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THE EFFECT OF LIGATION OF
PULMONARY VEINS IN THE DOG

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AN EXPERIMENTAL STUDY OF THE EFFECT OF LIGATION OF PULMONARY VEINS IN THE DOG

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IN THE course of experiments designed to explore the possibility of creating a venous shunt between the systemic and pulmonary venous systems, it became desirable to utilize the proximal end of a divided pulmonary vein to one lobe in an end-to-end anastomosis. This would necessitate ligation of the distal end of the divided pulmonary vein to the lobe and would, in effect, be exactly equivalent to simple ligation of the pulmonary vein in so far as subsequent changes in the lobe itself are concerned. We wished to know, therefore, what changes in a pulmonary lobe are to be expected following simple venous ligation. In turning to the literature for the answer to this problem, we were surprised to find that, so far as we could discover, this simple experiment had never been fully exploited, and the answer was not fully known. Accordingly, a series of dogs were subjected to simple total ligation of the pulmonary vein from the upper lobe of the right lung and the subsequent pathologic changes in the lobe were observed at different time intervals following operation.

REVIEW OF THE LITERATURE

Interest in pulmonary vein ligation first arose because it suggested itself as a therapeutic method in the treatment of tuberculosis. Tiegel's work,¹ published in 1911, has been offered as evidence that advanced pulmonary fibrosis is the end result of pulmonary vein ligation. However, in reviewing this study, it was apparent that Tiegel was not attempting complete venous ligation. He described placing silver wire rings around the pulmonary veins of rabbits and dogs to partially obstruct their lumina. In animals which survived, this was followed by an immediate intense engorgement of the pulmonary capillaries, accompanied by pulmonary hemorrhage. After weeks or months, firm pleural adhesions were found containing many blood vessels, and there was thickening of the pleura and alveolar septa. The lobes were said to be smaller, paler, and firmer than the normal lobes on the opposite side. In only two of his animals was complete ligation performed, and he noted that in many of the lungs histologic changes were minimal. Kawamura² confined his studies in rabbits to ligation of the pulmonary *artery* to the left lower lobe. In 1923, Schlaepfer³ reported on the clinicopathologic aspects of air embolism following minor or major intrapleural manipulations. Experimental observations on two dogs following partial ligation of the pulmonary vein on one side were described, with special attention to the development of collateral venous channels which

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developed through parietovisceral adhesions and through enlargement of the bronchial veins. This author's subsequent work was confined to the effects of pulmonary arterial ligation.^{4, 5}

We believe that the first clinical cases with pulmonary venous ligation were those reported by Kerschner⁶ in 1931. Four patients with tuberculous cavities in the upper lobes underwent this operative procedure with mildly encouraging but not spectacular clinical results. No pathologic studies were available at the time of the report. In 1932 appeared the careful experimental studies of Mathes⁷ and co-workers on the bronchial, pulmonary, and lymphatic circulations of the lung under various experimentally produced pathologic conditions. Among other conditions investigated, complete ligation of the pulmonary vein to one lobe of the lung was usually, although not invariably, followed by death of the animal in four or five days. The pleural cavity was found to be filled with a thin blood-stained effusion and the lobe was large, firm, and of a deep red, liverlike consistency. The bronchial artery appeared normal; the pulmonary artery was injected poorly with bismuth mass because of peripheral venous congestion. The number of animals used and the particular lobe whose vein was ligated were not stated.

This work apparently escaped the attention of European surgeons, because O'Shaughnessy,⁸ in 1935, published three clinical cases with vein ligation using the report of Tiegel as experimental background. His patients had been followed less than one year, and no pathologic observations were available. In the same year, Valkányi⁹ reported on three experimental and five clinical cases with pulmonary vein ligation. He tied the vein to the upper or middle lobe of the lung in three dogs. The mortality was not stated. The pathologic changes seen three to five weeks postoperatively were described by Professor Jarmay. There was moderate shrinkage and a firm consistency of the lobe. Microscopically confluent areas of fibrosis were seen; the pleura was thickened, the alveoli were smaller and contained hemosiderin-laden phagocytes. Of the five patients with tuberculous cavities, one died postoperatively, two were unimproved, and two demonstrated moderate healing.

The study reported in 1938 by Ameuille¹⁰ and his co-workers was concerned chiefly with the development of collateral venous channels following pulmonary vein ligation. Ten dogs were operated upon transpleurally. Six died in the immediate postoperative period. The remaining four were sacrificed at six weeks, four months, six months, and seven and one-half months, respectively. The pulmonary vessels were studied by injection. Firm vascular adhesions developing at the operative site and between the pleura and the chest wall contained enlarged collateral venous channels. There was no change in the pulmonary artery, but the bronchial artery and the artery of the pulmonary ligament seemed slightly enlarged. No description of the tissue changes found in the lung was given.

In his description of a two-stage operation for pneumonectomy in 1938, Rienhoff¹¹ states that if the pulmonary veins were ligated in the first stage, wet gangrene supervened. The observations which formed the basis for this statement were not described.

It would appear, therefore, that there is conflicting opinion as to the fate of a lobe of a lung following ligation of its veins, and that the only available evidence is comprised of the three animals of Valkányi and the unknown number of animals used by Mathes and associates. Observations were made, therefore, at various postoperative periods on eleven dogs in which the venous return from a single lobe had been ligated and cut, and on two animals in which the entire pulmonary vein to one side was ligated and cut.

METHOD

Healthy mongrel dogs of medium or large size were used. In the performance of all surgical procedures, operating room technique and aseptic precautions were the same as used in the main operating room of the hospital. All procedures were done under endotracheal positive pressure ether anesthesia. Following operation, the animals were placed in individual cages until fully recovered, and then returned to the kennel runs. In the protocols, the term ligation will be used throughout to mean double ligation and complete division of the vessel. The postmortem tissues were fixed in 4 per cent formaldehyde, washed in tap water, cleared by dioxane, imbedded in paraffin, cut at 8 microns thickness, and stained by hematoxylin and eosin, Turnbull's blue, and Weigert's elastic tissue stain. Each animal served as its own control. In all cases none of the nonoperated lobes of the right lung and none of those of the left lung showed changes comparable to those observed in the lobes whose veins were ligated and severed. The necessity for dummy control operations was, therefore, eliminated.

PROTOCOLS

I. SINGLE LOBE LIGATIONS

DOG NUMBER V-1.—A stocky, slick-haired, brown dog weighing 22 kg.

May 24, 1946. Operation. Ligation of veins to right upper lobe.

May 27, 1946. Dog appears well but has moderate cough, with thick mucoid sputum.

May 31, 1946. Reoperation. Right upper lobe appears a deep dull red in color; is very firm, and feels solid. Lobe removed as a specimen. Middle lobe utilized for a different experiment, then removed. Lower lobe veins ligated. Moderate shock.

June 1, 1946. Dog found dead.

Autopsy.—Moderate amount of reddish exudate in pleural cavity. Right lower lobe solid, very hemorrhagic. Left lung normal.

Microscopic Examination.—(A) Right lower lobe (six to eighteen hours post-operative): The pleura showed fibrinopurulent pleuritis. The alveoli, bronchioles, and many bronchi were filled with edema fluid, packed erythrocytes, or inflammatory exudate (Fig. 3). The veins, venules, and capillaries were severely engorged. *Microscopic diagnosis:* (1) acute fibrinopurulent pleuritis; (2) pulmonary hemorrhage; (3) pulmonary hyperemia and edema; (4) focal bronchopneumonia.

(B) Right upper lobe (seven days postoperative): The pleura was covered by a thick layer of fibrin containing neutrophiles, nuclear debris, and swollen mesothelial cells, and penetrated at the edge by proliferated capillaries and fibroblasts (Fig. 4). Groups of alveoli beneath the pleura were surrounded and filled by proliferated fibroblasts. In several areas deeper alveoli and alveolar ducts showed loss of the outlines of their walls and were packed with edema fluid and erythrocytes, some including segmented neutrophiles and nuclear debris. Many bronchioles were filled with masses of fibrin enmeshing segmented neutrophiles. The alveolar capillaries and venules were engorged. Some of the larger veins showed thrombosis. *Microscopic diagnosis:* (1) organizing fibrinopurulent pleuritis; (2) pulmonary

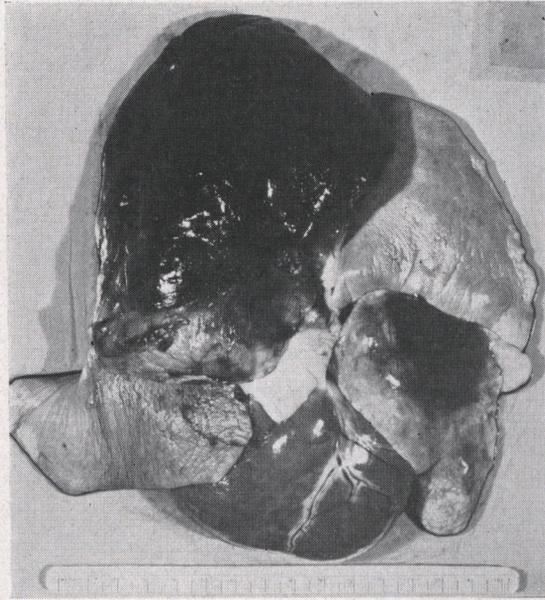


Fig. 1.—Photograph of heart and lungs of dog sacrificed three days following ligation of the pulmonary veins to the right upper lobe.

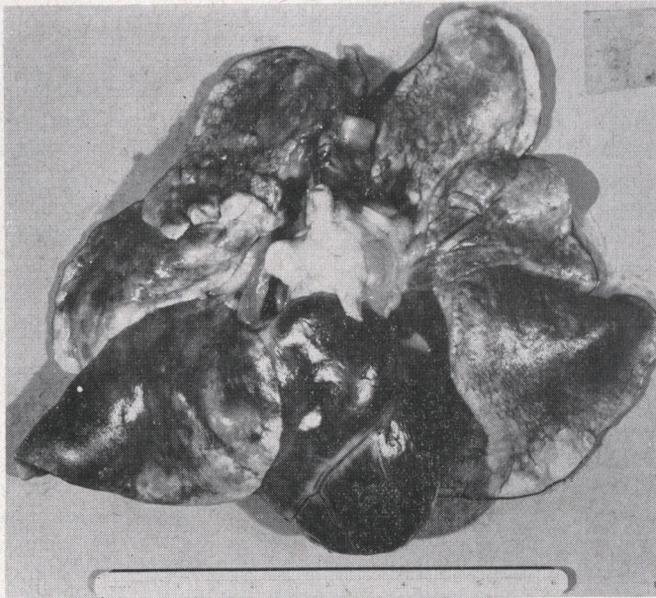


Fig. 2.—Photograph of heart and lungs of dog sacrificed 134 days following ligation of pulmonary veins to right upper lobe.

hemorrhage (with small scattered infarcts); (3) thrombosis of pulmonary veins; (4) organizing pneumonia.

DOG NUMBER V-2.—A black and white shaggy-haired dog weighing 21 kg.

June 2, 1946. Dog given 25 mg. dicoumarin.

June 3, 1946. Dog given 15 mg. dicoumarin. Prothrombin time, twenty seconds (normal). Operation. Ligation of pulmonary veins to right upper lobe.

June 4, 1946. Dog seems quite ill and weak, with severe cough producing blood-stained sputum.

June 5, 1946. Dog found dead.

Autopsy.—Right upper lobe was a deep greyish red and appeared solidified. Middle and lower lobes appeared atelectatic. Left lung normal.

Microscopic Examination.—The right upper lobe (two days postoperative) showed the pleura lightly covered with fibrinopurulent exudate. Many alveoli, ducts, bronchioles, and bronchi were crammed with erythrocytes. Some peripheral alveoli contained edema fluid; others were cystic and empty. The alveolar capillaries, venules, and veins were engorged. *Microscopic diagnosis:* (1) acute fibrinopurulent pleuritis; (2) pulmonary hemorrhage; (3) pulmonary hyperemia and edema; (4) bronchiolectasis.

DOG NUMBER V-3.—A large German shepherd dog weighing 30 kg.

June 6, 1946. Operation. Ligation of pulmonary veins to right upper lobe. Middle lobe vein used for an anastomosis.

June 7, 1946. Dog appears in good condition. Breathing is easy. Moderate cough.

June 8, 1946. Dog died at 8:30 A.M.

Autopsy.—The right chest cavity was filled with blood. The source of the bleeding was not determined. Anastomosis patent. No thrombosis. Upper lobe hemorrhagic and solidified. Middle lobe reddened and slightly shrunken. Left lung normal.

Microscopic Examination.—The right upper lobe (two days postoperative) showed changes almost identical with those described in dog V-2. *Microscopic diagnosis:* (1) acute fibrinopurulent pleuritis; (2) pulmonary hemorrhage; (3) pulmonary hyperemia and edema; (4) bronchiolitis and bronchitis, acute.

DOG NUMBER V-4.—A slick-haired, black dog weighing 15 kg.

Sept. 15, 1946. Operation. Ligation of veins to right upper lobe.

Sept. 17, 1946. Dog doing well. Mild cough.

Sept. 21, 1946. Dog fully recovered; asymptomatic.

Oct. 7, 1946. Dog in excellent health. Sacrificed.

Autopsy.—Wound well healed. Pleural cavities clean. Moderate firm adhesions of right upper lobe to parietal pleura and to mediastinum. Right upper lobe was shrunken, pale, and felt thickened and relatively airless. Other lobes normal.

Microscopic Examination.—Right upper lobe (twenty-three days postoperative). The pleura was thickened with connective tissue poor in elastic fibrils and containing new-formed capillaries. A few small groups of alveoli were collapsed. In many areas proliferated fibrous connective tissue and new capillaries were mingled with macrophages (containing brown pigment granules positive for iron) and lymphocytes. This tissue either filled alveoli and bronchioles, or surrounded and entrapped these structures. The larger veins showed organizing thrombi. *Microscopic diagnosis:* (1) fibrous pleuritis; (2) organizing pneumonitis with interstitial fibrosis and hemosiderosis; (3) thrombosis and recanalization of veins.

DOG NUMBER V-5.—A small, gray-black, long-haired dog weighing 14 kg.

Sept. 13, 1946. Operation. Ligated pulmonary veins to right upper lobe.

September 14, 1946. Dog making uneventful recovery.

October 7, 1946. Dog in good health. Sacrificed.

Autopsy.—Small superficial wound infection lower end incision. Pleural cavities clean. Adhesions between upper lobe and the wound. Right upper lobe slightly reddened and firm. Other lobes normal.

Microscopic Examination.—Right upper lobe (twenty-four days postoperative). The pleura showed thickening, with masses of neutrophils, macrophages, and lymphocytes mingled

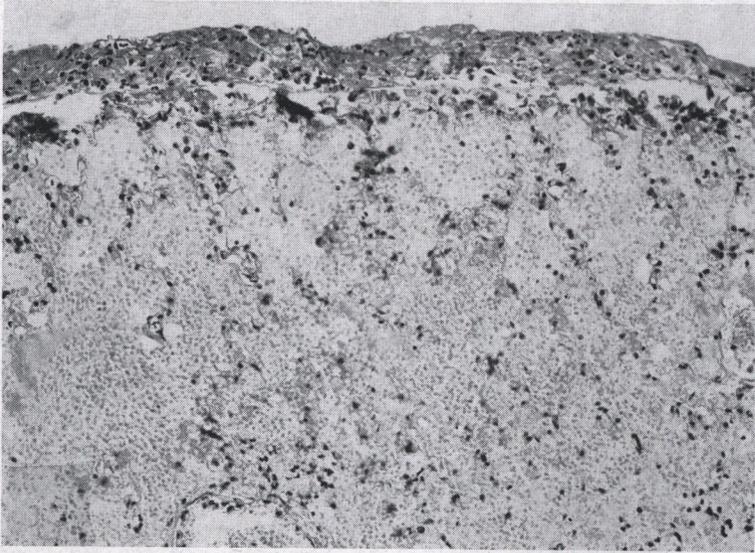


Fig. 3.—Dog V-1. Twelve hours. Fibrinopurulent exudate on pleura. Alveoli and alveolar ducts engorged and hemorrhagic. Hematoxylin and eosin stain. ($\times 150$.)

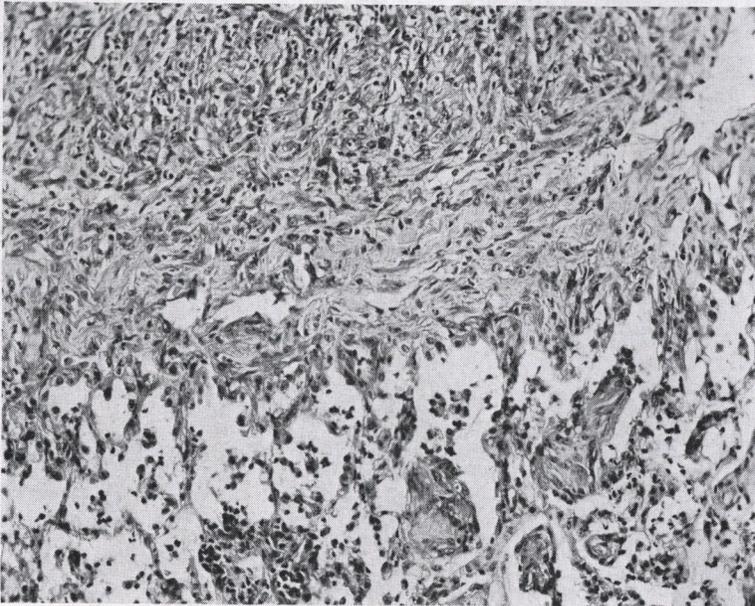


Fig. 4.—Dog V-1. Seven days. Granulation tissue and thickened pleura at top. Alveoli inclosing inflammatory cells and proliferated fibroblasts. Hematoxylin and eosin stain. ($\times 150$.)

with proliferated fibroblasts and capillaries, as well as new fibrous tissue poor in elastic fibrils. Alveoli, alveolar ducts, and bronchioles showed widespread collapse. The more superficial ones contained proliferated fibroblasts intermingled with leucocytes. Venules and capillaries were mildly engorged. Macrophages were present, containing iron-positive pigment. *Microscopic diagnosis*: (1) chronic pleuritis; (2) atelectasis; (3) organizing pneumonitis with focal hemosiderosis.

DOG NUMBER V-6.—A German shepherd dog weighing 18 kg.

Sept. 3, 1946. Operation. Ligation of the pulmonary veins to the upper right lobe.

Sept. 9, 1946. Dog has made excellent recovery.

Oct. 7, 1946. Dog in good health. Sacrificed.

Autopsy.—Wound well healed. Pleural cavities normal. Very thick adhesions between upper lobe and the chest wall and mediastinum. Upper lobe appeared whitish, was shrunken, and felt firmer than normal, but not solid.

Microscopic Examination.—Right upper lobe (thirty-four days postoperative) (Fig. 5). The pleura showed thick fibrous connective tissue poor in elastic fibrils and inclosing new capillaries and venules. Much fibrous connective tissue was proliferated in the stroma, thus obliterating or entrapping alveoli, alveolar ducts, and bronchioles. Many hemosiderin macrophages were intermingled in this tissue and were free in a few alveoli. Organizing thrombosis of larger veins was present. *Microscopic diagnosis*: (1) fibrous ("vascular") pleuritis; (2) interstitial fibrosis and hemosiderosis; (3) thrombosis of pulmonary veins.

DOG NUMBER V-7.—A brown collie bitch weighing 17 kg.

Aug. 30, 1946. Operation. Ligation of pulmonary veins to right upper lobe.

Sept. 4, 1946. Dog has had slight cough.

Sept. 10, 1946. Dog seems entirely well.

Oct. 7, 1946. Dog has remained in good health. Sacrificed.

Autopsy.—Wound was well healed. Pleural cavities clean. Many firm adhesions between chest wall and upper lobe. Right upper lobe was pale, moderately shrunken, and felt relatively airless. Other lobes were normal.

Microscopic Examination.—Right upper lobe (thirty-eight days postoperative). Similar to dog number V-6. *Microscopic diagnosis*: (1) fibrous ("vascular") pleuritis; (2) interstitial fibrosis and hemosiderosis; (3) thrombosis of pulmonary veins.

DOG NUMBER V-8.—A light brown chow dog weighing 26 kg.

May 27, 1946. Operation. An end-to-end venous anastomosis made using right upper lobe vein. The distal end of this vein ligated.

May 29, 1946. Dog in good condition. Has not developed cough.

July 2, 1946. Operation. Right chest opened in order to perform a second and unrelated experimental procedure. There were dense adhesions surrounding the upper lobe. The lobe was dark in color and seemed partially solidified. A generous biopsy of the right upper lobe was taken for examination.

Microscopic Examination.—Right upper lobe (forty-five days postoperative). The pleura was greatly thickened by a vascular fibrous connective tissue poor in elastic fibrils. Many alveoli, alveolar ducts, and bronchioles were collapsed; very few were filled with erythrocytes and edema fluid. Many macrophages (Fig. 6) containing iron-positive pigment were seen. The larger veins showed organized thrombosis. *Microscopic diagnosis*: (1) fibrous pleuritis; (2) atelectasis; (3) focal hemorrhagic edema and hemosiderosis; (4) thrombosis and recanalization of pulmonary veins.

DOG NUMBER V-9.—A short-haired, black and white dog weighing 17 kg.

Aug. 15, 1946.—Operation. An end-to-end anastomosis using right upper lobe vein. Pulmonary end of vein ligated.

Aug. 20, 1946. Dog making uneventful recovery.

Oct. 25, 1946. Dog has remained healthy. Sacrificed.

Autopsy.—Wound well healed. Pleural cavities clean except for adhesions between right upper lobe and the chest wall. Right upper lobe pale, slightly firm. Other lobes normal.

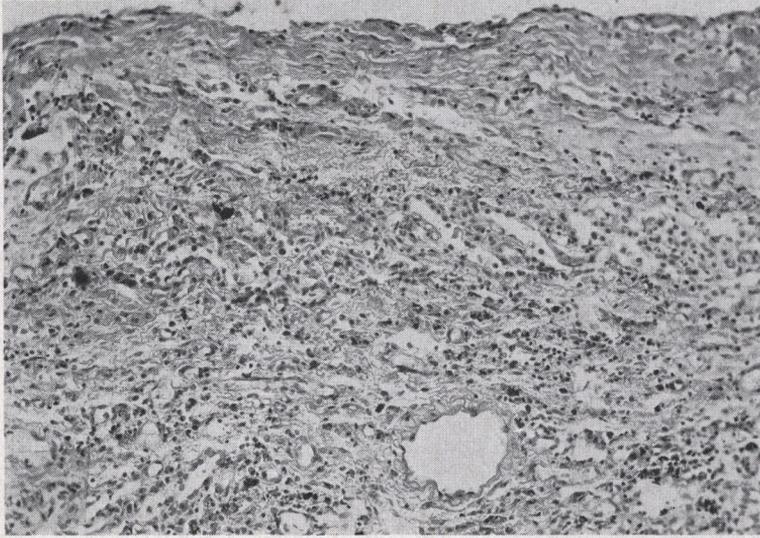


Fig. 5.—Dog V-7. Thirty-four days. Thickened pleura, collapsed alveoli and alveoli ducts, interstitial fibrosis. Hematoxylin and eosin stain. ($\times 150$.)

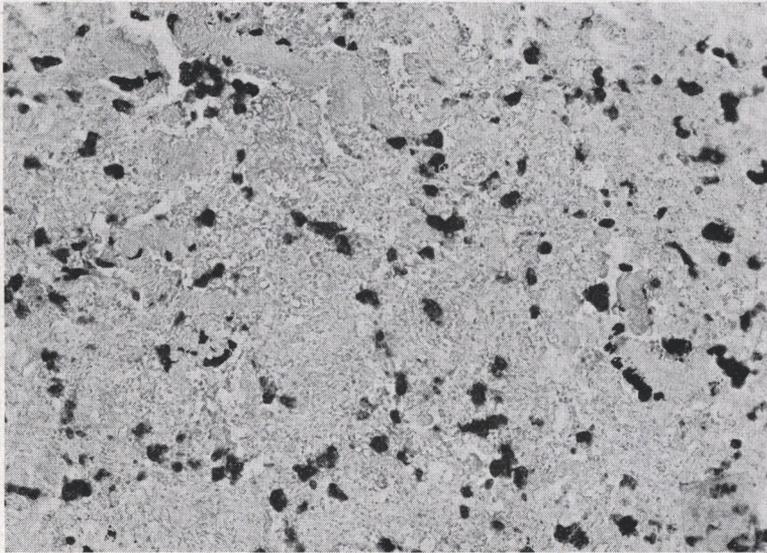


Fig. 6.—Dog V-8. Forty-five days. Collapsed alveoli and alveolar ducts. Many hemosiderin macrophages. Iron stain, Turnbull's blue method. ($\times 150$.)

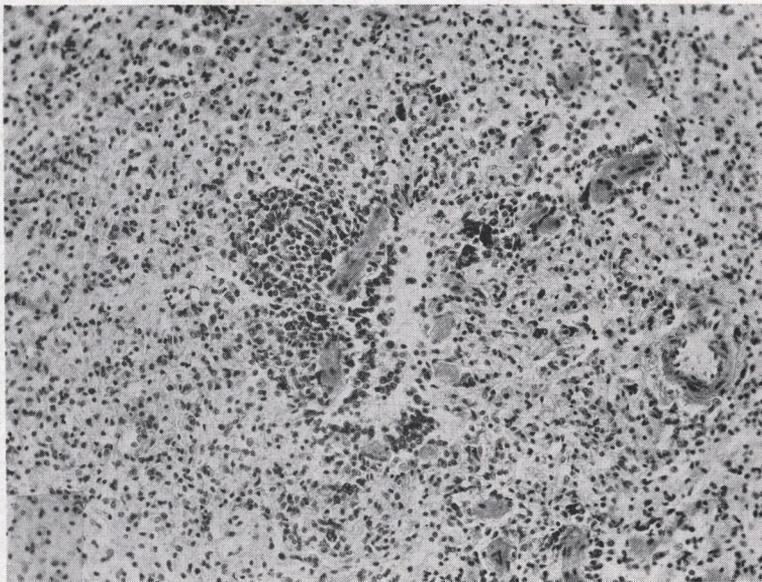


Fig. 7.—Dog V-9. Seventy-one days. Bronchiole at center surrounded by collapsed alveolar ducts and alveoli. Hematoxylin and eosin stain. ($\times 150$.)

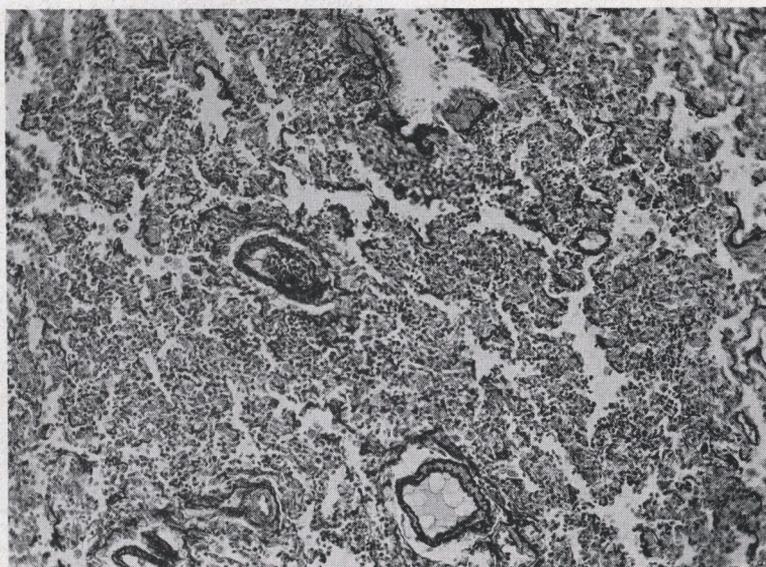


Fig. 8.—Dog V-9. Seventy-one days. Atelectasis. Weigert's elastic tissue stain. ($\times 150$.)

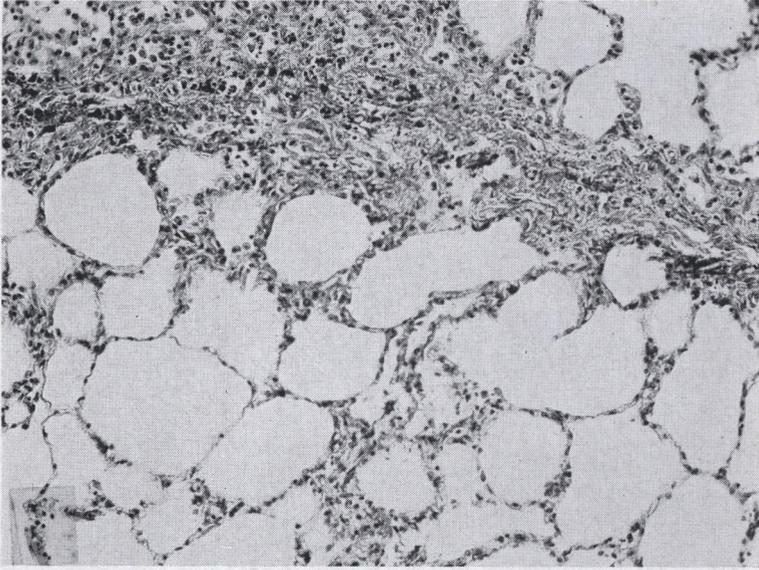


Fig. 9.—Dog V-11. One hundred thirty-four days. Band of interstitial fibrosis at top. Re-expanded alveoli in lower half. Hematoxylin and eosin stain. ($\times 150$)

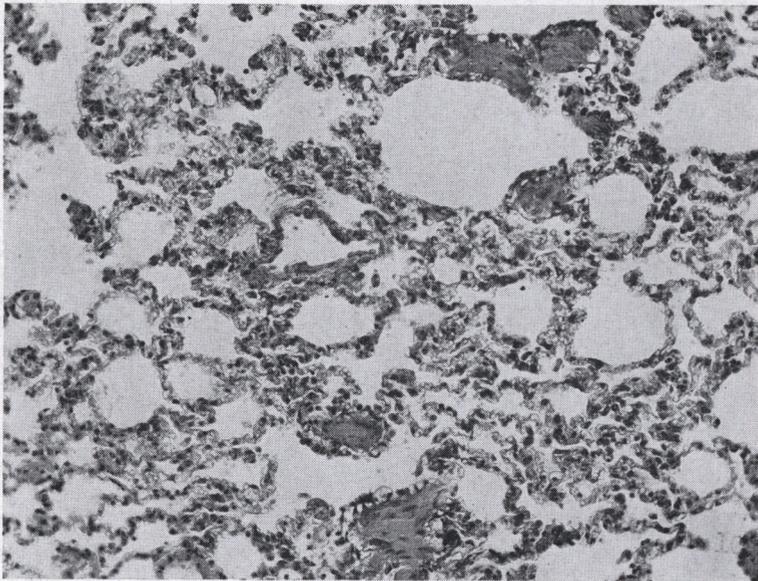


Fig. 10.—Dog V-11. One hundred thirty-four days. Normal lobe of left lung for comparison with Fig. 7. Hematoxylin and eosin stain. ($\times 150$)

Microscopic Examination.—Right upper lobe (seventy-one days postoperative) (Figs. 7 and 8). The pleura was thickened with a chronic suppurative fibrotic reaction. Many alveoli, alveolar ducts, and bronchioles, were collapsed; others were surrounded by strands of proliferated fibrous tissue. *Microscopic diagnosis:* (1) chronic suppurative fibrous pleuritis; (2) atelectasis; (3) focal interstitial fibrosis.

DOG NUMBER V-10.—A tan collie dog weighing 20 kg.

Aug. 12, 1946. Operation. Ligation of pulmonary veins to right upper lobe.

Aug. 15, 1946. Dog has mild productive cough.

Dec. 2, 1946. Dog has remained in excellent health. Sacrificed.

Autopsy.—Wound well healed. Upper right lobe was adherent to chest wall and to mediastinum with fine adhesions, which were dense only in the region of the chest incision. The right upper lobe appeared slightly shrunken, but was almost normal in color, soft to touch, and crepitant. Other lobes were normal.

Microscopic Examination: Right upper lobe (111 days postoperative). The pleura was thickened with vascular fibrous tissue. Many alveoli, alveolar ducts, were well expanded. In several areas thin strands of fibrous connective tissue infiltrated with lymphocytes and iron-positive pigment-laden macrophages, were proliferated around alveoli, alveolar ducts, bronchioles, and in the septa. The large veins showed recanalizing thrombosis. *Microscopic diagnosis:* (1) fibrous pleuritis; (2) interstitial fibrosis and hemosiderosis; (3) thrombosis and recanalization of pulmonary veins.

DOG NUMBER V-11.—A large, black dog weighing 26 kg.

July 30, 1946. Operation. Ligation of pulmonary veins to right upper lobe.

July 31, 1946. Dog has cough productive of blood-tinged sputum.

Aug. 5, 1946. Dog recovered from operation. Cough disappeared.

Dec. 2, 1946. Dog has remained in good health. Sacrificed.

Autopsy.—Wound firmly healed. Right upper lobe adherent to chest wall with breakable adhesions. The lobe appeared normal in size, shape, color, and consistency. Other lobes normal.

Microscopic Examination.—Right upper lobe (134 days postoperative) (Figs. 9 and 10). The pleura was thickened with vascular connective tissue poor in elastic fibrils. Occasional iron-positive pigment-laden macrophages were seen. Strands of fibrous connective tissue extended between some alveoli and in the septa, but most of the alveoli were normally patent. It was estimated that the lobe was 80 per cent aerated. *Microscopic diagnosis:* (1) fibrous pleuritis; (2) interstitial fibrosis and hemosiderosis; (3) thrombosis and recanalization of pulmonary veins.

II. ENTIRE LUNG LIGATIONS

DOG NUMBER L-1.—A small, slick-haired bitch weighing 12 kg.

Sept. 25, 1946. Operation. The left pulmonary vein to the entire left lung was ligated.

Sept. 26, 1946. Animal died at twenty-four hours following operation. She showed extreme weakness, pallor of the mucous membranes, dyspnea, and cough productive of bloody sputum. She presented the picture of progressive shock.

Autopsy.—Pleural cavity on left contained blood-stained fluid. The entire left lung was dark red, completely solidified, and gave the appearance of liver.

Microscopic Examination.—(One day postoperative.) The appearance in all of the left lobes was similar to that seen in the right lower lobe of dog V-1. *Microscopic diagnosis:* (1) acute fibrinous pleuritis; (2) pulmonary hemorrhage, pulmonary hyperemia, and edema; (3) bronchopneumonia; (4) thrombosis of pulmonary veins.

DOG NUMBER L-2.—A brown, long-haired bitch of collie extraction, weighing 11 kg.

Sept. 26, 1946. Operation. Ligation of the entire pulmonary venous return from the right lung.

Sept. 27, 1946. Animal is very weak and is coughing up blood.

Sept. 29, 1946. Animal died three days following operation, and became progressively weaker with increasing pallor.

Autopsy.—The entire right lung is a dark red color, completely solidified, and quite heavy.

Microscopic Examination.—The right lung (3 days post-operative).

Microscopic diagnosis.—(1) Acute fibrinous pleuritis; (2) pulmonary hemorrhage, pulmonary hyperemia, and edema; (3) bronchopneumonia; (4) thrombosis of pulmonary veins.

COMMENT

These experiments indicate that healthy dogs may have the veins from the right upper lobe ligated and divided and survive the operation, probably indefinitely. Of the three deaths in this series occurring following operation, two were the result of an additional but unrelated experimental procedure (dogs V-1 and V-3), and one (V-2) was in an animal under the effect of dicoumarin. We have never had an animal survive a major operative procedure while under the effect of this drug. Eight dogs survived from 23 to 134 days, and were then sacrificed.

On the other hand, ligation of the entire venous return from a lung was fatal within three days in two animals (L-1, L-2). These animals appeared to die of blood loss and shock. The pathologic findings in these lungs were identical with those seen in the single lobe following venous ligation. The difference between survival and death, therefore, would appear to be quantitative, and is related, we think, to the volume of blood loss as pulmonary hemorrhage.

The sequence of events following ligation and division of the veins of one lobe of a lung may be briefly sketched. The first reactions in the lobe include a fibrinous or fibrinopurulent pleuritis with adhesions of the lobe to the parietal pleura. The lobe is pumped full of blood by the intact arteries to it. Consequently, severe hyperemia, hemorrhage, and edema are noted, especially involving the aveoli, alveolar ducts, and bronchioles. Along with the reduced vitality of the pulmonary parenchyma, bronchopneumonia becomes an accompanying reaction. As a result of their ligation, thrombosis occurs in the veins to the lobe.

The process of recovery from these acute changes includes the establishment of adhesions between the visceral and parietal pleura through organization of the acute pleuritis and the formation of new blood vessels, including capillaries, venules, and arterioles to furnish a collateral blood supply, especially venous. Along with this reaction, blood monocytes coming into the arteries migrate from the alveolar capillaries into the alveoli and alveolar ducts and pick up cell debris, especially broken down erythrocytes and the degradation products of hemoglobin, so well demonstrated by the abundant hemosiderin in numerous macrophages, mainly in alveoli, alveolar ducts, and bronchioles early and chiefly in interstitial fibrous connective tissue later. Granulation tissue grows out into alveoli, alveolar ducts, and bronchioles to organize contained exudate. In addition, air is evidently resorbed from some alveoli and alveolar ducts. Widespread atelectasis results from the emptying of the content of these structures by both the scavenging of the hemorrhagic and inflammatory debris and the resorption of edema fluid and residual air. As the collateral blood supply established by the pleural adhesions becomes more abundant in the later stages, especially as seen in dogs V-8 and V-10, the still intact arterial blood vessels are able to vascularize the lobe, especially the alveolar

capillaries, and the still intact bronchial tree is able to admit air for the re-expansion of the lobe. The atelectatic areas then largely disappear, the re-expansion beginning first at the periphery of the lobe and then extending centrally. The granulation tissue within the alveoli, alveolar ducts, and bronchioles is either resorbed or incorporated into the interstitial fibrous connective tissue.

The final result after three or four months is a lobe at least 80 per cent re-expanded and apparently functioning with residual vascularized pleural adhesions and focal interstitial fibrosis and hemosiderosis. The thrombi in the proximal ends of the severed veins to the lobe become organized and the veins are recanalized to different degrees.

SUMMARY

1. The pathologic changes in the right upper lobe of the lungs of eleven healthy dogs observed at increasing intervals following ligation and division of the pulmonary veins to that lobe are described.

2. Healthy dogs may survive indefinitely following ligation of the veins to a single lobe, but ligation of the veins to the entire lung in two animals was fatal.

3. There is no significant death of pulmonary tissue following venous ligation. The primary reaction is severe pulmonary engorgement and hemorrhage. Gradually, in a period of about four months, this hemorrhage is resolved, the accompanying intraluminal and interstitial fibrous reaction is absorbed, and with the development of collateral venous channels through adhesions, the lung returns toward normal, approaching full functional activity.

The authors wish to express their appreciation of the excellent technical assistance of Dr. Charles Monroe.

REFERENCES

1. Tiegel, M.: Operative Lungenstauung und deren Einfluss auf die Tuberkulose, *Arch. f. klin. Chir.* 95: 810, 1911.
2. Kawamura, K.: Über die künstliche Erzeugung von Lungenschrumpfung durch Unterbindung der Pulmonalarterienäste und den Einfluss derselben auf die Lungentuberkulose, *Deutsche Ztschr. f. Chir.* 125: 373, 1913.
3. Schlaepfer, K.: Collateral Circulation in Chronic Obstruction of the Pulmonary Veins and Its Relation to Air Embolism Following Various Diagnostic and Therapeutic Procedures (Pneumolysis), *Surg., Gynec. & Obst.* 37: 510, 1923.
4. Schlaepfer, K.: Ligation of the Pulmonary Artery of One Lung With and Without Resection of the Phrenic Nerve, *Arch. Surg.* 9: 25, 1924.
5. Schlaepfer, K.: The Effect of the Ligation of the Pulmonary Artery of One Lung Without and With Resection of the Phrenic Nerve, *Arch. Surg.* 13: 623, 1926.
6. Kerschner, E.: Die Ligatur der Vena pulmonalis bei Lungentuberkulose; Ein neuer Versuch ihrer chirurgischen Behandlung, *Ztschr. f. Tuberk.* 60: 198, 1931.
7. Mathes, M. E., Holman, E., and Reichert, F. L.: A Study of the Bronchial, Pulmonary, and Lymphatic Circulation of the Lung Under Various Pathologic Conditions Experimentally Produced, *J. THORACIC SURG.* 1: 339, 1932.
8. O'Shaughnessy, L.: Surgery of the Lung Root, *Lancet* 1: 476, 1935.
9. Valkanyi, R.: Erzeugung einer venösen Stauung und ihre Wirkung auf Lungenlappen, als eine neue chirurgische Behandlungsart der Lungentuberkulose. I. Teil. Topographisch-anatomische und tierexperimentelle Studien. II. Teil. Durch die Lobovenoligatur erzielte klinische Heilungsergebnisse, *Arch. f. klin. Chir.* 182: 742, 1935; 191: 504, 1938.
10. Ameuille, P., Lemoine, J. M., and Nouaille, J.: Suppléance Circulatoire par les Adhérences Après Ligature des Veines Pulmonaires, *Ann. d'anat. path.* 15: 85, 1938.
11. Reinhoff, W. F., Jr.: A Two-stage Operation for Total Pneumonectomy in the Treatment of Carcinoma; Demonstrating a New Technique for Closure of the Bronchus, *J. THORACIC SURG.* 8: 254, 1938.