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Tracheal gas insufflation for refractory hypercapnia

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Abstract

A 65-year male patient got admitted to ICU after alleged intake of ~ 250 ml of Chlorpyrifos (Organophosphate insecticides which cause cholinergic toxidrome) and cypermethrin (Synthetic pyrethroid) and presented with cholinergic toxidrome with severe hypercapnia (supercarbia). All conventional and advanced modes of ventilation failed to ventilate the patient because of severe bronchospasm and a prolonged expiratory time constant with high airway pressures and high auto-peep. As a last resort, we resorted to unconventional modes, as the patient could not afford ECMO.

Tracheal gas insufflation was done using a coaxial flow of humidified oxygen at 8 lpm with a suction catheter and ventilator parameter were adjusted to match the added gas flows.

Tracheal gas insufflation can be delivered by a thin catheter placed through the endotracheal tube (terminating within 1 to 2 cm of the main carina) or via a modified endotracheal tube with channels embedded in the walls of the tube. Tracheal gas insufflation flow can be forward (toward the alveoli) or reversed in direction toward the proximal end of the endotracheal tube.

Keywords: TGI, Hypercapnia, organophosphate toxicity

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Case report

A 65 year male patient got admitted to ICU after alleged intake of ~ 250 ml of Chlorpyrifos (Organophosphate insecticides which cause cholinergic toxidrome) and cypermethrin and presented with cholinergic toxidrome with severe hypercapnia (supercarbia). At first, various modes were attempted to ventilate the patient. Patient was deeply sedated and paralysed using propofol and atracurium infusions. The ventilator was showing high continuous airway pressure alarm and there was opening of safety valve for every breath. Patient was ventilated with pressure controlled (PCV) mode with PEEP of 10 cmH_2O, PC above PEEP of 30 cmH2O, FiO_2 60%, I:E 1:5, respiratory rate of 10/minute. At first, $PaCO_2$ slightly decreased but subsequently rose (Figure 1) due to severe bronchospasm and a prolonged expiratory time constant characterized by high airway pressures and high auto-peep along with a display of "continuous positive airway pressure" alarm. As a last resort, as patient could not afford ECMO, we proceeded with Tracheal Gas Insufflation (TGI) as an adjunct to mechanical ventilation.

Time	16-04-2024 01:26	15-04-2024 23:28	15-04-2024 22:02	15-04-2024 21:38	15-04-2024 20:59
pH	7.29	7.29	7.12	6.81	6.86
$PaCO_2$	109 mmHg	94 mmHg	>115 mmHg	>115 mmHg	>115 mmHg
PaO_2	320 mmHg	282 mmHg	478 mmHg	339 mmHg	427 mmHg
Lac	1.9 mmol/L	1.2 mmol/L	1.1 mmol/L	1.4 mmol/L	1.5 mmol/L
Vent mode	PRVC	PRVC	VC	VC	Non intubated

Time	16-04-2024 18:15	16-04-2024 14:45	16-04-2024 10:32	16-04-2024 04:38	16-04-2024 08:15
pH	7.30	7.51	7.45	7,26	7.30
$PaCO_2$	107 mmHg	60 mmHg	67 mmHg	99 mmHg	107 mmHg
PaO_2	390 mmm Hg	317 mmHg	417 mmHg	278 mmHg	390 mmHg
Lac	1.1 mmol/L	1.9 mmol/L	1.6 mmol/L	1.2 mmol/L	1.1 mmol/L
Vent Mode	PC	PC + TGI	PC + TGI	PC + TGI	PC

Time	17-4-24 20:58	17-4-24 14:13	17-4-24 04:46	17-4-24 00:19	16-4-24 19:45
pH	7.45	7.53 1	7,49 1	7.46 1	7.32 1
$PaCO_2$	45 mm Hg	56 mm Hg 1	63 mm Hg 1	67 mm Hg 1	96 mm Hg 1
PaO_2	242 mm Hg 1	233 mm Hg t	195 mmHg 1	259 mm-Hg 1	314 mm Hg 1
Lact	0.7 mmol/L	1.0 mmol/L	2.3 mmol/L 1	1.4 mmol/L	1.2 mmol/L
Vent Mode	PC + TGI	PC + TGI	PC + TGI	PC + TGI	PC + TGI

Figure 1: Time sequence of ABG. Lac: serum lactate, PC: pressure controlled ventilation mode, TGI: Tracheal gas insufflation.

TGI was done using a coaxial flow of humidified oxygen @ 6 lpm delivered with a 14 Fr suction catheter which was placed in the endotracheal tube (ETT) through a catheter mount (figure 2) such that the tip of suction catheter was just outside the endotracheal tube and above the carina and ventilator parameters (PC above PEEP was increased to 38 cmH_2O, circuit leak alarms were turned off, trigger change to pressure of –5 cmH_2O) were adjusted to match the added gas flows and by using nebuliser settings in the ventilator. ABGs were done to monitor for efficacy of CO_2 washout. After Tracheal gas insufflation was implemented, CO_2 gradually decreased by up to 60 mmHg, prompting the cessation of TGI. Once TGI was stopped, there was a gradual and steady increase in $PaCO_2$ following which TGI was restarted and there was again a decrease in $PaCO_2$ (figure 3) which decreased up to 45 mmHg, following which TGI was again stopped patient was gradually weaned.

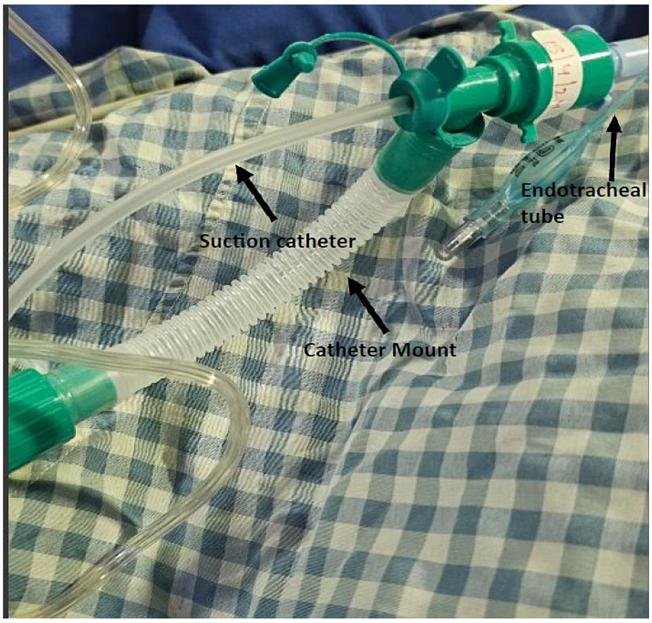

Figure 2: The above figure depicts the placement of 14 Fr Suction catheter through the catheter mount into the endotracheal tube for tracheal gas insufflation

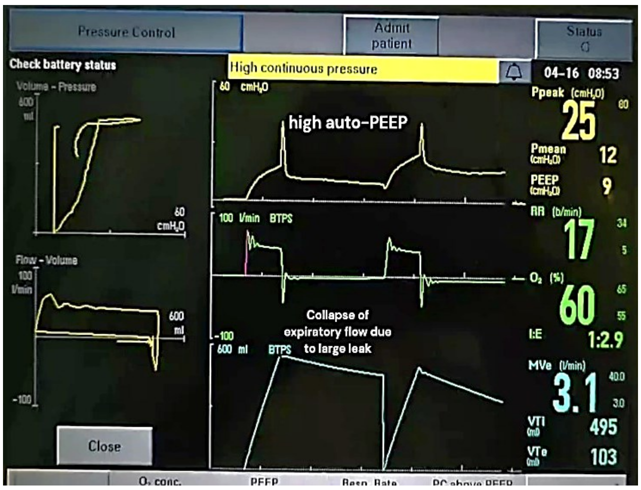

Figure 3: the concavity was due to severe bronchospasm. Pressure scalar also shows high auto PEEP and the immediate collapse of expiratory flow in flow scalar was due to large leak as a result of tracheal gas insufflation

Discussion

Chlorpyrifos was the most widely used pesticide in agricultural sector in the world. [1] Acute cholinergic crisis happens rapidly after organophosphate exposure owing to the acetylcholinesterase inhibition and the features involve nicotinic and muscarinic signs and symptoms. [2] Symptoms of organophosphate poisoning is comprised of muscle twitching, weakness, excessive bronchial secretions and respiratory failure. Neuromuscular blockade and cerebral depression may also develop and contribute to respiratory failure, consciousness disturbance and mortality. [2]

Synthetic pyrethroids such as cypermethrin have been used as an insecticide in agricultural sector. It behaves as a fast-acting neurotoxin in insects. The effects of which are mediated through preventing the closure of the voltage-gated of sodium channels in the axonal membranes. [3] Symptoms of acute poisoning may manifest as dizziness, loss of appetite, fatigue, nausea, vomiting, and unusual sensations in the face. The more serious cases developed coarse muscular fasciculations in large muscles of extremities, altered sensorium or coma.

The rate of respiratory failure is also higher in patients who take a chlorpyrifos and cypermethrin pesticide mixture compared to others. [4] Presence of severe bronchospasm and predominant type II respiratory failure necessitated use of alternative strategies in our patient as the patient’s financial constraints prevented usage of Extra corporeal life support.

Tracheal Gas Insufflation

Tracheal gas insufflation is a technique whereby a low flow (e.g., 6 -10 L/min) of fresh gas is delivered to the distal end of the endotracheal tube through a small diameter catheter. This flow can be continuous (i.e., throughout the ventilatory cycle) or delivered only during exhalation. Tracheal gas insufflation is commonly delivered through either a stand-alone catheter or a catheter imbedded in the endotracheal tube wall positioned just above the carina.

Rationale

The rationale behind Tracheal gas insufflation is simple. At end-exhalation in a patient on a ventilator, the endotracheal tube is filled with gas brought up from the alveolar regions. This gas has values for PO_2 and PCO_2 approximating pulmonary capillary values. The next mechanical breath drives this gas back into the alveolar regions. Because of this, endotracheal tube gas at end-exhalation significantly contributes to functional dead space and "wasted" ventilation.

The primary purpose of TGI is to flush the endotracheal tube with fresh gas during exhalation. Endotracheal tube PCO_2 is thus reduced (or eliminated) and functional dead space decreases consequently. [5,6] TGI may also improve gas mixing because the turbulent flow created at the tip of the catheter can enhance gas mixing and improve CO_2 clearance. [7] By improving CO_2 removal, TGI may lessen the minute ventilation requirement during mechanical ventilatory support.

Techniques

Two different gas flow strategies exist. The first is to direct gas flow downstream at the carina. This approach appears to enhance gas mixing and CO_2 clearance but is also more likely to produce intrinsic positive end expiratory pressure (PEEPi) and potentially injure airway epithelium as compared with other approaches.

A second strategy uses a "reverse" flow in which gas is directed up the endotracheal tube. [8] Although gas mixing in the trachea may be less with this approach, intrinsic PEEP may also be less. Another potential advantage of reverse flow is that it may enhance secretion clearance.

The fresh gas delivered by TGI should be heated and humidified to prevent mucous plug formation and to prevent TGI gas from causing bronchial injury via cooling and dehydration of the bronchial mucosa.

Endotracheal tube design

In most human studies, a small-caliber catheter is introduced through an angled sidearm adapter attached to the ETT and positioned just above the main carina. Placing a catheter through the ETT interferes with suctioning and can increase airway resistance by partially occluding the airway. Moreover, the catheter is not fixed in space and may cause injury to bronchial mucosa if it whips within the trachea at high flows. Alternatively, the catheter can be placed outside the ETT along the trachea. This technique requires visualization of the vocal cords and deflation of the ETT cuff and risks puncturing the cuff.

Salient features of tracheal gas insufflation

Inspired Oxygen fraction:

The actual fraction of oxygen (FIO_2) during Tracheal gas insufflation depends on two factors:

the contribution of TGI to total inspired tidal volume (VT) and the FIO_2 of the catheter gas. If, however, the FIO_2 of the catheter gas is matched to ventilator FIO_2, the actual inspired FIO_2 will be identical to that delivered by the ventilator.

During expiration, fresh gas is insufflated through the TGI catheter washes out the CO_2 that remains in the dead space proximal to the catheter tip and less CO_2 is inhaled during inspiration. [5] In addition, the turbulence generated by gas exiting from the catheter tip enhances gas mixing beyond the catheter tip, increasing CO_2 removal from more peripheral airways. Therefore, TGI has the potential to make ventilation with a lower VT more efficient. The change in $PaCO_2$ with TGI has been shown to be flow dependent, with higher flows causing a greater reduction in $PaCO_2$.

Continuous forward flow, TGI may also decrease $PaCO_2$ by enhancing distal gas mixing. During volume-cycled ventilation, continuous TGI augments tidal volume and will increase alveolar distending pressure and the risk of volutrauma in ARDS. [9] The effect can be diminished by using pressure control ventilation, by downward adjusting machine delivered tidal volume during volume-cycled ventilation, or by using Tracheal gas insufflation timed to occur only during expiration (expiratory TGI).

Even when using the latter strategy, TGI can impede expiration, resulting in the development of intrinsic positive end-expiratory pressure. Using reverse flow or end-expiratory (rather than pan-expiratory) TGI or the addition of tracheal gas exsufflation, may help alleviate this problem.

Additional safety issues with TGI include concerns about ensuring adequate humidification, increased risk of airway mucosal injury, and adverse effects on secretion clearance (especially if desiccation occurs)

Other TGI safety issues must be addressed. When TGI is utilized throughout the respiratory cycle, several modifications are required to compensate for the additional gas delivered by the catheter. The combination of continuous TGI with VCV will increase VT and peak airway pressure unless the ventilator-derived VT is decreased to compensate for the added inspiratory gas from the TGI flow. (figure 4)

If the set inspiratory pressure or set ventilator PEEP are changed, it is necessary to make appropriate adjustments in order to maintain the target pressure (set pressure plus PEEP). The approach of using a pressure-relief valve is not appropriate when using expiratory TGI If intrinsic PEEP develops during expiratory TGI, there will be a decrease in the pressure gradient between proximal airway and end-expiratory intrapulmonary pressure, which dictates delivered VT. Consequently, set inspiratory pressure must be adjusted to maintain the pressure gradient. [8]

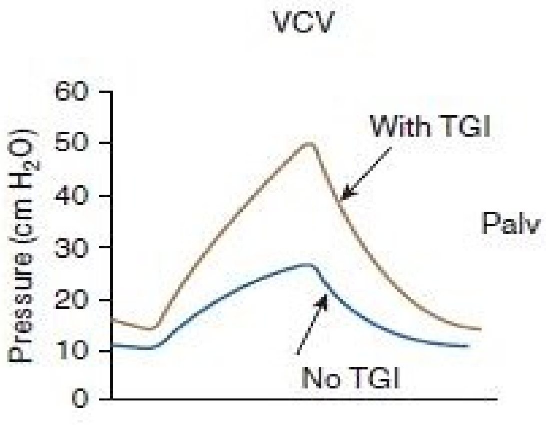

Figure 4: Pressure-versus-time tracings of system pressure measured both at the airway opening and distal to the entrance of the TGI flow (Palv) during volume controlled ventilation with and without the addition of 12 L/min of TGI flow in a lung model.

At present, no system exists commercially that can deliver the necessary ventilator modifications for expiratory TGI (e.g. use of the expiratory valve as a trigger for TGI). Because it does not require ventilator modification, we preferred to use continuous TGI in our case, since it offers better CO_2 washout and is easier to implement.

Both expiratory and continuous TGI may produce intrinsic PEEP. [10,11] Both continuous and expiratory TGI cause problems in monitoring exhaled volumes. If the expiratory pathway of the ventilator circuit were to become occluded, the catheter could rapidly deliver large volumes of gas, potentially causing serious barotrauma or hemodynamic compromise. Given the risk of complications should catheter obstruction develop, it seems advisable to periodically remove the Tracheal gas insufflation catheter at least every 24 hours in order to inspect the tip for mucous plug formation.

Limitations

TGI's efficacy in lowering $PaCO_2$ diminishes when an increased alveolar component dominates the total physiologic dead space and the complications associated with it including barotrauma, airway injury etc. preclude its routine use.

Conclusion

TGI associated reduction in $PaCO_2$ is a potentially important maneuver in patients with cerebrovascular injury with intracranial hypertension and concomitant acute lung injury and/or ARDS, who need lung-protective ventilation and aggressive treatment to maintain intracranial pressure as low as possible.

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