OXYGENATION DURING CHEST SURGERY IN THE RIGHT LATERAL POSITION IN DOGS

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IN SURGICAL PROCEDURES necessitating one-sided thoracotomy in the lateral position it is becoming evident that, despite the use of endotracheal and double lumen tubes, the amount of alveolar arterial (a-a) oxygen difference is very high and the PaO_2 of many patients may become dangerously low.^{1,2}

Investigations were carried out on a practical level to try to find the cause for this and to devise simple methods of improving oxygenation.

DOG EXPERIMENTS

Method

All dogs received the same premedication, anaesthesia and preparation.

Young, healthy, mongrel dogs of various sizes and ages varying in weight from 10 to 19 kg were premedicated with Acepromazine Maleate (Atravet) 0.2 mg/kg intramuscularly. Thirty minutes later they were anaesthetized with a sleep dose of Thiopental (Pentothal), an endotracheal tube was placed in the trachea, the cuff-inflated and they were connected to a Manley MN 2 ventilator delivering 50 per cent oxygen, 50 per cent Nitrous Oxide and 0.75 per cent to 1.0 per cent halothane. They were then placed in the right lateral decubitus position.

A ventilation rate of 10/min was set and tidal volume was adjusted to give a PCO_2 of 30–40 mm Hg (usually 20 ccs/kg). A cannula was placed in the femoral artery from which blood samples could be drawn. Samples were drawn in heparinized glass syringes when needed, for blood gas measurements.

All samples were analysed on an Astrup Radiometer AME.I within five minutes of being taken. The error of this machine being ± 2 per cent.

In the first 4 experiments 5 dogs were used in each, in the last 2 experiments 2 dogs in each.

1. Ten minutes after positioning in the right lateral decubitus position, an arterial PCO_2 was taken. The animal was then sighed three times to 40 cms H_2O and PaO_2 readings were taken at four minute intervals over the next 20 minutes. The lungs were sighed again and a PaO_2 measured immediately.

2. The chest was opened through the sixth intercostal space and held open with rib spreaders. The animal was sighed immediately three times to 30 cms H_2O and then serial PaO_2 readings were done over 20 minutes. The animal was then sighed as before and a further PaO_2 reading done immediately.

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3. With conditions similar to Experiment II, except that the end of expiratory tubing of the ventilator was led under 2 cms H₂O, to provide a positive expiratory pressure plateau (PEPP) of 2 cms H₂O.

4. With conditions similar to Experiment III but with a resistance to expiration of 5 cms H₂O (PEPP 5 cms H₂O).

5. Upon opening the chest, through the sixth intercostal space, rib spreaders were positioned. Then after sighing to 30 cms H₂O $\times$ 3 the Pa_{O₂} was measured immediately. A lung retractor was put in place to simulate retraction during surgery. Serial Pa_{O₂} readings were taken over the next 20 minutes. The animal was then sighed to 30 cms H₂O $\times$ 3 and serial Pa_{O₂} readings taken over 20 minutes with a PEPP of 2 cms H₂O. The PEPP was then removed and further arterial oxygen readings were taken over 20 minutes. The retractor was removed and the lungs were then sighed until all areas of atelectasis were visibly gone. A Pa_{O₂} reading was done immediately.

6. Upon opening the chest through the sixth intercostal space, rib spreaders were positioned, then the lungs were inflated to 30 cms H₂O $\times$ 3 and a Pa_{O₂} immediately taken. A lung retractor was put in place to simulate retraction during surgery. Serial Pa_{O₂} readings were taken over the next 20 minutes. The animal was then sighed as before and serial Pa_{O₂} readings taken over 20 minutes with a PEPP of 2 cms H₂O and then 5 cms H₂O. The retractor was then removed, and the lungs sighed until all visible areas of atelectasis were gone. The Pa_{O₂} was re-measured.

Results

Results are tabulated in Figure 1. In Experiment I, with the chest closed and following sighing the Pa_{O₂} levels do not drop significantly over the first 20 minutes, whereas it can be seen in Experiment II that the Pa_{O₂} levels decrease over a period of 20 minutes and seem to plateau at this point. Whatever the cause of this decrease of Pa_{O₂}, it seems to be reversed by utilizing a PEPP of +2 cms H₂O or 5 cms H₂O. (Experiments III and IV.)

With these positive expiratory pressures in use the non-dependent lung was becoming much larger than without PEPP and without retraction, surgery in the thorax would be impossible.

When retractors were applied to the non-dependent lung a really large drop of Pa_{O₂} occurred (Experiments V and VI, Figures 2 and 3). This drop of Pa_{O₂} was partially reversed by utilizing a PEPP of 2 cms H₂O or 5 cms H₂O, dropped to its

Experiment		After sighing	Time in minutes					After sighing	per cent Change
		0	4	8	12	16	20	0	
Chest Closed	I	308	310	307	308	312	308	308	0
Chest Open	II	317	271.5	263	263	246	257	320	-18.9
PEPP + 2	III	288	291	292	289	284		291	+1.04
PEPP + 5	IV	308	310	307.5	307.5	307.5		308	0

Pa_{O₂} Levels in mmHg

FIGURE 1. The tables show arterial Pa_{O₂} levels in anaesthetized dogs in the right lateral position undergoing left thoracotomy. (Average results of 5 dogs in each experiment.)

EXPERIMENT V

Time in minutes	Dog 1						Dog 2					
	0	4	8	12	16	20	0	4	8	12	16	20
Chest Open	260*						260*					
Lung Retracted	185	181	182	182	182	182	128	126	122	130	124	120
PEPP + 2 cms H ₂ O	225*	220	210	220	215	220	196*	184	178	170	172	170
PEPP Off	220	200	188	184	186	180	170	130	122	122	126	120
Retractor Removed	250*						250*					
*Sighed	PaO ₂ readings in mmHg											

FIGURE 2. The table shows PaO₂ readings in anaesthetized ventilated dogs in the right lateral position undergoing left thoracotomy. The effects of lung retractors, PEPP and removal of PEPP are shown.

initial level with removal of the PEPP and came back to preretractor level with removal of the retractors and sighing to remove all visible atelectasis. The use of PEPP did cause a rise of CO₂ levels to some small degree as seen in Experiment VI.

Discussion

The lowering of the PaO₂ seen in Experiment II (open chest) which did not occur in Experiments III (PEPP + 2 cms H₂O) and 4 (PEPP + 5 cms H₂O) can only be explained adequately on the basis that atelectasis was occurring and the PEPP was preventing its recurrence following its removal by sighing. With the admission of air into the intrapleural space, the non-dependent lung falls away from the chest wall and its functional residual capacity becomes smaller. The dependent lung now has the weight of the mediastinum plus the weight of the non-dependent lung resting on it. These are ideal conditions for atelectasis to occur in both lungs. The PEPP would seem to be capable (after sighing) of preventing this atelectasis from recurring, which it would otherwise do (See Experiment II).

It has been shown in humans undergoing thoracotomy in the lateral position and being given IPPB via an endotracheal tube, that the upper lung receives the majority of the ventilation.^{1,2} At the same time the lower lung receives the majority of the blood flow.²⁻⁴ The v/q for the non-dependent lung is therefore higher than that for the dependent lung. As has been shown, both in these experiments and elsewhere,¹ a more significant lowering of the PaO₂ occurs when the lungs are retracted. It was seen that the retractors cause a reduction of gas flow to the non-dependent lung (by restricting its expansion). If the total tidal volume stayed constant (which it did) then the dependent lung would get more ventilation than before. The v/q ratio for the two lungs will become more equal. The PaO₂ is, however, lower. Blood is now flowing through many atelectatic areas in the non-dependent lung caused by the lung retractor's pressure. The total number of perfused but unventilated alveoli is greater than before. The shunt (Qs/Qt) has therefore increased.

Sighing at this point expanded the lungs to fill as much of the thoracic cage as

Time in minutes		Dog 1 8 4 0		Dog 2 8 4 0			
Chest open	270* (Pco ₂) 37 mm Hg				210* (Pco ₂) 36 mm Hg		
Lung retracted EPP + 2 cms H ₂ O	200	138	154	158	168	PccO ₂ 42 mm Hg	PCo ₂ 43 mm Hg
EPP + 5 cms H ₂ O	230*	220	215	220	220	PCCO ₂ 45 mm Hg	PCO ₂ 45 mm Hg
Retractor removed	200	210	205	210	205		
	290*					220*	

FIGURE 3. The table shows PaO_2 and PaCO_2 readings in anaesthetized dogs in the right lateral position undergoing left thoracotomy. The table shows the changes occurring with insertion of a lung retractor and then the effects of PEEP (with sighing).

was left to them by the restrictions of the pleura (dependent lung) and the restrictions caused by the retractor (non-dependent lung) and rib cage. PEPP maintained the patency of the alveoli opened by the sighing (Experiments v and vi). However, the alveoli have a tendency to collapse again and so lower the Pa_{O_2} as is seen (in Experiment v) when the PEPP is removed.

Recent studies on the use of PEPP⁵⁻⁷ have all suggested, as is suggested here, that the "modus operandi" of PEPP is to keep open alveoli which for any reason may have a tendency to collapse (following pneumothorax, loss of surfactant, etc).

The sequelae to the use of PEPP are: reduced cardiac output,⁸ increase in functional residual capacity⁶ and hence, physiological dead space. Since the Pa_{O_2} levels stayed higher than before with PEPP in use, the effect on the cardiac output could be considered to be small unless the decrease in the shunt (Qs/Qt) more than compensated for the fall in cardiac output. In one series of patients with acute respiratory failure⁶ PEPP of 5 cms H_2O caused no change in cardiac output. The effects of PEPP on blood flow were shown markedly on one reported series of cases⁷ when PEPP of 10 cms H_2O was applied during endobronchial anaesthesia directed to the dependent lung (causing collapse of the upper lung). The increase of mean intra alveolar pressure in the ventilated lung increased the resistance to blood flow through that lung and hence caused the blood to "shunt" through the collapsed lung. The Pa_{O_2} fell!

Functional residual capacity increases with PEPP.⁶ This was clearly shown in Experiment vi by an increase in CO_2 levels caused by the resulting decreased alveolar ventilation.

Conclusion

Dogs undergoing left thoracotomy whilst in the right lateral decubitus position have temporary improved arterial oxygenation if sighed. If, following sighing, positive expiratory pressure plateau of 2 or 5 cms H_2O is applied, then improvement is sustained.

The application of lung retractors to the non-dependent lung lowers the Pa_{O_2} markedly. This effect can be partially reversed and the reversal sustained by the use of sighing followed by PEPP of 2 or 5 cms H_2O . No residual deficit to lung function appears to result from these manoeuvres. The clinical significance of PEPP in humans undergoing chest surgery with endotracheal anaesthesia has yet to be elucidated. Following these encouraging results a study involving humans is being undertaken.

SUMMARY

Experiments were carried out on dogs to determine the effects of sighing and sighing plus PEPP on the Pa_{O_2} levels whilst the animals were undergoing a left thoracotomy in the right lateral decubitus position.

Sighing did not affect the Pa_{O_2} with the chest unopened. However, opening the chest caused the Pa_{O_2} to fall. This fall was partially reversed by sighing alone, but this lasted a few minutes only. This rise in Pa_{O_2} was maintained by the immediate institution of PEPP of +2 or +5 cms H_2O . The insertion of lung retractors lowered

the Pa_{O_2} much more markedly. This lowering could be partially reversed by sighing followed by PEPP of $+2$ or $+5$ cms H_2O .

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RÉSUMÉ

Nous avons fait des expériences sur des chiens pour étudier les effets du "soupir" et du soupir accompagné de PEPP sur les niveaux de la Pa_{O_2} alors que les animaux étaient placés en position latérale droite et étaient soumis à une thoracotomie gauche.

En thorax fermé, le soupir n'a pas influencé les niveaux de la Pa_{O_2} . Toutefois, l'ouverture du thorax a entraîné une diminution de la Pa_{O_2} . Cette chute de la Pa_{O_2} a été partiellement corrigée par le soupir, mais cette correction n'a duré que quelques minutes. Avec l'installation immédiate d'une PEPP de 2 à 5 cms H_2O , l'élévation de la Pa_{O_2} s'est maintenue. L'installation d'écarteurs pulmonaires a abaissé la Pa_{O_2} de façon beaucoup plus prononcée. Ce dernier abaissement a pu être corrigé partiellement par un soupir suivi de PEPP de 2 à 5 cms d' H_2O .

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