Oxygenation by Ventilation with Fluorocarbon Liquid (FX-80)

Jerome H. Modell, M.D., C. Ian Hood, M.D.,† Earlene J. Kuck,‡ Bruce C. Ruiz §*

Thirty-six mongrel dogs were ventilated with oxygenated fluorocarbon liquid (FX-80) for an hour and then reconverted to breathing gaseous oxygen. For several days after breathing this liquid, the dogs were hypoxemic while they breathed air. The authors attributed this to residual fluorocarbon in the lung and/or partial airway closure. By ten days after liquid ventilation, Pa_{O_2}'s had returned to pre-experimental control levels. Pathologic examination of the lungs three hours after termination of liquid ventilation disclosed an acute exudative inflammatory reaction largely confined to the bronchioles. By 72 hours the acute reaction had subsided and the dominant change consisted of vacuolated intra-alveolar macrophages, presumably containing fluorocarbon. At ten days, macrophages were still present, but generally in much smaller numbers; after a month only scattered small groups were found. At 18 months the lungs were normal. (Key words: Liquid ventilation; Fluorocarbon; Pulmonary lavage.)

In 1966, Clark and Gollan observed that mice and cats could breathe liquid fluorocarbon. One of their cats survived for three days but died of pulmonary edema.[1] Recently, Modell, Newby and Ruiz demonstrated that adult dogs can survive after being ventilated with oxygenated fluorocarbon liquid. Although the animals appeared normal a month later, they had hypoxemia and ventilatory difficulty for approximately a week following liquid ventilation.[2] The study reported herein was undertaken to investigate the nature of the ventilatory insufficiency observed in the earlier pilot study.

Methods

Thirty mongrel dogs (weight 13.3 ± SD 2.0 kg) were anesthetized with intravenous sodium pentobarbital (24 mg/kg). Each dog was secured on an operating table in the supine position and the trachea was intubated with a double-cuffed endotracheal tube. A thermistor probe was passed into the esophagus to the heart level to monitor body temperature. Under sterile surgical conditions, a polyethylene catheter was threaded from the left femoral artery into the abdominal aorta. The distal end of the catheter was implanted subcutaneously to facilitate sampling of blood for the next 72 hours. A silastic catheter was introduced into the left femoral vein and threaded so that its tip rested in the pulmonary artery. The position of the catheter was confirmed by pressure patterns. Both catheters were connected, via a triple stopcock assembly, to pressure transducers and a recorder. Two ml of heparinized arterial blood were drawn anaerobically while the dogs breathed air; pH_a, Pa_{CO_2} and Pa_{O_2} were determined with direct-reading electrodes maintained at 37 C. Temperature corrections were made when appropriate. A reservoir bag and a nonrebreathing valve then were connected to the endotracheal tube. After the dog had

* Professor and Chairman, Department of Anesthesiology.
† Associate Professor, Department of Pathology.
‡ Research Assistant, Department of Anesthesiology.
§ Technologist, Department of Anesthesiology.
Received from the Departments of Anesthesiology and Pathology of the University of Florida College of Medicine, Gainesville, Florida 32601, and the Department of Anesthesiology, University of Miami School of Medicine, Miami, Florida. Accepted for publication November 18, 1970. Supported in part by grants from the U. S. Public Health Service, 7 R01 GM17246, and the Florida Tuberculosis and Respiratory Disease Association. Presented at the annual meeting of the American Society of Anesthesiologists, New York City, October 21, 1970.
The research described in this report involved animals maintained in animal care facilities fully accredited by the American Association for Accreditation of Laboratory Animal Care.

breathed 100 per cent oxygen through this system for 15–20 minutes, a second sample of blood was drawn and analyzed for pH_a, Pa_{CO_2} and Pa_{O_2}.

Fifteen dogs were paralyzed with intravenous succinylcholine hydrochloride (3–10 mg). Their endotracheal tubes were connected to a reservoir chamber containing 1,200 ml of fluorocarbon fluid (FX-80).¶ An aerator was immersed in the fluorocarbon, and oxygen was bubbled through the liquid at a flow rate of 3–5 l/min. The dogs' lungs were then ventilated with a tidal volume of 300–400 ml of oxygenated fluorocarbon liquid by raising and lowering the chamber three to four times per minute. The frequency of ventilation for each animal was determined by the length of time necessary for "exhalation," or draining of fluorocarbon, after each "breath." The remaining 15 dogs also were ventilated with fluorocarbon as described above; however, they did not receive the muscle relaxant.

Aortic and pulmonary arterial pressures were monitored throughout the experiment. Intratracheal pressure, as reflected in a T side-arm where the endotracheal tube was connected to the reservoir chamber, was measured and recorded. Arterial blood samples were drawn for determination of pH_a, Pa_{CO_2} and Pa_{O_2} 5, 10, 15, 30, 45, and 60 minutes after ventilation with fluorocarbon was begun.

After an hour of continuous ventilation with liquid, the fluorocarbon was drained by gravity from the lungs and the chamber was disconnected. The reservoir bag and nonrebreathing valve were reconnected to the endotracheal tube and the animals breathed 100 per cent oxygen for three hours. The dogs in the nonparalyzed group breathed spontaneously, while those in the paralyzed group were ventilated with a volume-limited respirator ($V_T = 10$ ml/lb) until adequate spontaneous ventilation returned.

Ten dogs (five in each group) were anesthetized with intravenous sodium pentobarbital and sacrificed with intravenous potassium chloride three hours after reconversion to breathing gaseous oxygen. The tracheas and lungs were removed *en bloc* and photographed. The lungs of half of the dogs were then inflated with 10 per cent buffered formalin at 30–50 cm (formalin) pressure and fixed for two or more days prior to sectioning; the lungs from the remaining dogs were sectioned without inflation. Samples for histologic examination were taken from each lobe of all lungs; generally, one sample was taken from each of the smaller lobes and two or more from the larger lobes. All lobes were inspected and when any gross abnormality was noted the area containing it was included in the tissue samples. As many as 15 pulmonary sections from each animal were examined. All sections were stained with hematoxylin and eosin. Selected sections were stained with Masson's trichrome, Verhoeff's elastic, PAS or oil red O stains.

The pulmonary artery catheters, endotracheal tubes and esophageal thermistors were removed from the remaining 20 dogs, and they were placed in an oxygen tent containing 30–45 per cent oxygen. Arterial blood was drawn 24, 48 and 72 hours after ventilation with liquid for determination of pH and blood gas tensions at FI_{O_2}'s of both 0.21 and 1.0. When Pa_{O_2} was above 65 torr at $FI_{O_2} = 0.21$, supplemental oxygen was discontinued. Ten of these dogs (five in each group) were sacrificed 72 hours after the end of breathing fluorocarbon liquid and their lungs examined. The indwelling arterial catheters were removed from the remaining ten dogs and they were returned to their cages. Seven and ten days after the end of ventilation with liquid, pH_a, Pa_{O_2} and Pa_{CO_2} were determined at $FI_{O_2} = 0.21$ and $FI_{O_2} = 1.0$. These dogs were then also sacrificed and their lungs examined.

An additional group of six dogs was studied in a manner similar to the non-paralyzed group above. Four of these animals were sacrificed for study a month after ventilation with liquid and two were sacrificed at two months.

Results

All animals survived ventilation with oxygenated fluorocarbon liquid and reconversion to breathing gaseous oxygen. During ventilation with liquid, mean Pa_{O_2} and pH_a usually were higher and Pa_{CO_2} was lower in the paralyzed dogs than in the nonparalyzed dogs (table 1). We noted that it was easier to move the liquid in and out of the lungs of dogs that were para-

¶ Courtesy of 3M Company, St. Paul, Minnesota.

TABLE 1. Blood-gas Tensions and *p*H Values of Group A (15 Nonparalyzed) Dogs and Group B (15 Paralyzed) Dogs (Means ± SD)*

Minutes	pH_a		P_{aCO_2} (torr)		P_{aO_2} (torr)	
	Group A	Group B	Group A	Group B	Group A	Group B
Breathing oxygen						
0	7.41 ± 0.07	7.41 ± 0.06	32.9 ± 4.7	33.2 ± 4.4	522 ± 65	543 ± 68
Breathing liquid fluorocarbon						
5	7.27 ± 0.07	7.32 ± 0.07‡	46.9 ± 8.3	41.5 ± 7.2†	275 ± 125	419 ± 71§
15	7.20 ± 0.08	7.25 ± 0.09†	50.2 ± 13.7	46.3 ± 8.0	192 ± 90	278 ± 62§
30	7.15 ± 0.07	7.21 ± 0.10†	63.5 ± 12.3	51.1 ± 9.0	219 ± 98	267 ± 56†
45	7.14 ± 0.08	7.21 ± 0.10‡	67.7 ± 16.6	54.3 ± 10.5‡	214 ± 98	270 ± 55
60	7.13 ± 0.06	7.22 ± 0.09§	67.0 ± 12.8	52.4 ± 4.0	210 ± 70	274 ± 50§
Breathing oxygen						
75	7.36 ± 0.06	7.37 ± 0.09	35.6 ± 4.3	36.4 ± 5.9	349 ± 102	386 ± 89
90	7.37 ± 0.04	7.39 ± 0.10	36.5 ± 2.9	34.6 ± 7.4	364 ± 107	370 ± 102
120	7.40 ± 0.04	7.41 ± 0.09	35.9 ± 3.8	32.8 ± 8.1	399 ± 82	383 ± 110
150	7.39 ± 0.06	7.40 ± 0.07	35.8 ± 3.7	32.4 ± 7.1	403 ± 82	390 ± 114
180	7.41 ± 0.04	7.39 ± 0.07	34.6 ± 5.2	33.4 ± 6.1	399 ± 88	368 ± 101
210	7.41 ± 0.05	7.40 ± 0.07	34.5 ± 3.3	32.6 ± 7.0	409 ± 87	400 ± 79
240	7.41 ± 0.04	7.43 ± 0.08	34.4 ± 4.2	30.0 ± 7.0	439 ± 78	398 ± 92

* The dogs were ventilated from 0 through 60 minutes with oxygenated fluorocarbon liquid. The values listed at 0 time and from 75 to 240 minutes were taken while the dogs breathed 100 per cent oxygen. The two groups were compared for significant differences.
† $P < 0.10$; ‡ $P < 0.05$; § $P < 0.01$.

lyzed. Many animals in the nonparalyzed group conformed to the pattern of ventilation supplied. However, others made spontaneous inspiratory efforts while fluorocarbon was being drained from their lungs. After conversion to breathing 100 per cent gaseous oxygen, there were no significant differences between pH_a, P_{aCO_2} or P_{aO_2} in the two groups.

pH_a and P_{aCO_2} values in the two groups permitted to live three and ten days after ventilation with liquid fluorocarbon were comparable. When pH_a and P_{aCO_2} values from one to ten days after ventilation with fluorocarbon liquid were compared with those obtained before liquid ventilation, no significant differences were seen (table 2).

TABLE 2. Blood-gas Tensions and *p*H Values before (0 Time) and 24, 48, 72, 168, and 240 Hours after Dogs were Ventilated with Oxygenated Fluorocarbon Liquid for an Hour (Means ± SD)*

Hours	pH_a		P_{aCO_2} (torr)		P_{aO_2} (torr) (F_{IO_2} = 0.21)		P_{aO_2} (torr) (F_{IO_2} = 1.0)	
	Group A	Group B	Group A	Group B	Group A	Group B	Group A	Group B
0†	7.40 ± 0.08	7.43 ± 0.05	32 ± 6	34 ± 5	92 ± 19	92 ± 14	536 ± 67	544 ± 67
24†	7.38 ± 0.06	7.35 ± 0.07	42 ± 6	43 ± 5	64 ± 5	58 ± 10	478 ± 41	391 ± 127
48†	7.40 ± 0.08	7.42 ± 0.06	42 ± 7	36 ± 6	62 ± 8	57 ± 11	468 ± 54	422 ± 69
72†	7.44 ± 0.04	7.44 ± 0.05	41 ± 6	41 ± 5	67 ± 7	60 ± 11	481 ± 54	409 ± 117
168‡	7.52 ± 0.05	7.46 ± 0.06	32 ± 5	34 ± 2	78 ± 7	75 ± 23	474 ± 28	454 ± 49
240‡	7.46 ± 0.05	7.42 ± 0.08	34 ± 4	34 ± 9	85 ± 12	85 ± 17	490 ± 13	466 ± 33

* The animals in Group B were paralyzed during the period of ventilation with liquid,—those in Group A were not paralyzed.
† Twenty animals: 10 in Group A and 10 in Group B.
‡ Ten animals: 5 in Group A and 5 in Group B.

Arterial oxygen tension during breathing of air was significantly lower than control values during the first 72 hours after liquid ventilation ($P < 0.01$). However, by 168 hours (seven days) Pa_{O_2} at $FI_{O_2} = 0.21$ returned toward normal, and was not significantly different from control values ($P > 0.10$). Although Pa_{O_2} during the breathing of 100 per cent oxygen was slightly reduced after liquid ventilation, these values were not significantly different from pre-experimental values in any group at any time. Mean values for Pa_{O_2} were higher during breathing of either room air or 100 per cent oxygen at 24 to 72 hours in the group that was not paralyzed than in the group that received succinylcholine (table 2). However, these differences were not statistically significant ($P > 0.05$).

During ventilation with fluorocarbon the peak positive intratracheal pressure reached on inhalation was higher ($P < 0.01$) and the negative pressure during exhalation lower ($P < 0.01$) in the nonparalyzed dogs (table 3). Higher systolic blood pressures were also observed in the pulmonary arteries and aortas of the nonparalyzed animals (table 3); however, the difference between the two groups was not statistically significant in all time periods. The systolic blood pressure in the aorta was uniformly higher during exhalation of fluorocarbon than during inhalation in every dog.

On gross examination three hours after the end of liquid ventilation, the lungs had a translucent sheen suggestive of intra-alveolar fluorocarbon in their dependent portions. On section of fresh unfixed lungs, these areas oozed fluorocarbon. In general, nondependent portions were of normal consistency, pink, and contained air. On section, it was obvious that some fluorocarbon still remained in some of these areas, but not to the extent seen in the dependent portions.

Seventy-two hours after the end of liquid ventilation the translucent areas characteristic of intra-alveolar fluorocarbon were much less extensive and less numerous. At ten days, only occasional lobes contained areas grossly suggestive of intra-alveolar fluorocarbon. The remainder of the lobes were pink and crepitant. After one and two months, the lungs were pink, crepitant, and appeared normal on gross examination.

On microscopic examination, the lungs of

TABLE 3. Systolic Pulmonary Arterial, Systolic Aortic and Airway Pressures during 60 Minutes of Ventilation with Fluorocarbon Liquid (Means ± SD)* (torr)

	Time in Minutes											
	0	1		6		15		30		60		
		Inhalation	Exhalation	Inhalation	Exhalation	Inhalation	Exhalation	Inhalation	Exhalation	Inhalation	Exhalation	
Pulmonary arterial pressure												
Group A	25 ± 10	50 ± 25	40 ± 45	49 ± 20	37 ± 34	38 ± 14	44 ± 25	48 ± 32	33 ± 24	35 ± 16	32 ± 21	
Group B	32 ± 12	39 ± 16	36 ± 9	32 ± 14	29 ± 13	30 ± 12	28 ± 11	32 ± 12	29 ± 13	30 ± 11	25 ± 10	
Aortic pressure												
Group A	181 ± 18	160 ± 36	195 ± 40	140 ± 21	195 ± 27	133 ± 27	179 ± 22	130 ± 16	174 ± 24	128 ± 17	168 ± 27	
Group B	161 ± 22	131 ± 37	161 ± 28	135 ± 27	160 ± 20	144 ± 28	160 ± 25	138 ± 18	157 ± 18	141 ± 17	107 ± 22	
Airway pressure												
Group A	—	62 ± 37	−22 ± 28	52 ± 32	−21 ± 31	47 ± 25	−35 ± 20	43 ± 19	−30 ± 23	37 ± 11	−31 ± 10	
Group B	—	23 ± 12	1 ± 9	26 ± 14	−2 ± 9	23 ± 11	−8 ± 12	22 ± 7	−8 ± 12	23 ± 9	−9 ± 13	

* The 15 dogs in Group B received succinylcholine; those in Group A did not.

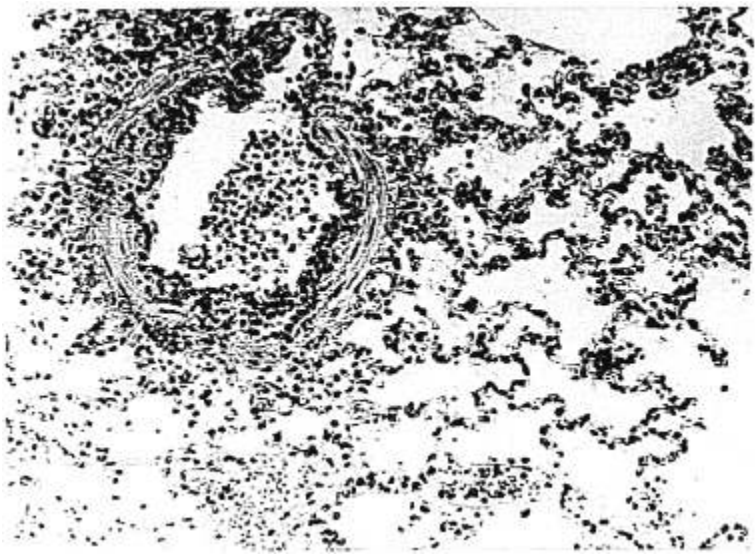

FIG. 1. Lung three hours after the end of liquid ventilation with oxygenated fluorocarbon. Note polymorphonuclear leukocytic exudate in bronchiole, congested alveolar septa, exudate and scattered leukocytes in alveoli (hematoxylin and eosin ×190).

those animals paralyzed during liquid ventilation could not be distinguished from those not paralyzed. Three hours after the end of liquid ventilation, the lungs of all ten dogs were hyperemic. They also contained a focal exudative bronchitis and bronchiolitis characterized by exudates of polymorphonuclear leukocytes in the airways (fig. 1). Occasionally, these exudates spilled into the peribronchiolar alveoli. In one lung the process was diffuse. In two lungs there were focal intra-alveolar hemorrhages. Vacuolated intra-alveolar macrophages were sparse in these three-hour samples.

Seventy-two hours after the end of liquid ventilation, all lungs contained numerous intra-alveolar macrophages; smaller numbers of macrophages were present in the interstitium. The extent of this response varied considerably from lung to lung, and from lobe to lobe in any one lung. The macrophages contained numerous discrete vacuoles, presumably fluorocarbon, in their cytoplasm. They generally were peribronchial, peribronchiolar and perivascular in distribution. In those lobes containing the largest numbers of macrophages, the latter often showed a striking concentration around respiratory bronchioles (fig. 2, *a* and *b*). In some foci there were also admixed polymorphonuclear leukocytes.

Ten days after the end of liquid ventilation, macrophages were still present, but generally in much smaller numbers. They were predominantly peribronchial (fig. 3), but some were present in the alveoli and interstitium also. Lobar involvement was quite variable, with only minimal evidence of reaction in some dogs. In one animal there was also a coincidental, apparently unrelated, peribronchial lymphocytic-plasmacytic infiltrate. Subpleurally, and in some alveoli, there were occa-

FIG. 2. *A*, (above) lung 72 hours after the end of liquid ventilation with oxygenated fluorocarbon. Note accumulation of intra-alveolar macrophages, which tend to concentrate around respiratory bronchioles (hematoxylin and eosin ×85). *B* (below), detail of *A*, showing vacuolated macrophages in alveoli and airway (hematoxylin and eosin ×270).

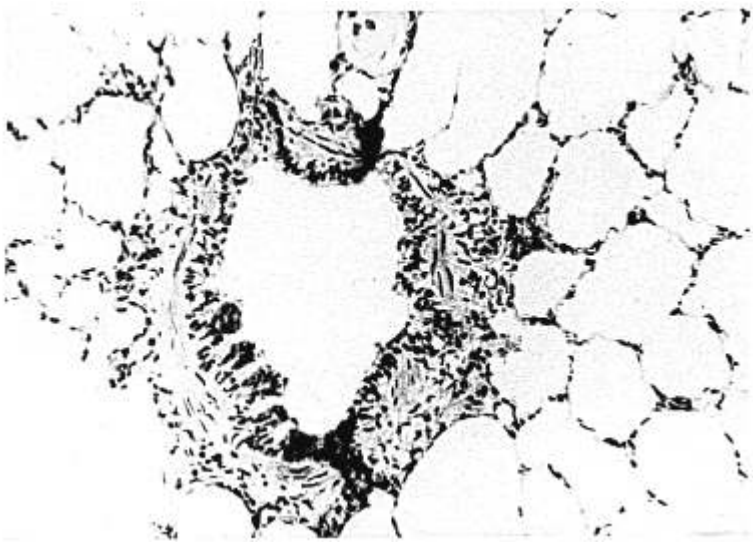

FIG. 3. Lung ten days after liquid ventilation with oxygenated fluorocarbon. Note small numbers of peribronchiolar macrophages and the absence of other reactions (hematoxylin and eosin ×175).

sional small foci of macrophages with an associated fibroblastic proliferation.

One month (four dogs) and two months (two dogs) after liquid ventilation, the lungs appeared relatively normal. There were rare parabronchiolar lesions comprising small groups of vacuolated macrophages. In addition, there were occasional small, microscopic subpleural fibrous plaques in which there were scattered vacuolated macrophages. In two of these dogs there were dilated peribronchial, perivascular and subpleural lymphatics. In one, the lesions were focal; in the other, more diffuse. The cause of the lymphangiectasia was obscure, but could not be related to either pulmonary inflammation or scarring.

We also examined the lungs of four dogs that had breathed fluorocarbon 18 months previously in another study.[2] Three of these animals had breathed fluorocarbon for 30 minutes and one for eight hours. These lungs were normal in appearance (fig. 4). Occasional small parabronchial collections of round cells with a few admixed pigmented macrophages (dust cells) were found, and there were rare, thin, subpleural, fibrous plaques containing a few round cells and pigmented macrophages. Vacuolated macrophages similar to those present at one month were not found. There was no other scarring and no evidence of emphysema.

Discussion

The fluorocarbon liquid, FX-80, used in this study is an azeotropic mixture of perfluorobutyltetrahydrofuran and isomeric compounds[3] which is immiscible with aqueous media and can hold high concentrations of oxygen in solution.[**] These properties, plus the observation that fluorocarbon neither affects the surface tension properties of pulmonary surfactant nor washes it from the lung,[4] suggest that mammals might breathe this liquid at atmospheric pressure. All the animals ventilated with fluorocarbon liquid in this study survived, thus confirming that breathing of liquid by mammals at 1 atmosphere is feasible, and that

[**] 31 vol per cent at 37 C (Laver, M. B., and Modell, J. H., unpublished data).

they can predictably be reconverted to breathing oxygen in the gaseous state.

Our dogs showed increases in Pa_{CO_2} and decreases in pH_a during ventilation with liquid. These changes were similar to those found in the previous pilot study.[2] The minute ventilation of these animals was only 0.9–1.6 liters. The dogs that received the muscle relaxant were easier to ventilate and had lower Pa_{CO_2}'s than those that were not paralyzed. Several dogs in the nonparalyzed group made spontaneous ventilatory efforts in opposition to the passive ventilation by gravity, which led to lower effective minute ventilation. These observations indicate that the hypercarbia was secondary to hypoventilation; however, the diffusion rate and solubility characteristics of carbon dioxide in fluorocarbon must be measured before these can be excluded as possible contributing factors to the hypercarbia. Of further interest is the fact that within 15 minutes of termination of ventilation with liquid the dogs hyperventilated, and their Pa_{CO_2} and pH_a values returned to levels comparable to those observed prior to liquid ventilation.

Twenty-four hours after the end of breathing liquid, all dogs had significantly lower arterial oxygen tensions when breathing room air than they had had prior to the experiment. During this period, all of the dogs had labored ventilation. In many dogs, expiratory wheezing was heard, suggesting partial airway closure. However, when the dogs were breathing 100 per cent oxygen, Pa_{O_2}'s were not significantly lower than values prior to ventilation with liquid. This suggests that a relative intrapulmonary shunt due to either a diffusion problem or a low ventilation–perfusion ratio was responsible for the hypoxia seen at $F_{I_{O_2}} = 0.21$, and that a true (or absolute) intrapulmonary shunt due to perfused but nonventilated alveoli could be excluded as the major cause of the hypoxia. This relative shunt persisted for at least 72 hours, and had disappeared by the seventh to tenth day after ventilation with liquid.

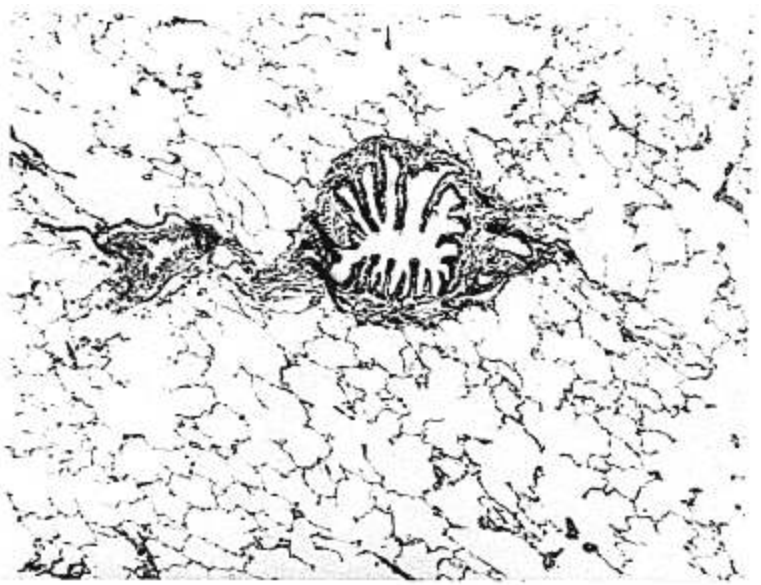

FIG. 4. Lung 18 months after liquid ventilation with oxygenated fluorocarbon. Note normal bronchiolar and alveolar structures (hematoxylin and eosin ×80).

The microscopic appearance of the lung correlated with these blood-gas changes. Three hours after discontinuation of ventilation with liquid, the lung showed acute hyperemia and a generalized inflammatory reaction. This could be explained by either the trauma of forcible distention of the airways and alveoli with liquid or an irritant effect of the fluorocarbon itself, or both. By 72 hours, the predominant finding in the lungs was macrophages engulfing the fluorocarbon. These were seen primarily in peribronchial, peribronchiolar and perivascular areas; however, in many of the dogs dispersed intra-alveolar macrophages were found as well. Although studies of the rate at which oxygen diffuses in fluorocarbon liquid are not available, we can speculate that the diffusion rate of oxygen through a layer of fluorocarbon liquid would be less than the diffusion rate through an air column of the same thickness. Indeed, if this were true, then a fluorocarbon coating in parts of the lung would act as a barrier to diffusion of oxygen, and could account for the decreased arterial oxygen tension observed when the dogs breathed room air.

By ten days, the arterial oxygen tensions were not significantly different from those prior to breathing fluorocarbon liquid. This correlates well with the microscopic findings that at ten days only a small number of vacuolated macrophages and minimal scarring remained, and major portions of the lung looked entirely normal. A month after the dogs had breathed fluorocarbon liquid, only rare parabronchiolar lesions comprising small groups of vacuolated macrophages were found, suggesting that the major portion of the fluorocarbon had been removed, probably by mucociliary mechanisms, evaporation via the airways, and to a lesser extent via lymphatics. Vacuolated macrophages were demonstrable in some hilar lymph nodes. Removal of the residual fluorocarbon was eventually complete, since the lungs of animals examined a year and a half after breathing fluorocarbon liquid were normal.

Of particular interest is the fact that the fluorocarbon used in this study, FX-80, is not a single compound. It shows at least eight peaks by gas chromatography.[3] Presumably, these are all isomers of one basic chemical compound. Unless these isomers can be separated and studied individually, it is impossible to state whether the acute response of the lung observed in this study was due to one of these isomers or to the mechanical aspect of liquid ventilation.

None of the dogs in this study developed emphysematous changes in the lungs. This further supports our previous conclusion that breathing FX-80, *per se*, does not cause these lesions. Rather, emphysema occurred only when very high intratracheal pressures were generated during liquid ventilation with this compound. In the pilot study, the dog that showed emphysematous changes in the lungs was ventilated at pressures which frequently exceeded 100 torr.[2] In the present study, intratracheal pressures were considerably lower.

The moderate decline in aortic systolic blood pressure during inhalation probably was due to mechanical interference with venous return and cardiac output from transmitted pressure as the lungs filled with fluorocarbon. During exhalation the blood pressure returned to normal.

In conclusion, we have shown that mammals can breathe fluorocarbon liquid for an hour with reconversion to breathing oxygen in gaseous form. During the first few days after breathing this liquid, Pa_{O_2}'s during breathing of air were less than control values. We believe this was due to a decreased diffusion rate of oxygen across the residual fluorocarbon liquid in the lung and/or partial airway closure. By ten days, sufficient fluorocarbon had been removed so that a significant diffusion deficit no longer existed and wheezing was not heard. The lungs showed an early acute inflammatory reaction followed by appearance of macrophages. Macrophages were most numerous at 72 hours, and then decreased with time. They were rare after a month and completely gone after 18 months.

References

1. Clark LC Jr, Gollan F: Survival of mammals breathing organic liquids equilibrated with oxygen at atmospheric pressure. Science 152: 1755–1756, 1966
2. Modell JH, Newby EJ, Ruiz BC: Long-term survival of dogs after breathing oxygenated fluorocarbon liquid. Fed Proc 29:1731–1736, 1970
3. Holaday DA, Modell JH: Uptake and distribution in the dog of an inert fluorocarbon, FX-80. Fed Proc 29:684, 1970
4. Modell JH, Gollan F, Giammona ST, *et al.*: Effect of fluorocarbon liquid on surface tension properties of pulmonary surfactant. Chest 57:263–265, 1970