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Distribution of pulmonary blood flow in the perfluorocarbon-filled lung

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Abstract *Objective*: Partial liquid ventilation (PLV) improves gas exchange in animal studies of lung injury. Perfluorocarbons (PFCs) are heavy liquids and are therefore preferentially delivered to the most dependent areas of lung. We hypothesised that improved oxygenation during PLV might be the consequence of a redistribution of pulmonary blood flow away from poorly ventilated, dependent alveoli, leading to improved ventilation/perfusion (V/Q) matching. This study investigated whether partially filling the lung with PFC would result in a redistribution of pulmonary blood flow.
Design: Prospective experimental study.
Setting: Hospital research institute laboratory.
Participants: Six anaesthetised pigs without lung injury.
Interventions: Animals were anaesthetised and ventilated (gas tidal volume 12 ml/kg, PEEP 5, FIO_2 1.0, rate 16). Whilst the pigs were maintained in the supine position, regional pulmonary blood flow was measured during conventional gas ventilation and repeated during PLV. Flow to regions of lung was determined by injection of radioactive microspheres (Co^{57}, Sn^{113}, Sc^{46}). Measurements were performed with ventilation held at end-expiratory pressure and, in two PLV animals only, repeated with ventilation held at peak inspiratory pressure.
Results: During conventional gas ventilation, blood flow followed a linear distribution with the highest flow to the most dependent lung. In the lung partially filled with PFC a diversion of blood flow away from the most dependent lung was seen ($p = 0.007$), resulting in a more uniform distribution of flow down the lung ($p = 0.006$). Linear regression analysis ($r^2 = 0.75$) also confirmed a difference in distribution pattern. On applying an inspiratory hold to the liquid-containing lung, blood flow was redistributed back towards the dependent lung.
Conclusions: Partially filling the lung with PFC results in a redistribution of pulmonary blood flow away from the dependent region of the lung. During PLV a different blood flow distribution may be seen between inspiration and expiration. The clinical significance of these findings has yet to be determined.

Key words Liquid ventilation · Perfluorocarbon · Pulmonary blood flow · Haemodynamics · Microspheres

Introduction

Partial liquid ventilation (PLV) has been shown to improve gas exchange in a number of animal models of lung injury [1, 2, 3]. In acute lung injury the predominant areas of low ventilation:perfusion (V/Q) ratio and true shunt are within the most dependent lung [4]. Perfluorocarbons (PFCs) are heavy liquids (density 1.75–2.0 g/cm^3) and therefore preferentially fill the most dependent lung, resulting in an increase in alveolar pressure in the dependent regions [5]. An improvement in oxygenation during PLV could be secondary to recruitment of atelectatic alveoli, analogous to that achieved by positive end-expiratory pressure [6]. Alternatively it could be the result of a redistribution of pulmonary blood flow away from poorly ventilated dependent alveoli, both mechanisms resulting in improved V/Q matching. Previous studies of liquid ventilation have demonstrated inconsistent effects on pulmonary vascular resistance (PVR), pulmonary artery pressure (PAP) and cardiac output [7, 8, 9].

This study examined changes in pulmonary blood flow distribution during PLV in a group of animals without lung injury. In addition, it sought to determine whether a change in pulmonary blood flow distribution would be associated with changes in PVR, PAP and cardiac output.

Methods

After ethical approval by the Animal Care Committee, six male pigs (mean weight 17.4 (SD 2.3) kg) were studied. Animals were premedicated with intramuscular ketamine and acepromazine, anaesthetised with inhaled halothane and intubated with a cuffed endotracheal tube. Anaesthesia was maintained throughout the study with an infusion of pentobarbital sodium and intermittent doses of a muscle relaxant (pancuronium 0.1 mg/kg). A catheter was placed in the carotid artery and a thermodilution pulmonary artery catheter inserted via the jugular vein. The animal was given heparin (50 units/kg) once the catheters were inserted. An overhead heater was used to maintain the temperature of the pig. Animals were ventilated with the following ventilator settings using a Humming V ventilator (Medtran, Japan): FIO_2 1.0, frequency 16 breaths/min, positive end-expiratory pressure (PEEP) 5 cmH_20, peak inspiratory pressure to achieve a tidal volume of 12 ml/kg, inspiratory time 1.5 s (I:E ratio 1:1.5). During partial liquid ventilation (PLV) the inspiratory pressure was adjusted to maintain the gas tidal volume at 12 mls/kg. The other ventilator settings remained unchanged. Tidal volumes were measured using a hot wire pneumotachometer (Bear NVM; Medical Systems, Riverside, Calif.).

Continuous monitoring of arterial, central venous and PAP was performed, with intermittent measurement of pulmonary artery occlusion (wedge) pressure. Variables were continuously displayed on a monitor (Hewlett Packard 78534; Andover, Mass.) and recorded prior to each pulmonary blood flow estimation. Cardiac output was measured intermittently by thermodilution (American Edwards 702A, Deerfield, Ill.).

Animals were studied in the supine position. The head of the animal was supported so that the end of the snout was at the same level as the uppermost part of the thorax. Aliquots of 10 ml/kg of warmed, pre-oxygenated perfluorocarbon (RM 101, Mercantile Development) were instilled via the endotracheal tube until a meniscus remained visible within the tube when disconnected from the ventilator. During PLV this is referred to as liquid 'functional residual capacity' and in these animals required approximately 40 ml/kg of perfluorocarbon (PFC).

Pulmonary blood flow distribution at different stages of the experiment was measured using radioactive microspheres labelled with Co^{57}, Sn^{113} or Sc^{46} (Nen-Trac microspheres, Du Pont Canada). For each measurement 2.5–6 million microspheres (15 μm in diameter) were injected via the right atrium. A reference sample was obtained from the pulmonary artery catheter for 2 min after microsphere injection. This provided a radioactive count at a known blood flow rate, allowing subsequent quantification of blood flow to lung regions. Microsphere measurements were obtained with airway pressure maintained at a PEEP of 5 cmH_20 for the initial 30 s, except for the measurement obtained at inspiration, when airway pressure was held at peak inspiratory pressure for 30 s. Measurements were made (1) during conventional (gas) ventilation (GV) (at end-expiratory pressure), (2) PLV (at end-expiratory pressure) and (3) PLV at peak inspiratory pressure (2 animals only). The mean duration of each study was 166 min with a mean delay between measurements (1) and (2) of 84 min, and measurements (2) and (3) of 27 min.

The animals were re-heparinised before they were killed. A sternotomy was performed and the heart and lung block removed. A cannula was inserted into the main pulmonary artery and, after opening the left atrium, the lungs were perfused with normal saline until clear of blood. The lungs were then suspended and allowed to dry over 3–4 days at an inflation pressure of 25 cmH_2O. When dry, the lungs were divided into sections. Initially each lung was divided into serial transverse sections from apex to diaphragm, with slices made perpendicular to the longitudinal axis of the lung (Fig. 1 a). Each of these sections was then divided by coronal slices through its vertical axis from non-dependent (ventral) to dependent (dorsal) (Fig. 1 b). The lungs were divided into sections of a fixed width (~ 2.5 cm). This was felt to be more appropriate, given the hypothesis of the study, than arbitrarily dividing lungs of differing size into a fixed number of sections of variable width. The variation in lung size between animals resulted in some variation in the number of transverse sections (7 sections [n = 2], 8 sections [n = 4]) and coronal sections (4 sections [n = 3], 5 sections [n = 3]). Airways and vessels were dissected and removed and each lung sample was weighed and radioactivity for the various radionuclides measured in a multi-channel gamma counter (Beckman Gamma 8000; Beckman Instruments, Fullerton, Calif.) with correction for spectral overlap of the three nuclides. Individual lung sample counts were converted to flows after measurement of a surrogate organ flow with the reference sample technique [10].

To calculate a reference flow (Qref) to a surrogate organ during microsphere injection, a timed reference blood sample was obtained through the pulmonary artery line using an infusion-withdrawal variable-speed pump. The sample was drawn into a preweighed syringe over 2 min beginning 30 s before microsphere injection. The full syringe was then reweighed, the volume of blood withdrawn over 2 min was calculated and Qref was calculated as:

$$Q_{ref}(\text{mls/min}) = \text{Blood volume (mls)/Withdrawal time (min)}$$

Flow was then calculated for each individual lung sample (Qs) using the formula:

$$Q_s\ (\text{mls/min}) = \frac{\text{Tissue count [sample]}}{\text{Tissue count [reference blood sample]}} \times Q_{ref}$$

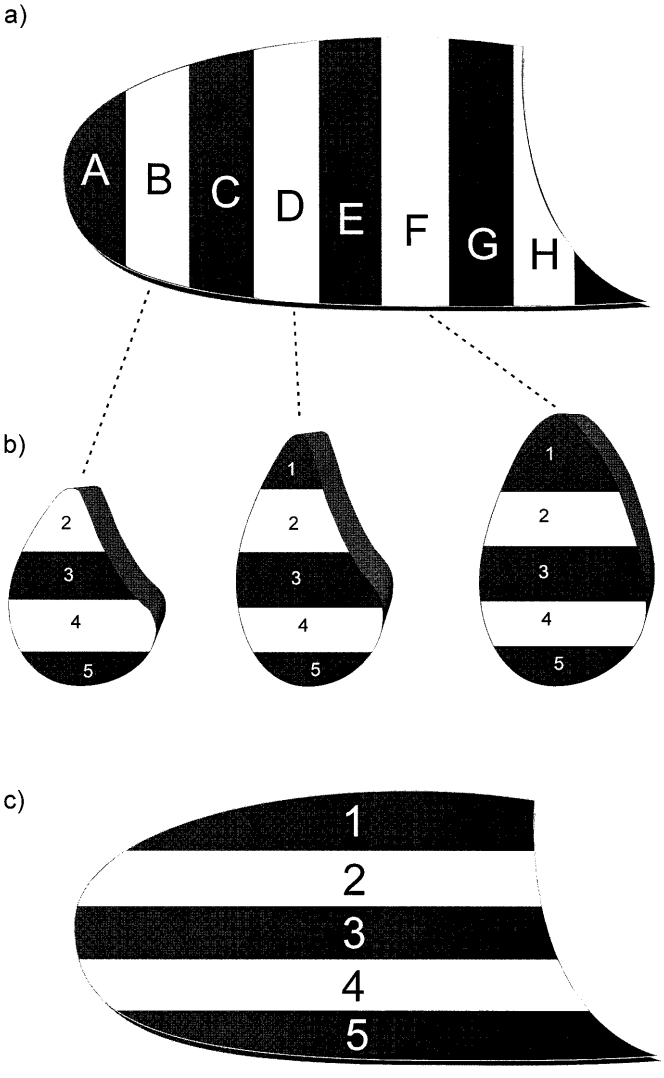

Fig. 1 Method of lung sectioning. Each lung was first sectioned in a craniocaudal direction into transverse sections (**a**) and each of these sections was then divided into coronal (gravitational) slices (**b**). 'Reconstruction' of the whole lung into coronal sections was used to evaluate differences in regional perfusion down the lung, from the most non-dependent (ventral) to the most dependent (dorsal) lung (**c**)

Standard methodology to facilitate analysis and interpretation of blood flow data involves the calculation of relative blood flow. Relative blood flow for a lung sample, corrected for weight, is calculated as:

$$\text{Relative flow} = \frac{\text{flow [sample]}/\text{total flow [lung]}}{\text{weight [sample]}/\text{total weight [lung]}}$$

In this way a lung sample with a relative blood flow of 1.0 has the same blood flow per unit weight as the whole lung.

Differences in regional perfusion down the lung, from the most non-dependent (ventral) to the most dependent (dorsal) lung, was evaluated by 'reconstructing' the entire lung into coronal sections and comparing relative perfusion between coronal (gravitational) sections of lung (Fig. 1 c). When combining the data for the group of animals the four sections of the smaller lungs were taken as corresponding to the four most dependent sections of the larger lungs (sections 2–5). Differences in perfusion along the horizontal axis was evaluated by comparing relative perfusion between transverse sections of lung, from the apex to the diaphragm (Fig. 1 a). When evaluating the group data the seven sections of the smaller lungs were taken as corresponding in the larger lungs to the seven sections closest to the diaphragm (sections B–H).

For statistical analysis, peak inspiratory pressure, blood gas and haemodynamic data during gas and liquid ventilation were compared using paired *t*-tests. A summary measure for blood flow within each lung was derived to avoid the need for multiple tests for significance if each level of lung was compared separately [11]. In order to test whether blood flow became more uniform across different gravitational levels during PLV we calculated, for each animal, the standard deviation of the relative blood flow values across the four or five gravitational levels and compared gas and liquid ventilation values using a paired *t*-test on log-transformed standard deviations. Linear regression analysis was used to compare the patterns of relative blood flow during gas and liquid ventilation (Stata Statistical Software, Release 5, 1997). We tested for both a linear and non-linear pattern of blood flow. The standard errors and *p* values in these regressions were adjusted to allow for potential non-independence in results within animals, using the information sandwich method [12].

Results

The respiratory and haemodynamic findings are shown in Table 1. A higher peak inspiratory pressure was required to deliver a gas tidal volume of 12 ml/kg during PLV compared to GV (mean difference 4.8 cmH_2O, 95 % CI 3.8, 5.8; $p < 0.001$). A lower PaO_2 was achieved during PLV (mean difference 146 mmHg, 95 % CI 74, 218; $p < 0.01$), while no difference was seen in pH or $PaCO_2$. No difference in thermodilution cardiac output or systemic vascular resistance was found, though a small reduction in mixed venous oxygen saturation was seen during PLV (mean difference 5.0 %, 95 % CI 1.4, 8.5; $p = 0.02$). PVR and PAP measured at end expiration both increased during PLV (mean difference 1.9 Woods units [95 % CI 0.7, 3.0] and 5.2 mmHg [95 % CI 2.7, 7.8]; $p = 0.01$ respectively).

Blood flow to both lungs was measured in the first two animals studied and found to show a similar pattern in each lung. Thereafter only the right lung was dissected and analysed. The pattern of blood flow to different gravitational levels within the lung is presented in Fig. 2. During GV a fairly linear relationship between level and flow was found, with the highest flow directed to the most dependent lung. During PLV a diversion of blood away from the most dependent lung region was seen in every animal studied (Fig. 2; Table 2; mean [SD] relative flow GV 1.30 [0.19] vs PLV 0.95 [0.09], $p = 0.007$). The same pattern of blood flow diversion was seen whether more apical or diaphragmatic slices of lung were analysed sepa-

Table 1. Haemodynamic and respiratory data during gas ventilation (GV) and partial liquid ventilation (PLV) ($n = 6$). Data shown are means (standard deviation), p value refers to paired t-test (*SAP* systemic arterial pressure, *PAP* pulmonary arterial pressure, *PA* pulmonary artery, *CVP* central venous pressure, *SVR* systemic vascular resistance, *PVR* pulmonary vascular resistance)

	GV	PLV	p-value
Heart rate (/min)	120.8 (13.1)	116.8 (5.8)	0.477
Cardiac output (l/min)	2.65 (0.75)	2.45 (0.53)	0.469
Mean SAP (mm Hg)	78.6 (26.5)	85.8 (20.8)	0.149
Mean PAP (mm Hg)	19.2 (3.3)	24.4 (3.6)	0.005
PA wedge pressure (mm Hg)	8.4 (2.8)	9.6 (2.6)	0.109
CVP (mm Hg)	7.0 (1.4)	6.4 (1.8)	0.208
SVR (Woods units)	30.3 (19.8)	34.5 (16.2)	0.119
PVR (Woods units)	4.5 (1.8)	6.3 (2.1)	0.011
Mixed venous O_2 saturation (%)	88.7 (4.7)	83.8 (4.1)	0.019
pH	7.46 (0.07)	7.47 (0.06)	0.684
PaO_2 (mm Hg)	535.8 (48.7)	390.0 (74.3)	0.008
$PaCO_2$ (mm Hg)	36.2 (4.3)	38.7 (4.6)	0.099
Peak inspiratory pressure (cms H_2O)	17.0 (1.2)	21.8 (1.5)	< 0.001

Table 2. Relative pulmonary blood flow measurements for coronal (gravitational) and transverse (craniocaudal) sections of lung. Values shown are the group means (SD) during gas ventilation (GV) and partial liquid ventilation (PLV)

	No. of animals	Relative Pulmonary Blood Flow	
		GV	PLV
Gravitational level			
1 (non-dependent)	3	0.44 (0.09)	0.56 (0.19)
2	6	0.56 (0.19)	0.74 (0.20)
3	6	0.84 (0.13)	1.10 (0.18)
4	6	1.13 (0.09)	1.14 (0.08)
5 (dependent)	6	1.30 (0.19)	0.95 (0.09)
Craniocaudal level			
A (cranial)	4	0.54 (0.04)	0.61 (0.14)
B	6	0.77 (0.19)	0.94 (0.20)
C	6	0.86 (0.10)	0.96 (0.18)
D	6	0.98 (0.09)	0.89 (0.21)
E	6	1.12 (0.10)	1.08 (0.11)
F	6	1.22 (0.11)	1.15 (0.16)
G	6	1.14 (0.10)	1.11 (0.23)
H (caudal)	6	0.85 (0.09)	0.93 (0.30)

Table 3. Linear regression analysis for relative blood flow using the following variables: method of ventilation (gas [GV] or partial liquid [PLV]), gravitational level of the lung (1 = most non-dependent, 5 = most dependent), and interaction between method and level. The level is centred at level 3 so that linear and quadratic components are approximately independent. The results demonstrate a significant linear trend to increased blood flow at more dependent lung level for both methods of ventilation but a significant quadratic (non-linear) component only for PLV

	Regression coefficient	Standard error*	P-value*
Intercept (relative blood flow in level 3)			
GV	0.842	0.053	< 0.001
PLV	1.051	0.053	< 0.001
Linear increase with level			
GV	0.235	0.027	< 0.001
PLV	0.127	0.038	0.020
Quadratic change with level			
GV	0.004	0.015	0.785
PLV	–0.181	0.012	0.001

* Robust standard error and p-value allowing for intra-subject correlation (12)

rately, suggesting a fairly homogeneous response (Fig. 3). Whilst the regression analysis confirmed a significant linear trend to increased flow at more dependent lung levels during both GV and PLV (Table 3; $r^2 = 0.75$), the quadratic (non-linear) component was significant only during PLV ($p = 0.001$), demonstrating that PLV resulted in a different blood flow pattern to that seen in the gas-filled lung. We were also able to confirm a more uniform distribution of blood flow across gravitational levels during PLV by showing a reduction in the average within-animal standard deviation of the relative blood flow measurements during PLV compared with GV (mean difference 0.15, 95 % CI 0.06, 0.23; $p = 0.006$).

Two animals were studied with a third radioactive microsphere to measure blood flow during PLV at peak inspiratory pressure as well as at end-expiratory pressure (Fig. 2; animals 5 and 6). This number of animals precludes statistical analysis, but the measurements suggest that a change in blood flow distribution may be seen between inspiration and expiration, with an increase in flow back towards the dependent lung when a gas tidal volume is delivered to a lung partially filled with PFC.

Analysis of the data for craniocaudal distribution of blood flow failed to demonstrate any significant differences between the gas- and liquid-filled lung (Table 2).

Discussion

The current study has investigated the effects of PLV in a group of animals without lung injury. It has shown that partially filling an uninjured lung with PFC results in a diversion of blood flow away from the most depen-

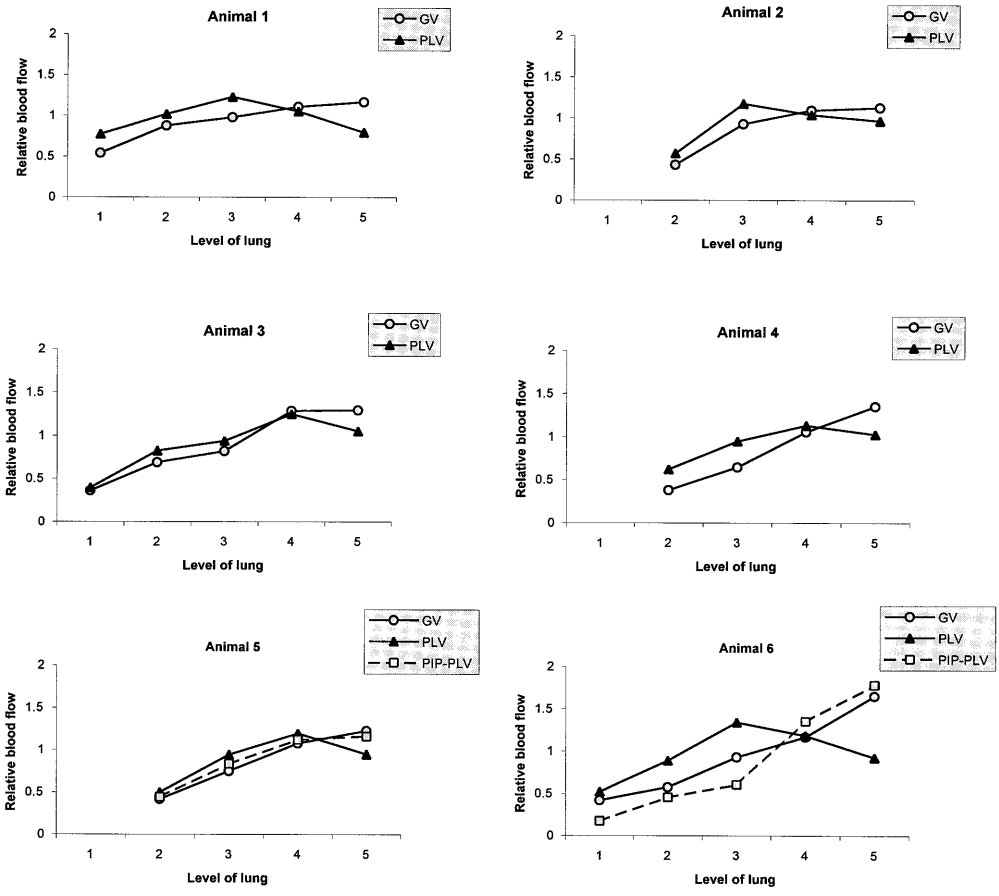

Fig. 2 Relative pulmonary blood flow in relation to gravitational level within the lung for individual animals obtained at end-expiratory pressure during gas (GV) and partial liquid ventilation (PLV). Level 1 represents the most non-dependent lung and level 5 the most dependent. For animals 5 and 6 data obtained at peak inspiratory pressure during partial liquid ventilation (PIP-PLV) are also shown

dent lung regions, and that this is associated with an increase in PAP and PVR. Preliminary data in two animals strongly suggest that the phase of the respiratory cycle during PLV also has an important influence on the distribution of pulmonary blood flow.

In a series of seminal publications, West described the distribution of pulmonary blood flow and its relation to vascular and alveolar pressures [13, 14]. He divided the lung into three zones according to the relative magnitude of alveolar pressure (Palv) relative to PAP and pulmonary venous pressure (PVP). He demonstrated a vertical gradient of blood flow for lung zones 2 (PAP > Palv > PVP) and 3 (PAP > PVP > Palv), hypothesising that gravity was the major determinant of blood flow. More recently others have challenged this hypothesis and, for lungs obeying zone 3 conditions, have demonstrated important gravity-independent factors [15, 16]. These authors have demonstrated, in a variety of animals, that there is no consistent vertical gradient to pulmonary blood flow and that considerable perfusion heterogeneity exists, indicating that factors other than gravity contribute to the distribution of pulmonary blood flow in gas-breathing animals. Extrapolation of these findings to the PFC-filled lung would be unwise as it is likely to behave very differently from the gas-filled lung in view of the large alveolar pressure gradient that exists from non-dependent to dependent lung [5]. Because PFC has a density almost twice that of blood, the hydrostatic pressure gradient within alveoli will be greater than that within blood vessels. D'Angelo and Agostoni [17] measured a pleural gradient of 1.28 cmH_2O/cm in a PFC-filled lung compared to 0.25 cmH_2O/cm in a gas-filled lung. It is therefore conceivable that most of the PFC-filled lung obeys zone 1 and 2 conditions, with blood flow largely determined by the balance of hydrostatic pressures within pulmonary artery and alveolus.

Previous studies have shown that filling the lung with saline leads to a reduction in blood flow to the dependent lung and a more even distribution of blood flow throughout the lung [18]. Similarly, in alveolar flooding from pulmonary oedema a diversion of blood flow away from dependent lung is seen [19]. The diversion of blood flow during PLV could be the result of hypoxic pulmonary vasoconstriction, though this is unlikely given the absence of hypoxia in this and other studies. Alternatively, it could be due to direct vascular compression by PFC, with an increase in alveolar pres-

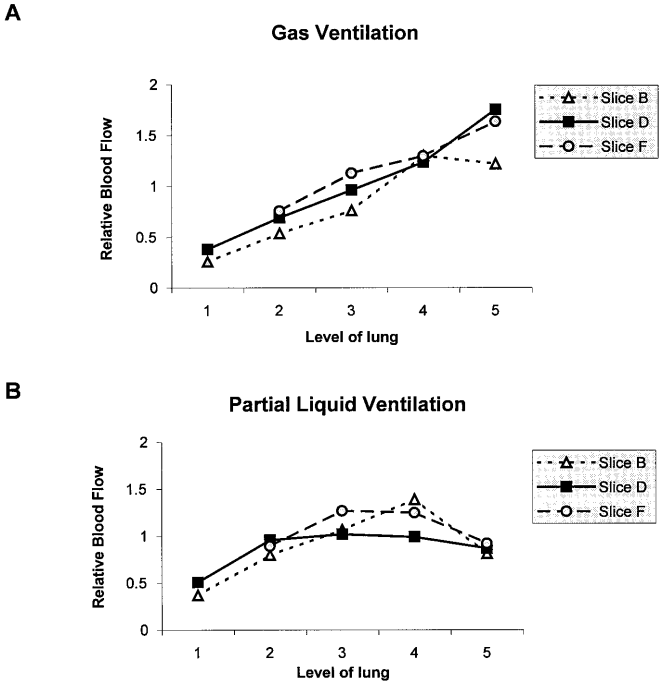

Fig. 3 Mean relative pulmonary blood flow in relation to gravitational level of lung for different transverse sections from apical (slice B), hilar (slice D) and diaphragmatic (slice F) regions of lung. Data are shown for gas ventilation (A) and partial liquid ventilation (B). A similar pattern of blood flow distribution is seen across the different transverse sections

sure relative to arterial pressure. Lowe and Shaffer [7], using an in situ isolated lung preparation, demonstrated that filling a lung with PFC caused a redistribution of blood flow away from the most dependent lung. We have been able to confirm these findings in an in vivo model. The results of this study cannot necessarily be extrapolated to human subjects with lung injury, although other investigators have reported preliminary findings in animals with lung injury, showing a similar redistribution of blood flow away from dependent areas of lung with a reduction in the number of low V/Q units [20].

A recently published study in lambs without lung injury confirmed a diversion of blood flow away from dependent areas during PLV, but noted that this was confined to apical and hilar slices of lung [21]. Blood flow to diaphragmatic regions of lung was globally reduced during PLV with blood flow being diverted in the craniocaudal plane towards the apical lung. In this study we found no evidence of a diversion of blood flow away from the diaphragmatic lung towards apical lung and a consistent pattern of blood flow diversion away from dependent lung affecting both apical and diaphragmatic slices of lung. Possible explanations for this difference include the larger animal size in the present study and an important difference in positioning of the animals. In the study by Doctor et al. [21] the anatomical position of the lambs was such that the dorsal surface of the lung formed a gradient of approximately 20° with respect to the horizontal, resulting in preferential filling of the dependent lung adjacent to the diaphragm well before filling of the dependent lung at the apex. Under these circumstances it would not be surprising to see a diversion of blood flow away from the PFC-filled diaphragmatic lung towards the more gas-filled apical lung. During the present study the animals were positioned to keep the dorsal surface of the thorax as close to the horizontal plane as possible, resulting in a more uniform pattern of blood flow response.

The effect of tidal ventilation on pulmonary blood flow is likely to be very different during PLV, in which the tidal volume is gas, and total liquid ventilation, in which it is PFC. Using a computer tomographic assessment in an animal model of lung injury, Quintel et al. demonstrated that gas is predominantly delivered to non-dependent lung during PLV [22]. Using the same methodology we have previously shown that this is also true in animals with healthy lungs undergoing PLV [23]. As a result the alveolar pressure gradient that is present down the liquid-filled lung is abolished following a gas tidal volume [5]. This would provide an explanation for the variation in distribution of blood flow between inspiration and expiration suggested by this study. By comparison, at peak inspiration with total liquid ventilation a large alveolar pressure gradient persists between non-dependent and dependent lung [5], so that a more consistent effect on blood flow is likely to be seen during inspiration and expiration during total liquid ventilation. Unfortunately pulmonary blood flow distribution has not been studied during 'dynamic' total liquid ventilation, though Lowe and Shaffer [7] demonstrated that filling an in situ isolated lung with 90 ml/kg PFC resulted in a greater redistribution of flow away from the dependent lung than 30 ml/kg PFC. An alternative explanation for the apparent change in blood flow distribution in inspiration during PLV would be that an inspiratory hold results in a marked reduction in cardiac output and therefore global pulmonary blood flow. This might be expected to result in blood flow directed predominantly to dependent areas of lung. Our preliminary findings require confirmation and further exploration in a larger sample.

No consistent change in cardiac output measured by thermodilution was demonstrated during this study. In an earlier study of total liquid ventilation a marked reduction in cardiac output was seen together with a reduction in coronary blood flow [9]. That study, however, used very large volumes of PFC and compared cardiac output values to those of control animals who were breathing spontaneously and not mechanically ventilated. Subsequent studies have not shown a consistent

change in cardiac output during liquid ventilation [8, 24].

In this study the redistribution of pulmonary blood flow during PLV was accompanied by a significant increase in PAP and PVR. Previous studies have reported similar findings in healthy animals [24], but a different pattern has been observed in a model of lung injury [10]. In animals with lung injury PAP prior to PLV is higher than in healthy animals and initiation of PLV results in a reduction in PAP and PVR [10]. This may reflect a difference in the relative contributions of liquid density and improved oxygenation that are likely to exist between uninjured and injured lungs. In uninjured lungs the liquid density effects on PAP may predominate whereas in injured lungs the benefit of improved oxygenation, resulting in a reduction in hypoxic pulmonary vasoconstriction, may outweigh any opposing effect of liquid density. Several studies, in a variety of models of lung injury, have shown that PLV improves oxygenation [1, 2, 3]. This most probably reflects an improvement in V/Q matching during liquid ventilation. Studies in patients with ARDS [25] and animal models of lung injury [22] show that the dependent lung is poorly aerated and there is a resultant physiological shunt. Application of PEEP in ARDS improves aeration of these areas and reduces shunt [25]. PFC is preferentially distributed to the most dependent lung units in view of its density and is able to re-expand collapsed areas of lung, in effect behaving as 'liquid PEEP' [22]. The current and a previous study of PLV in animals with normal lungs show poorer oxygenation compared to gas ventilation with the same FIO_2 [24]. This has been attributed to the limited diffusibility and solubility of oxygen in PFC.

In conclusion, this study has shown that there is a redistribution of blood flow away from the most dependent lung when a healthy pig lung is partially filled with PFC. This is accompanied by an increase in PAP and PVR. In contrast to one comparative study, no redistribution of blood flow was seen in the craniocaudal direction. Further study is needed to confirm the difference in blood flow distribution pattern during PLV between inspiration and expiration and to determine its relevance with regard to optimum ventilator settings.

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