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Roles of the Visceral Pleura in the Production of Pleural Effusion in Permeability Pulmonary Edema

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Ashino, Y., Tanita, T., Ono, S., Suzuki, S., Koike, K. and Fujimura, S. *Roles of the Visceral Pleura in the Production of Pleural Effusion in Permeability Pulmonary Edema.* Tohoku J. Exp. Med., 1997, **182** (4), 283-296 —— We investigated the roles of the mesothelium of the visceral pleura on hydraulic conductivity in dogs under normal conditions and condition of permeability pulmonary edema. Nineteen mongrel dogs were divided into following 4 groups: thoracotomy alone (control group, $n=7$); thoracotomy and striping of the mesothelium using Gelfilm (C+G group, $n=4$); injection of oleic acid to increase the permeability of the pulmonary vessels (OA group, $n=4$); injection of oleic acid and striping of the mesothelium (OA+G group, $n=4$). A hemispherical capsule filled with physiological saline was attached to the visceral pleura. The transpleural fluid flow (ΔV) was measured at given incremental or decremental hydrostatic pressures (ΔPcap) in the capsule. Hydraulic conductivity was calculated from the slope of linear regression line obtained from relationship between ΔPcap and the fluid flow rate ($\dot{v}$) according to the Starling's equation. The conductivity obtained were 1.49 ± 0.69 ($nl \cdot min^{-1} \cdot cmH_2O^{-1} \cdot cm^{-2}$) in the control group, 1.37 ± 0.88 in the C+G group, 3.75 ± 0.74 in the OA+G group, and 7.07 ± 2.49 in the OA+G group. The hydraulic conductivity was not increased by striping of the mesothelium (1.49 ± 0.69 [$nl \cdot min^{-1} \cdot cmH_2O^{-1} \cdot cm^{-2}$] vs. 1.37 ± 0.88, in the control group vs. C+G group, respectively). Visceral pleural hydraulic conductivity following OA injection was increased by striping of the mesothelium (3.75 ± 0.74 vs. 7.07 ± 2.49 in OA group vs. OA+G group, respectively). These findings suggest that the wall of pulmonary vessels acts as a barrier to movement of pleural effusion under normal conditions, whereas the mesothelium of the visceral pleura acts as that under condition of permeability pulmonary edema. ———— hydraulic conductivity; visceral pleura; mesothelium; pleural effusion

The mechanisms of the movement of pulmonary effusion has been described

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by the Starling's hypothesis and lymph flow (Pistolesi et al. 1989). The pleura has been considered to act as a barrier to the movement of pleural effusion (Negrini et al. 1991), and its role as a barrier is important for clarify the liquid movement mechanisms. The permeability of the pleura has been measured using various methods (Agostoni et al. 1957; Kim et al. 1979; Negrini et al. 1985, 1990, 1991; Payne et al. 1988). Our former report indicated that hydraulic conductivity of the pleura was similar to that of the wall of blood vessels (Ashino et al. 1993) suggesting that the wall of blood vessels is rate-limiting for pleural effusion under normal conditions.

Acute respiratory distress syndrome (ARDS) is associated with a significant increase in the permeability of pulmonary vasculature, and frequently with retention of pleural effusion is often observed (Aberle et al. 1988). This suggests that the permeability of the pleura might be altered in permeability pulmonary edema.

In pulmonary edema, excessive fluid outside the blood vessel partially flows through the interstitium to the lymph-duct and partially through the mesothelium into the thoracic cavity (Wiener-Kronish at al. 1988). However, it has not been clarified what roles the pleura plays in kinetics of pleural effusion. In the present study, the role of the pleura in kinetics of pleural effusion was evaluated by measuring hydraulic conductivity in dogs with permeability pulmonary edema induced by oleic acid, and roles of the mesothelium in producing pleural effusion

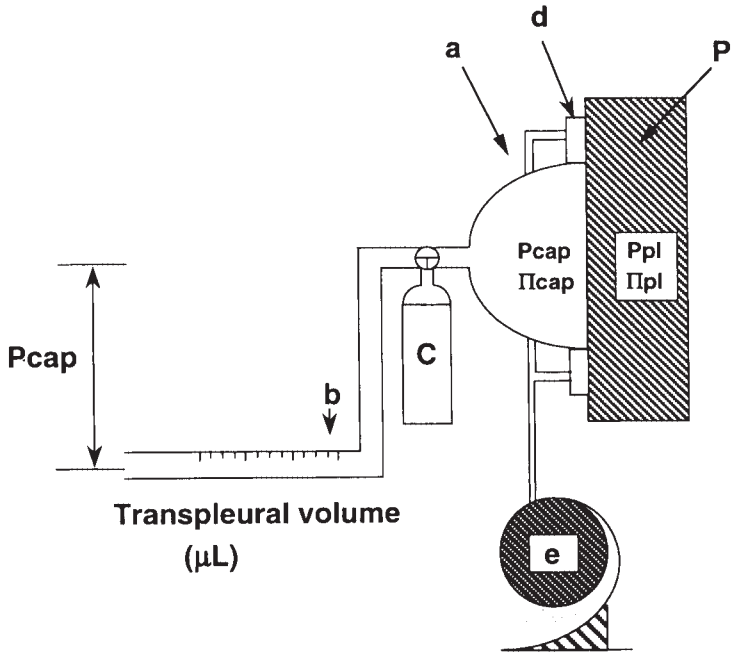

Fig. 1. Schematic illustration of the experimental apparatus.
The capsule is attached to the surface of the pleura by a suction pump, and connected to the pressure transducer and a silicon tube. Changes in volume gain through the pleura is observed by the fluid movement in the silicon tube. (a): Capsule, (b): Silicon tube, (c): Transducer, (d): Plate, (e): Suction pump, (p): Pleura

were examined by striping the mesothelium of the pleura.

Materials and Methods

Experimental theory

Passive transport of the fluid between the capsule attached to the visceral pleura and the pleura is expressed using Starling's equation as follows.

$$\dot{v} = K\ [(Pcap\text{-}Ppl) - \sigma(\pi cap\text{-}\pi pl)] \quad (1)$$

where $\dot{v}$ denotes the rate of fluid movement per unit time, K, the hydraulic conductivity of the visceral pleura, σ, the protein refection coefficient, Pcap (πcap), the hydrostatic pressure (colloid osmotic pressure) in the capsule, and Ppl (πpl), the hydrostatic pressure (colloid osmotic pressure) of the pleura, respectively. When the capsule is filled with physiological saline, πcap is zero. If Ppl and πpl remain unchanged during the measurement, equation (1) can be rewritten by substitutions, $\Delta P = (Pcap - Ppl)$ and $c = -\sigma(\pi cap - \pi pl)$, as follows:

$$\dot{v} = K\ (\Delta P + c) \quad (2)$$

That is, $\dot{v}$ in equation (2) is expressed using ΔP as a variable, and K, which can be determined in this study by measuring $\dot{v}$ and Pcap. By changing the pressure in the capsule, we determined ΔP1, ΔP2, ΔP3, and then obtained the corresponding rates of fluid movement, $\dot{v}1$, $\dot{v}2$, $\dot{v}3$, respectively. The slope of the linear regression line of the relationship between ΔP and $\dot{v}$ gives the hydraulic conductivity, (K).

Experimental apparatus

The apparatus for measurements of the hydraulic conductivity of the pleura is shown in Fig. 1. (a) is a hemispherical transparent capsule (volume, 0.58 ml; bottom size, 0.785 cm^2) with a disk (d) (diameter, 5 cm) attached at its opening. Grooves were cut on the capsule as concentric circles which were connected to an aspiration pump (e), and a negative pressure (30 mmHg) maintains the capsule attached to the pleura. Silicone tube (b) (ID 0.0625 cm, 602-155; Dow Corning Inc., Midland, MI, USA) was connected to the top of the capsule and its free end was open. A pressure transducer (c) (P23 ID; Gould Inc., Santa Ana, CA, USA) was connected via a three-way stopcock to the tube to measure intracapsular pressure. Vertical movements of the free end of the silicone tube made changes in the hydrostatic pressure (Pcap) in the capsule, and movements of the fluid surface in the tube, which allows to measure the changes in the fluid volume in the capsule (ΔV).

Experimental methods

We anesthetized mongrel dogs by intravenous injection of sodium pentobarbital (30 mg/kg), following endotracheal intubation and we used additional

sodium pentobarbital and muscle relaxant (pancuronium bromide [4 mg]) when necessary. Then their muscles were relaxed. We used a volume-controlled respirator (series 600; Harvard Inc., Apparatus Co., Millis, MA, USA) and ventilation was controlled at 15 ml/kg and FIO_2 0.6. Respiration frequency was set to maintain as the $PaCO_2$ at around 40 torr. The pulmonary arterial and wedge pressures and the cardiac output (output computer; Nihon Kohden Inc., Tokyo) were measured via a Swan-Ganz catheter (Edwards Lab., Irvine, CA, USA) inserted from the left jugular vein. With a catheter in the left carotid artery, the aortic pressure was measured, and the blood sample was obtained to measure the partial pressure of the arterial blood gas (ABL300; Radiometer Inc., Copenhagen, Denmark) and the plasma colloid osmotic pressure (4100 colloid osmometer; WESCOR Inc., Logan, UT, USA) .

Thoracotomy was performed at the left seventh intercostal space, and the capsule for measurements of permeability of the pleura filled with physiological saline was attached against the pleura on the left lung at the level of the left atrium. The air way pressure was set at 15 cmH_2O (positive pressure) at inspiration and 5 cmH_2O (positive pressure) at expiration, though the experiments. Pcap was changed from 0 to -5, -10, and -20 cmH_2O, maintaining each pressure for 30-60 minutes. The rate of change in the volume of the fluid in the silicon tube (ΔV) was measured at each pressure, and then the total protein concentration in the capsule was measured using the Coomassie brilliant blue (CBB) method.

Immediately after the measurements, the lung was removed and its wet/dry weight ratio was determined by the following equation according to the modified method by Pearce et al. (1965) and Ohkuda et al. (1982).

$$\text{Lung wet/dry weight ratio} = \frac{\text{(lung wet weight-blood wet weight in the lung)}}{\text{(lung dry weight-blood dry weight in the lung)}}$$

Experimental groups

In the control group ($n=7$), thoracotomy alone was performed. In the C+G group ($n=4$), following the thoracotomy, Gelfilm (Upjohn Inc., Kalamazoo, MI, USA) was applied on an area (25 mm × 25 mm) on the lung lobe using Watters' method (Watters and Buck 1972), and the mesothelium of the visceral pleura on this area was stripped off 5 minutes later by removing the film. The capsule was then attached to the surface of the area where the visceral pleura was stripped off. In the OA group ($n=4$), following the thoracotomy, 0.08 ml/kg of oleic acid (Wako Pure Chemicals Inc., Tokyo) was intravenously injected, and 2 hours later, the capsule was attached to the lung lobe. In the OA+G group ($n=4$), following the thoracotomy, the mesothelium was removed using Gelfilm, then 0.08 ml/kg of oleic acid was injected intravenously, and 2 hours later, ΔV was measured.

Histological examination

After the measurements, except for the measurement of the lung wet/dry weight ratio, the tissue specimens from the lung lobe surface of a dog in each group, was fixed in 10% formalin to examine histologically. They were stained with hematoxilin and eosin.

Statistical analyses

Values are shown as means ±S.D. Regression lines were obtained by the least squares method. In statistical analyses, changes within individuals were examined using the paired t-test, while differences between groups were compared by one-way analysis of variance and $p<0.05$ was regarded as significant.

Result

Hemodynamics

Results of the hemodynamics measurements of the 4 groups are shown in Table 1. In the control and C+G groups, no significant differences in the hemodynamics were observed during measurements. In the OA and OA+G groups, the aortic, and the pulmonary arterial pressures and the cardiac output were decreased following injection of oleic acid in 2 hours, however, they remained constant during ΔV measurement. On the other hand, the pulmonary arterial wedge pressure was slightly increased during ΔV measurement.

Lung wet/dry weight ratio

There was no difference in the lung wet/dry weight ratio between the control and C+G groups, while those in the OA and OA+G groups showed significantly higher ratios than those in the control and C+G groups (Table 2).

Table 1. *Hemodynamic variables*

	Control	C+G	OA		OA+G	
			Baseline	(i.v. oleic acid)	Baseline	(i.v. oleic acid)
$A\bar{P}$(cmH_2O)	137.2±35.2	153.0±23.0	172.0±12.0	(136.0±13.4)*	168.2±27.3	(131.0±21.3)*
$\bar{P}$pa(cmH_2O)	13.9±7.5	17.0±3.4	19.0±2.9	(14.2±1.9)	18.2±4.4	(12.9±3.2)
$\bar{P}$w(cmH_2O)	6.6±2.2	5.7±1.0	5.9±2.6	(8.1±3.1)*	5.2±3.1	(7.3±2.2)*
CO(liter/min)	1.5±0.3	1.4±0.2	2.4±0.4	(1.0±0.2)*	2.1±0.6	(0.8±0.3)

Data are shown as mean±S.D.

$A\bar{P}$, arterial pressure; $\bar{P}$pa, pulmonary arterial pressure; $\bar{P}$w, pulmonary arterial wedge pressure; CO, cardiac output.

C+G, mesothelium was removed by Gelfilm; OA, i.v. oleic acid; OA+G, i.v. oleic acid and mesothelium was removed by Gelfilm.

*$p<0.05$ vs. baseline

TABLE 2. *Wet/dry ratio*

	Control	C+G	OA	OA+G
Wet/dry ratio (g/g)	3.74±0.26	3.64±0.52	7.00±0.85*	7.86±3.33*

Data are shown as mean±S.D.
*$p<0.05$ vs. control
C+G, mesothelium was removed by Gelfilm; OA, i.v. oleic acid; OA+G, i.v. oleic

Arterial blood gas analysis

In the control and C+G groups, the PaO_2 and $PaCO_2$ remained almost constant during the measurements. In the OA and OA+G groups PaO_2 was decreased after the injection of oleic acid, while 2 hours after the injection, it remained constant (Table 3).

Protein concentration in the capsule and colloid osmotic pressure of the plasma

The protein concentration in the capsule after ΔV measurement was significantly higher in the OA and OA+G groups than in the control and C+G groups. The colloid osmotic pressures calculated from the protein concentrations (Yamada et al. 1991), in the control, C+G, OA, OA+G groups were 0.0026, 0.0031, 0.0110, and 0.0500 cmH_2O, respectively.
The colloid osmotic pressure of the plasma remained constant during the measurement in the control and C+G groups, while in the OA and OA+G groups it was slightly decreased after injection of oleic acid and remained almost constant thereafter.

TABLE 3. *Arterial blood gas analyses, protein concentration of fluid in capsule and colloid osmotic pressure*

	Control	C+G	OA		OA+G	
			Baseline	(i.v. oleic acid)	Baseline	(i.v. oleic acid)
PaO_2 (Torr)	330.1±81.0	339.5±45.7	337.3±40.6	(151.3±20.7)*	359.0±58.1	(149.8±25.3)*
$PaCO_2$ (Torr)	35.7±5.6	33.0±4.1	35.7±5.6	(39.4±8.4)	34.5±4.4	(37.3±4.3)*
Protein concentration ($mg \cdot 100\ ml^{-1}$)	8.7±2.1	10.5±5.7		37.3±18.8†		168±66.7†‡
Plasma C.O.P. (mmHg)	16.1±2.0	17.6±0.9	16.9±2.8	14.7±1.9	17.0±3.2	14.1±1.8

Data are shown as mean±S.D.
(Value) were indicated just before ΔV are mesured.
*$p<0.05$ vs. baseline †$p<0.05$ vs. control ‡$p<0.05$ vs. OA
C+G, mesothelium was removed by Gelfilm; OA, i.v. oleic acid; OA+G, i.v. oleic acid and mesothelium was removed by Gelfilm.

Calculation of the rate of fluid flow

The typical relationships between Pcap and ΔV in each group are shown in Fig. 2. The direction of outflow from the visceral pleura was regarded as positive. For each group, a linear regression line (correlation coefficient $R^2 = 0.06$-0.98) was obtained between ΔV and time (t) for each pressure in the capsule. The slope of each regression line represents the fluid flow rate ($\dot{v}$ μl/min).

Calculation of the hydraulic conductivity (K)

There was a good correlation between the fluid flow rate ($\dot{v}$) obtained in the previous chapter, and the capsule pressure within each group, and linear regression lines were obtained for each group (Fig. 3).

The hydraulic conductivity of the pleura was determined by dividing the slope of the regression lines by the area of the bottom of the capsule (0.785 cm^2)

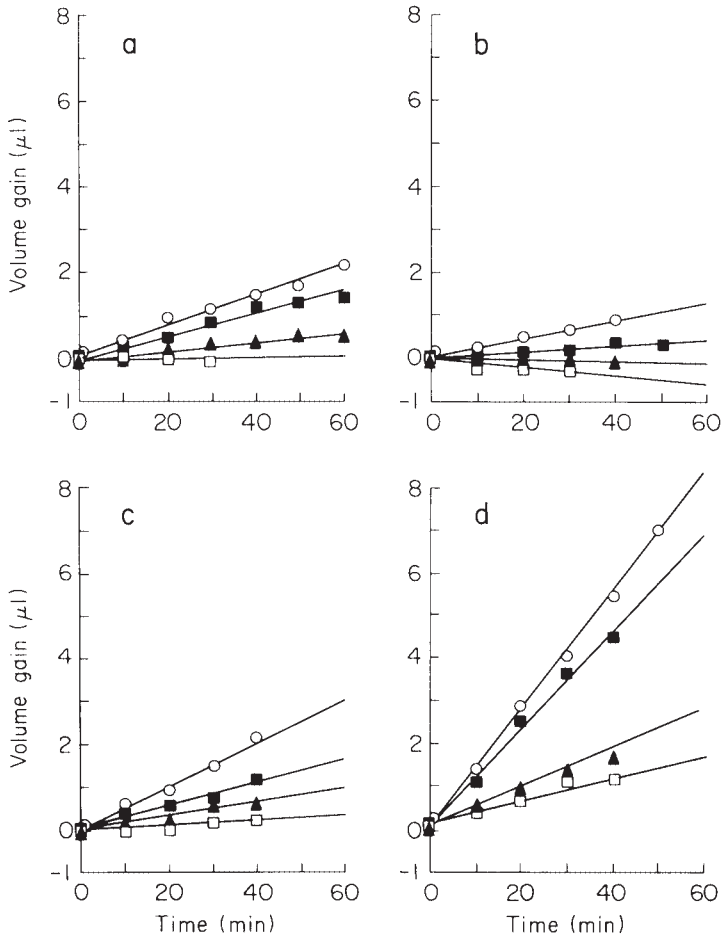

Fig. 2. Changes in transpleural volume gain at 4 different capsular pressures (duration of 30-60 minutes). The group are the control (a), C+G (b), the OA (c), and OA+G (d), respectively. □, 0 cmH_2O; ▲, −5 cmH_2O; ■, −10 cmH_2O; ○, −20 cmH_2O.
The transpleural flow rate was calculated from the regression lines at each condition.

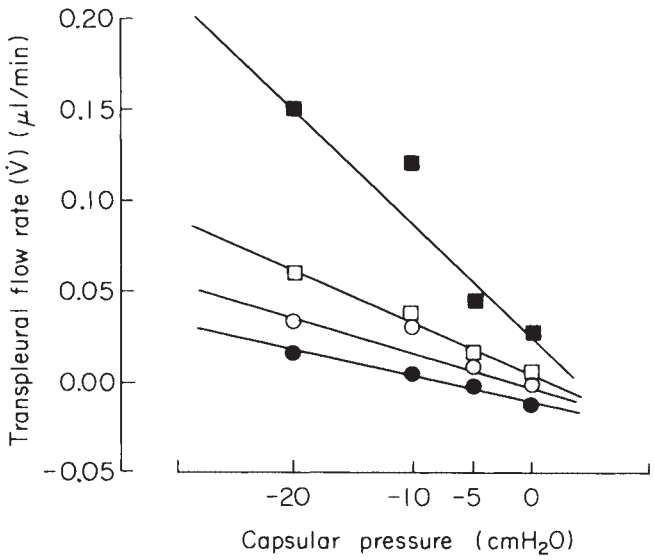

Fig. 3. The typical cases of relationship between Pcap and $\dot{v}$ each group were shown.
Changes in the transpleural flow rate as a function of capsular pressure changes.
○, Control group ($Y=-1.69\times10^{-3}X+2.94\times10^{-3}$)
●, C+G group ($Y=-0.77\times10^{-3}X-5.78\times10^{-3}$)
□, OA group ($Y=-2.19\times10^{-3}X+5.64\times10^{-3}$)
■, OA+G group ($Y=-6.80\times10^{-3}X+25.0\times10^{-3}$)

(Fig. 4). The values of the hydraulic conductivities of the control, C+G, OA and OA+G groups were 1.49 ± 0.69, 1.37 ± 0.88, 3.75 ± 0.74 and 7.07 ± 2.49, respectively. There was no significant difference between the control and C+G groups, while the OA group showed a significantly higher value than those of the control

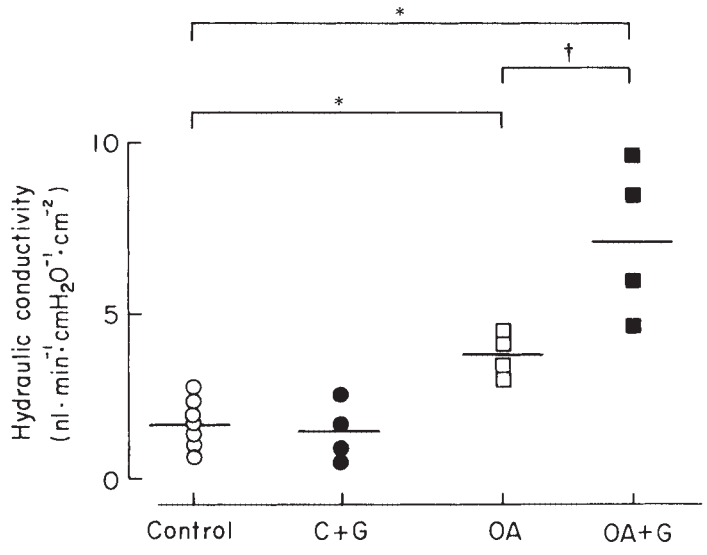

Fig. 4. Hydraulic conductivity was calculated from each slope using the least square method.
*$p<0.05$ vs. Control group
†$p<0.05$ vs. OA group

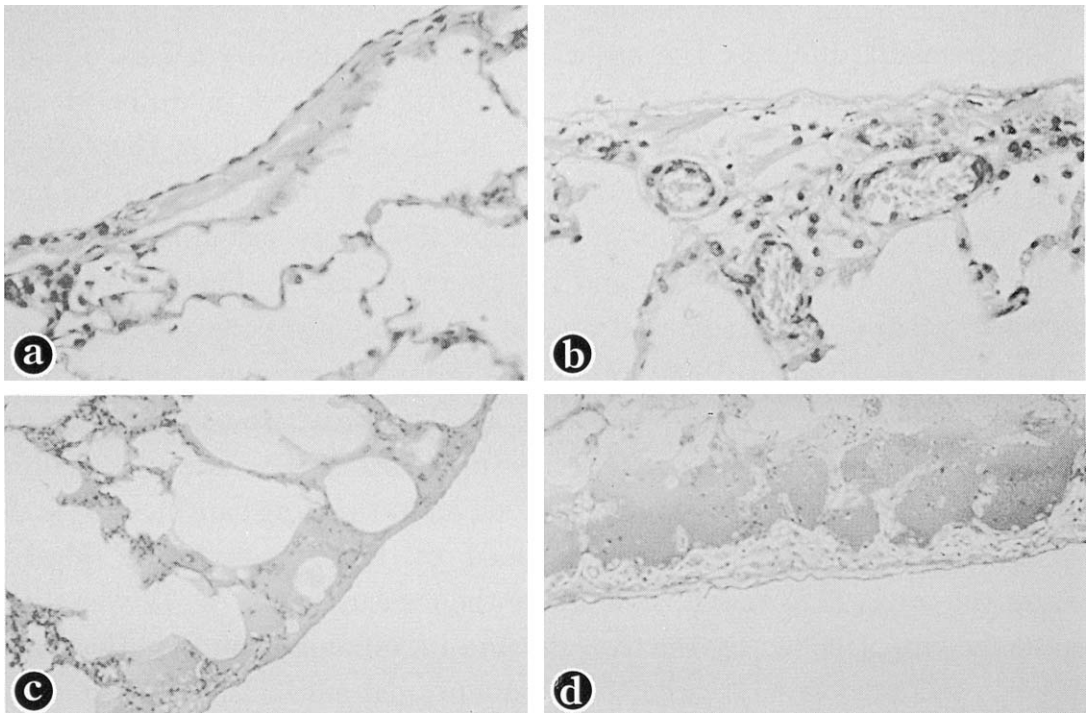

Fig. 5. Histological findings by H-E staining. Note that the mesothelium was removed in the C+G and OA+G groups.
a, Control; b, C+G; c, OA; d, OA+G.

and C+G groups. The OA+G group showed the highest value among the 4 groups.

Histological examination

The tissue specimens were histologically examined (HE staining, ×100) (Fig. 5). The control group (a) showed normal tissue structure from the mesothelium to the alveoli. In the OA (c) and OA+G (d) groups, edema of the interstitium and transudation into the alveoli were observed. No mesothelium was seen in the C+G (b) and OA+G groups, verifying its removal by Gelfilm.

Discussion

We investigated the roles of the pleural mesothelium, in accumulation of abnormal pulmonary effusion in permeability pulmonary edema from in situ measurements of hydraulic conductivity of the visceral pleura based on the Starling's equation.

The dynamics of pulmonary effusion has been studied by applying the Starling's equation between the pleura and the pleural cavity (Pistolesi et al. 1989). The pleura acts as a barrier to pulmonary effusion (Negrini et al. 1991). This indicated the importance of measuring hydraulic conductivity of the pleura for the elucidation of the dynamics of pulmonary effusion. There have been a number of attempts (Agostoni et al. 1957; Kim et al. 1979; Negrini et al. 1985, 1990, 1991; Payne et al. 1988; Ashino et al. 1993) to measure hydraulic conductiv-

ity of the pleura using various methods. However, the values of in vivo and in vitro measurements differ by the order of 102–103, indicating a lack of reliable measurements. Inconsistencies among the values obtained in different studies have been attributed to varying pressures in the body such as the left atrial pressure (Kinasewitz and Fishman 1981) and airway pressure (Agostoni et al. 1957) in the in vivo measurements of the fluid flow rates accompanying changes in the pressure between the pleura and the pleural cavity. They also have been attributed to pleural injuries caused by the stripping-off of the pleura for the in vitro measurements (Negrini 1990, 1991). Therefore, measurement methods under more physiological conditions are needed. In this study, we used an experimental apparatus shown in Fig. 1 for in situ measurements of the hydraulic conductivity. In this study, the capsule could be attached to the lung causing only a slight damage to the pleura, which was confirmed by light microscopy. Moreover, changes in the pressure in the capsule due to the measurements of ΔV were limited to around the site attached by the capsule, and its influences on the other parts of the lung is considered to be smaller than conventional methods, enabling measurements under more physiological conditions.

In this study, the capsule was attached to the lung lobe and filled with physiological saline. Applying the Starling's equation to the fluid flow from the capsule through the pleura, the flow rate of pleural effusion could be obtained at any given pressures in the capsule, while the hydraulic conductivity of the pleura, the protein reflection coefficient, the hydrostatic and the colloid osmotic pressures of the pleura were unknown. During measurements, the hydraulic conductivity and the protein reflection coefficient were assumed to remain unchanged. Since the hemodynamics and the colloid osmotic pressure of the plasma were kept constant during measurements in the control and C+G groups, the hydrostatic pressure of the pleura and the colloid osmotic pressure of the pleura were considered to be constant. At the start points of the measurements, the colloid osmotic pressure of the capsule filled with physiological saline is 0 cmH_2O. After each experiment, the protein concentration in the capsule was increased because of the inflow of the pleural effusion from the lung caused by the ΔV measurement. However, if the reflection coefficient of the mesothelium (Negrini et al. 1990) was taken into consideration, the colloid osmotic pressure calculated from the protein concentration was at the level of $10^{-3}\sim10^{-4}$ cmH_2O, which is negligible in all groups. Therefore, the Starling's equation can be approximated to $\dot{v}=K(\Delta P+c)$.

On the other hand, in the OA and OA+G groups which were administered oleic acid, the lung wet/dry weight ratios of the lungs and protein concentrations in the capsule were higher than those in the control and C+G groups. These findings and histological findings indicated that oleic acid is considered to induce pulmonary edema. Injured endothelium of the pulmonary blood vessels within 30 to 60 minutes via chemical mediators such as peptide LTs (leukotrienes) and/or free radicals (Ball et al. 1988), followed by changes in the arterial blood gas

analysis, pulmonary hemodynamics, extravascular lung water volume and the aortic pressure between 90 through 120 minutes until they reach steady state values (Yamaguchi et al. 1991). In this study, the measurement of ΔV was started at 120 minutes after injection of oleic acid and thereafter the parameters remained constant during the measurement. Movement of fluid and protein to the interstitium after injection of oleic acid is believed to be caused by elevation of permeability of pulmonary blood vessels. Fluid and protein are then transported to the lymphduct and the pleural cavity (Wiener-Kronish et al. 1988), and flow of interstitial fluid into the lymphatics is pressure-dependent (Miserocchi et al. 1993). The rate of protein movement within the interstitium is determined by fluid flow and the reflection coefficient of the interstitium (Granger et al. 1984). In the edematized interstitium, however, a decrease in the exclusion rate of protein causes fluid and protein to move easily (Granger et al. 1984). If the hydraulic conductivity of blood vessel wall remains high during the ΔV measurement, the flow of fluid and protein into the interstitium and its outflow through the lymphduct will be eventually equilibrated, and the hydrostatic pressure and the protein concentration in the interstitium will reach steady states. The parameters related to the hemodynamics and the colloid osmotic pressure of the plasma were kept constant after 2 hours after injection of oleic acid. Hemodynamic pulmonary edema is not caused by these parameters. It has also been shown that the amount of the fluid outside the pulmonary blood vessel remains constant (Yamada et al. 1991). These results suggested that our hypothesis is still valid in the OA and OA+G groups as well. Therefore, the Starling's equation can be approximated by $\dot{v}=K(\Delta P+c)$.

The hydraulic conductivity in the control group was 1.49 ± 0.69 nl $\cdot$ min^{-1} $\cdot$ cmH_2O^{-1} $\cdot$ cm^{-2}. The visceral pleura consists of (from the thoracic cavity side) the mesothelium, submesothelial tissue, external elastic layer, subpleural tissues containing blood vessels and lymphducts, and internal elastic layer (Bernaudin and Fleury 1985). In dogs, blood supply of the visceral pleura comes from the pulmonary artery, and the fluid exuded from the blood capillary flows into lymphducts via these layers (Wiener-Kronish et al. 1985). Each layer has its own filtration coefficient, and the filtration coefficient of the pulmonary capillary is ranged from 1.17×10^{-8} to 2.51×10^{-8} ml $\cdot$ sec^{-1} $\cdot$ cm^{-2} $\cdot$ $mmHg^{-1}$ (Levine et al. 1973), which is similar to our hydraulic conductivity obtained in the control and C+G groups. The permeability coefficient of the connective tissue is reported as 2.8×10^{-8} cm^2 $\cdot$ sec^{-1} $\cdot$ $mmHg^{-1}$ (Granger and Taylor 1975) which is too low to contribute to the value obtained as resistance in this study. Therefore, the blood vessel wall in the pleural layers appears to act as a barrier to production of pulmonary effusion in physiological condition. Since there was no difference in the hydraulic conductivity between the control and C+G groups, the mesothelium of the visceral pleura is unlikely to be a significant barrier.

The hydraulic conductivity in the OA group was twice as high as that in the

control and C+G groups. Probably resistance in the blood vessel wall no longer worked because of injection of oleic acid. When water content of interstitium is high, permeability coefficient of fluid in the interstitium is inversely related to the square of the fibrous coil density in the interstitial matrix (Granger et al. 1984). In the OA group of our study, the amount of fluid outside the blood vessel was doubled, and the resistance of the interstitium to the fluid flow was considerably reduced than in the control group. Therefore, the hydraulic conductivity obtained in the OA group suggested the presence of barrier tissues other than pulmonary blood vessel wall and interstitial tissues. In the OA+G group, the mesothelium was removed and oleic acid was injected, the permeability was twice as high as in the OA group.

In permeability pulmonary edema, the mesothelium was suggested to account for part of the resistance to pulmonary effusion. Oleic acid induces lung inflammation in 30-60 minutes. The pleura is filled with fluid and inflammatory cells from blood vessel, and swelled lymphducts and interstitial tissues (Yamaguchi et al. 1991). The fluid and inflammatory cells extend from the pleura to the thoracic cavity through the mesothelium (Wiener-Kronish et al. 1988). Examination of the pleura in permeability pulmonary edema by light and electron microscopy showed the normal structure of the mesothelial cells (Wiener-Kronish et al. 1988), and these were confirmed in the present study (Fig. 5). The mesothelium is derived from the mesoderm and forms a single layer squamoepithelium covering organs derived from the mesoderm. Mesothelial cells form tight junctions, gap junctions and desmosomes, which is similar to the adhesion between venulous endothelial cells (Wang 1985). Microvilli are present on mesothelial cells on the thoracic cavity side, which contain a large quantity of hyaluronic acid and proteoglycans, reducing the friction between the lung and the chest wall. Hyaluronic acid is also reported to suppress production of free radicals from leukocytes (Kimura 1987), suggesting that the mesothelium and the tissues in its vicinity may have anti-inflammatory effects. Therefore, it is likely that the mesothelium is a structural and biochemical barrier to pulmonary effusion in permeability pulmonary edema.

Conclusions

The hydraulic conductivities of the visceral pleura in dogs in the control, C+G, OA and OA+G groups were measured in situ. These results suggest that, as a barrier to production of pulmonary effusion, wall of pulmonary blood vessels works in the physiological conditions, and the mesothelium works in conditions of permeability pulmonary edema.

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