just below the tracheotomy (Fig. 2).

The left lung endotracheal tube was passed through the tracheotomy over a curved tip catheter, into the correct position in the left main bronchus. Correct tube placement was confirmed visually by

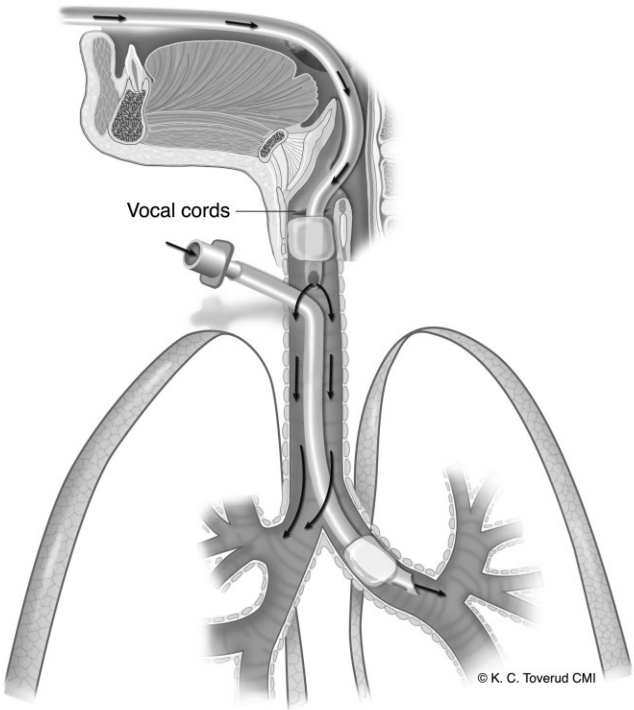


Fig. 1. Illustration of the airways with tubes in place for DLV.

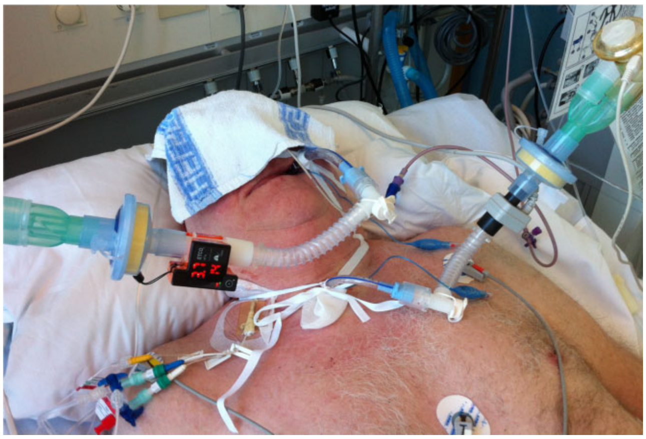
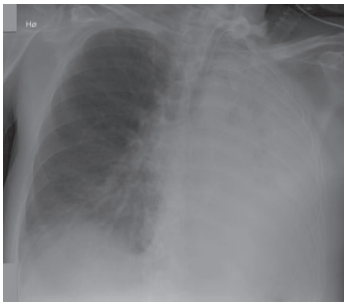
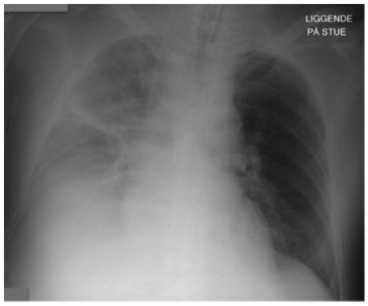
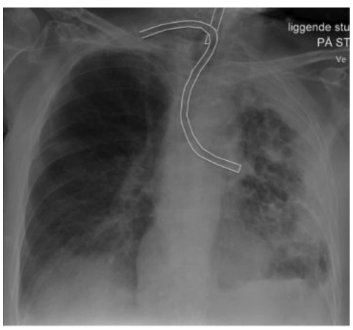
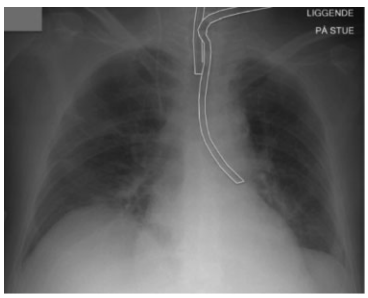
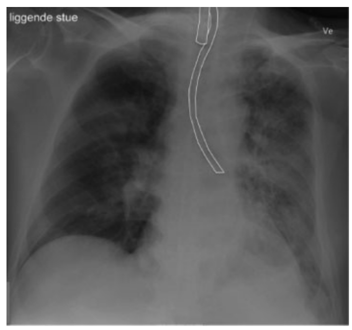


Fig. 2. Patient during DLV, with endotracheal tubes placed orally and through a tracheotomy.

Table 2

Ventilator settings and chest X-rays, before, during and after DLV.

Patient no	1	2	3
Chest X-ray prior to DLV			
Description	Compared with earlier chest X-rays: Increased density of the left lung because of a combination of pleural fluid, atelectasis and parenchymal infiltrates	Compared with earlier chest X-rays: Increased size and density of infiltrate in the left upper lobe	Compared with earlier chest X-rays: Increased density and area of infiltrates in the left lung field
Ventilator settings and dynamic Cdyn prior to DLV	PSV, IPAP 13 cm H_2O, PEEP 8 cm H_2O, FiO_2 0.3, Cdyn 43 ml/H_2O	PCV, IPAP 14 cm H_2O, PEEP 15 cm H_2O, FiO_2 0.35, RR 14/min, Cdyn 40 ml/H_2O	PSV, IPAP 12 cm H_2O, PEEP 6 cm H_2O, FiO_2 0.35, Cdyn 47 ml/H_2O
Ventilator settings and Cdyn at start of DLV	Right lung: PCV, IPAP 13 cm H_2O, PEEP 8 cm H_2O, FiO_2 0.3, RR 14/min, Cdyn 25 ml/H_2O; left lung: PCV, IPAP 35 cm H_2O, PEEP 15 cm H_2O, FiO_2 0.3, RR 14/min, Cdyn 2,5 ml/H_2O	Right lung: PCV, IPAP 9 cm H_2O, PEEP 18 cm H_2O, FiO_2 0.45, RR 14/min, Cdyn 15 ml/H_2O; left lung: PCV, IPAP 12 cm H_2O, PEEP 10 cm H_2O, FiO_2 0.25, RR 14/min, Cdyn 31 ml/H_2O	Right lung: PCV, IPAP 10 cm H_2O, PEEP 8 cm H_2O, FiO_2 0.4, RR 14/min, Cdyn 55 ml/H_2O; left lung: PCV, IPAP 10 cm H_2O, PEEP 15 cm H_2O, FiO_2 0.35, RR 14/min, Cdyn 5 ml/H_2O
Ventilator settings and Cdyn after 24 hours of DLV	Right lung: PCV, IPAP 13 cm H_2O, PEEP 10 cm H_2O, FiO_2 0.3, RR 14/min, Cdyn 25 ml/H_2O; left lung: PCV, IPAP 35 cm H_2O, PEEP 15 cm H_2O, FiO_2 0.3, RR 14/min, Cdyn 16 ml/H_2O	Right lung: PCV, IPAP 11 cm H_2O, PEEP 18 cm H_2O, FiO_2 0.45, RR 14/min, Cdyn 29 ml/H_2O; left lung: PCV, IPAP 15 cm H_2O, PEEP 10 cm H_2O, FiO_2 0.45, RR 14/min, Cdyn 35 ml/H_2O	Right lung: PCV, IPAP 13 cm H_2O, PEEP 15 cm H_2O, FiO_2 0.3, RR 14/min, Cdyn 53 ml/H_2O; left lung: PCV, IPAP 8 cm H_2O, PEEP 8 cm H_2O, FiO_2 0.3, RR 15/min, Cdyn 15 ml/ H_2O
Chest X-rays after 24 h of DLV outline of tubes superimposed			
Description	Improved aeration of the left lung, the right lung is as seen on the X-ray image above	Marked improvement in aeration of the right lung; the left lung is largely unchanged	Some improvement of aeration of the left lung; right lung with slight increase of infiltrate size

DLV, differential lung ventilation; PCV, pressure controlled ventilation; PSV, pressure support ventilation; IPAP, inspiratory positive airway pressure; PEEP, positive end-expiratory pressure; RR, respiratory rate; Cdyn, dynamic compliance; FiO_2, fraction of inspired oxygen.

Fig. 3. Patient during DLV, using two ventilators.

fibre-optic bronchoscopy through the oral endotracheal tube already in place. (Table 2, lower panels). The left lung cuff was inflated, and the tube was fixed to the neck using umbilical tape. Fibreoptic bronchoscopy was then performed through the left lung tube to exclude occlusion of the secondary left bronchi, and chest X-ray was also performed to certify correct tube placement. To prevent air-leak, the tracheostoma was packed with sterile gauze around the tube. Patients 1 and 3 had a tracheotomy in place when the left bronchus was intubated, while patient 2 had the left bronchus intubated in the same session as a tracheotomy was performed. We performed all three tracheotomies bedside with percutaneous dilatation technique (Portex® Griggs™ Forceps Percutaneous Dilation Tracheostomy Kit, Smiths Medical, Minnesota, USA).

DLV was performed for 24 h in all three cases, with the patients deeply sedated and receiving neuromuscular blockade. One ventilator was used per lung (Fig. 3). These ventilators were not synchronised other than by starting ventilation simultaneously using identical respiratory frequency and identical inspiratory-to-expiratory ratio. Ventilator settings and dynamic compliance in both ventilators/lungs prior to DLV at the start of DLV and after 24 h of DLV are presented in Table 2.

We performed recruitment manoeuvres on the diseased lung repeatedly and ventilated the diseased lung with higher PEEP for the duration of the DLV. After 24 h of DLV a normally placed tracheotomy cannula replaced both the left lung tube through the stoma and the endotracheal tube. Chest X-ray was obtained before DLV and after 24 h of DLV to evaluate efficacy (Table 2).

Results

In patient 1, we managed to improve aeration for the 24 h of DLV, but not sufficiently to keep the lung open permanently (Table 2). In consideration of a negative prognosis and in accord with the patient's wishes, life-prolonging treatment in the intensive care unit (ICU) was withdrawn 2 days after DLV, and in a short while, the patient died. In the other patients, the diseased lungs responded to DLV by increased compliance and radiographic increased aeration. In one of the patients, the diseased lung remained open, while the other showed radiographic signs of regression (Table 2). Clinically, the patient's condition improved, and further DLV was not necessary. We experienced no complications to the placing, the securing of the tubes or the DLV as such. And for the two patients that were weaned from the ventilator and could have their tracheotomy tubes removed, we observed no signs of airway complications.

Discussion

DLV to achieve optimised ventilation for each lung is rarely used in the ICU. The evidence base for DLV in the intensive care setting is therefore small, but DLV might be worth attempting in select cases where one lung is disproportionally affected our method of combining left main bronchus intubation through a tracheotomy and ventilating the right lung through a normally placed endotracheal tube has not been described earlier. The technique combines two of the most commonly used procedures in intensive care medicine, oral intubation and tracheotomy. No special equipment is needed. Measures to reduce potential complications to tracheotomy is important, such as keeping the procedure to fewer more experienced operators.[10] In our opinion, this new method exposes the patient to little extra stress, as these patients, in our ICU, would have had tracheotomies done to facilitate weaning from the ventilator. Using a normal endotracheal tube through the vocal cords and making sure that this tube does not overlap with the tube inserted through the tracheotomy should minimise the risk of vocal cord trauma and tracheal ischaemia. We packed the space around the tube in the tracheostoma with sterile gauze to prevent air leak and potential subcutaneous emphysema. Using a smaller tube through the tracheotomy and monitoring for this complication minimised the risk of partial airway obstruction from the tubes.

The left main bronchus was intubated selectively in all three patients. Intubation of the left main bronchus is less hazardous with respect to possible dislocation to the trachea and occlusion of the secondary bronchi. The right main bronchus is much shorter (average 2.3 cm in males, 2.1 cm in females) than the left main bronchus (average 5.4 cm in males, 5.0 cm in females).[7]

For the 24 h of DLV, the patients were sedated and paralysed, with the inherent risks that follow. We encountered no problems with respiratory or circulatory stability while performing the endobronchial intubation, or during the period of DLV. The ventilators were not synchronised because our ventilators are not interconnectable. Asynchronous ventilation makes DLV less complicated and with no proven disadvantage compared with synchronised DLV.[1]

In our patients, the patient with the longest standing lung disease, patient 1, did not respond to DLV, suggesting that both severity and lung pathophysiology are important factors in the success rate of the procedure.

The limitation of the current data on DLV is that they are confined to case reports and series with no prospective, systematic investigations available.[1] Accordingly, there are several limitations in this study. This procedure was only performed on three patients. With this small number, efficacy, outcome and safety aspects cannot be evaluated. Despite this, we believe that the technique described in this paper is a relatively simple, method to separate the lungs when DLV is considered necessary.

Conclusion

The technique described in this paper is a feasible means to enable DLV. In some rare cases, it may be useful if intensivists believe that DLV may be indicated. It can be considered in cases of respiratory failure involving one lung to a greater extent than the other, where traditional open lung ventilator strategies have failed to recruit portions of, or an entire, lung.

Conflict of interest: None.
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