The Circulation of the Secondary Lobule of the Human Lung

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The employment of corrosion models has proved to be a useful method for the study of the capillary circulation of the lung. Until recently, we felt that studying the capillary circulation in the component parts of the primary lobule** would reveal all the aspects of the terminal arterial circulation. It has been found, however, that the primary lobule does not disclose all the details of the terminal arterial vessels and their capillary networks. To understand the terminal and capillary circulation in its entirety, it is necessary to study the secondary lobule† as one unit. Only by doing so is it possible to demonstrate the importance of the different types of vessels which play their part in supplying the alveoli of the secondary lobule with their capillary networks.

The purpose of this paper is to demonstrate that there are three sources of blood supply to the secondary lobule from which arterial alveolar capillary networks are formed.

By the use of corrosion models it has also been possible to demonstrate how the arterial vessels by continuous subdivision form the capillary networks. Although there appear to be certain recognizable patterns, these cannot be strictly categorized, as variations occur between the various forms.

Study of the alveolar capillary network has impressed us again, as in earlier studies† with the richness of the anastomoses existing between capillary networks and also between the precapillary vessels. These anastomoses are extensive and plentiful and are probably of great physiologic significance.

Methods

Normal human lungs were used for this study.†† In removing the lung, great care was exercised not to tear the pleura or the pulmonary vessels. The pulmonary artery was severed at its base. In order to have as long a stem of the pulmonary artery as possible, part of the left auricle was removed with them.

Dissection of the hilar area was done carefully so as to avoid transection of vessels communicating with the lung parenchyma, for otherwise troublesome leaks occurred during the injection.††

Lungs were injected with Vultex Moulage‡ using a modified method of Lieb.⁷ The Vultex Moulage may be obtained in various colors. To facilitate recognition of the various structures during dissection, and also to make photography more distinctive, we use white Vultex Moulage for the bronchial tree, blue for the pulmonary arteries and red for the veins. The structures thus colored stand out distinctly and it is comparatively easy to follow them to the finest microscopic dimensions.

Suitable pieces of the model were studied and dissected under a dissection microscope. The secondary lobule described in Fig. 1 was located deep within the lung on the outer margin of a lobe. It was removed in toto and the dissection was done by following the arborizations of the bronchiole and its accompanying arterial vessel. The overlying structures were removed so

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**By the term "primary lobule" we mean the ensemble of alveolar duct, atria, air sacs and air cells (alveoli) as defined by Miller.¹
†A secondary lobule can be defined as a cluster of respiratory tissue which is surrounded by connective tissue and into which enters a bronchiole and its arterial vessel. The bronchiole subdivides into three to five terminal bronchioles, each in turn terminating into several respiratory bronchioles. There may be fifty or more primary lobules within a secondary lobule. The unit is recognizable anatomically and bronchographic ally.¹³

††From the Necropsy Service of the Vancouver General Hospital.
‡Obtained from General Latex and Chemicals, Ltd., Verdun, Quebec.
as to expose the pattern of circulation. Slides were prepared according to the method of Duff. Further details of the methods have been described in a previous publication. Measurements were made by the use of a calibrated grid located in the eyepiece of the dissection microscope. The drawings are faithful reproductions of the slides as seen in the dissection microscope.††

Observations

Dissection of secondary lobules revealed that there are three types of arterial vessels from which the alveolar capillary networks are derived (Fig. 1).

The first type is an arterial vessel which enters the secondary lobule in close association with the bronchiole (Fig. 1C). It continues to subdivide along the pattern of the bronchial tree until it reaches the alveolar duct. At this point, the arterial vessel, by now a precapillary vessel, breaks up into a capillary network which spreads across the nearby alveoli. The arterial vessel accompanying the bronchiole supplies primarily the alveoli of the inner core of the secondary lobule. Although it continues to subdivide like the bronchiole, it may also give off branches which proceed to certain groups of alveoli of the lobule without being in close proximity to a subdivision of the bronchiole. This can be seen in Figure 1, where the vessel (C) accompanying the bronchiole (B) lies somewhat behind it, but it gives off two branches, one to the right and one to the left (C₁ and C₂). These are not closely associated to the respective respiratory bronchioles (R₁ and R₂).

The second type of arterial vessel from which capillary networks are derived are

††Drawings were made by medical artist Nan Cheney, Department of Medical Illustration, Faculty of Medicine, University of British Columbia.

![Figure 1: Dissection of a secondary lobule of a human lung showing its three sources of blood supply. B.—Bronchiole entering the secondary lobule. Br. P.—Branches of peripheral arteries penetrating into the secondary lobule. Capillaries of these branches may reach as far as the respiratory bronchioles. C.—Arterial vessel accompanying the bronchiole (centro lobular supply). C₁ and C₂—Branches of C. Cap. An₁—Anastomoses between capillaries from the vessel accompanying the bronchiole (C) and branches of the peripheral vessels (Br. P.). Cap. An₂—Anastomoses between capillaries from two branches (Br. P.) of peripheral vessels. P.—Peripheral vessels located in the tissues between secondary lobules. R₁, R₂, R₃—Respiratory bronchioles.](image-url)
**FIGURE 2:** Demonstration of the formation of alveolar capillary networks from a precapillary vessel which arises from a vessel located in the tissues between secondary lobules. a.—Pulmonary alveolus. Cap.—Capillary measuring less than 0.014 mm. in diameter arising directly from a branch of a peripheral vessel measuring 0.072 mm. in diameter and forming a capillary network on alveolus “a”. P.—Peripheral vessel located in the tissues between secondary lobules and measuring 0.156 mm. in diameter. P.R.C.—Precapillary vessel, measuring 0.018 mm. proceeding to nearby alveoli and forming capillary networks over them.

**FIGURE 3:** Demonstration of the formation of alveolar capillary networks from precapillary vessels which arise from a vessel located in the tissues between secondary lobules. Cap.—Capillaries measuring less than 0.014 mm. in diameter and which by their anastomoses form hexagonal spaces measuring approximately 0.02 mm. square. P.—Peripheral vessel, located in the tissues between secondary lobules, measuring 0.06 mm. in diameter. P.R.C.—Precapillary vessels, measuring 0.018 mm. in diameter, arising from the peripheral vessel.
vessels which are located in the tissues between secondary lobules and which are on the way to more peripheral parts of the lung parenchyma (Figs. 1, 2 and 3—P). As they pass a secondary lobule, they may give off precapillary sized vessels (Figs. 2 and 3—P.R.C.—0.018 mm.), which form capillary networks over the neighboring alveoli.

This source of supply is confined to alveoli on the surface of the lobule and appears to be unpredictable in its extent. The number of alveoli supplied in this manner varies considerably among different secondary lobules.

The third type of supply again concerns itself with the arterial vessels located in the tissues between secondary lobules. In this case, however, the vessels give off larger than precapillary branches, some of which proceed along the surface (Fig. 1—S) of the lobule whereas others dip into the lobule and proceed toward its center (Fig. 1—Br. P.), forming capillary networks along their pathway.

The branches which penetrate into the secondary lobule (Fig. 1—Br. P.) may reach to the level of the respiratory bronchioles (Figs. 1—R₁, R₂, and R₃). These branches arising from vessels in the tissues between secondary lobules, supply capillary networks for alveoli located primarily on the surface and the outer core of the lobule. There is, however, a generous overlap in these regions of supply and anastomoses occur between the capillary networks derived from the vessel accompanying the bronchiule and the capillary networks derived from the surface of peripheral vessels (Fig. 1—Cap. An.).

The capillaries of the alveolar network measure less than 0.014 mm. in diameter* and by their anastomoses form hexagonal spaces on the surface of the alveoli measuring approximately 0.02 mm. square (Fig. 3).

The manner by which a network is formed may differ considerably. There appear to be several patterns.

The first pattern is observed within the secondary lobule (Fig. 4). The arterial vessel entering such a lobule continues to subdivide until its branches are approximately 0.036 mm. in diameter. At this point, the vessel divides into several, usually three to four, branches each measuring

*One division in the calibrated grid is equal to 0.014 mm.

Figure 4: Demonstration of the formation of capillary networks by continuous subdivision. a₁, a.—Alveoli. Cap.—Capillary measuring less than 0.014 mm. in diameter, connecting two alveoli which are some distance apart. P.R.C.—Precapillary vessels—measuring 0.018 mm. in diameter.
approximately 0.018 mm. in diameter. We have called these branches precapillary vessels (Fig. 4—P.R.C.). These, in turn, subdivide to form the capillary network. The capillary network stretches across several alveoli and there are rich anastomoses between the different sections of the network (Fig. 4—anastomoses from a1 to a.). Sometimes the parent vessel, as in Fig. 4, measuring 0.048 mm. in diameter, will give off a precapillary sized vessel which reinforces the capillary network (Fig. 4—P.R.C.).

According to Hayek9 precapillary vessels measure from 0.04 to 0.07 mm. in diameter which implies that the precapillary vessel is larger than the vessel from which it was derived. Our findings do not substantiate this.

The 0.036 mm. sized branches, as seen in Fig. 4, are not necessarily accompanying a branch of the bronchial tree such as a respiratory bronchiole or alveolar duct, but may proceed to alveoli that happen to be in its vicinity.

A second pattern has been observed in connection with vessels of larger calibre (Figs. 2 and 3). These vessels, as described above, are located between secondary lobules and during their course may give off precapillary sized vessels (Figs. 2 and 3—P.R.C. 0.018 mm.) which form capillary networks over neighboring alveoli. In some instances, capillary sized vessels (less than 0.014 mm. in diameter) branch off these larger vessels and attach themselves directly to a nearby alveolus to form a network, (Fig. 2a). This pattern differs from the first pattern in that there is no continuous subdivision to the precapillary sized vessel. The latter may arise directly as a branch from a larger vessel.9

A third pattern of capillary network formation may be observed in connection with the vessels running along the surface of a secondary lobule (Fig. 5—S.) and supplying the peripheral alveoli. Such a vessel may give off capillary sized vessels (Fig. 5, Cap.1 and Cap.2) which travel from alveolus to alveolus and give rise to a network on each alveolus they touch. In some instances several capillary sized vessels branch off from the surface vessel and by anastomoses form a network over a nearby alveolus (Fig. 5—alveolus a.). This demonstrates that capillary networks are not always formed from vessels of precapillary size (0.018 mm.).

In Figs. 6 and 7 anastomoses between the capillary networks are demonstrated.
Figure 6: Demonstration of an anastomosis between two vessels which supply the same capillary network. An.V.—Anastomotic vessel measuring 0.036 mm. in diameter.

Figure 7: Demonstration of an anastomosis between two vessels by means of an alveolar capillary network. Cap.An.—Capillary anastomosis. P.R.C.—Precapillary vessel measuring 0.018 mm. in diameter.
In some cases the anastomosis is by means of a vessel connecting the vessels feeding the capillary networks (Fig. 6—An.V—0.036 mm.) whereas in others the anastomosis is by means of the capillary networks themselves (Fig. 7—Cap. An.).

**DISCUSSION**

From this study it was learned that the alveolar capillary network is not necessarily confined to one alveolus but that in many instances it continues on from alveolus to alveolus. This is clearly demonstrated in Fig. 5 where a capillary (Cap.a) supplies capillary networks to several alveoli and in addition forms anastomoses with adjoining vessels. There are also numerous anastomoses between different capillary networks. The anastomoses may be by means of vessels connecting the vessels from which the capillary networks arise (Fig. 6—An.V.) or capillary networks of different origins may merge into one another (Fig. 7—Cap.An.).

The concept that the capillary networks of alveoli of a secondary lobule are fed by three different types of arterial vessels is of some interest. It is not easy to portray this concept in an illustration, but dissections show extensive anastomoses between the capillary networks arising from the three different parent vessels, (Fig. 1—Cap. An.1 and Cap. An.2). Although there is extensive overlap of the regions each type of vessel supplies, the inner core of the secondary lobule is supplied primarily by the vessel which accompanies the bronchiole entering the secondary lobule (Fig. 1—C).

The alveoli on the surface and many of the alveoli constituting the peripheral zone of the lobule are supplied by branches from the vessels on the surface of the secondary lobule (Fig. 1—S. and Br. P.).

Studying the blood supply of a secondary lobule brings out an advantage of having the peripheral surface vessels and their branches in addition to the centrolobular supply. It would appear that on inspiration the vessels which enter the lobule from the periphery become shortened and the angle at which they arise from the parent vessel becomes more obtuse. Both these factors tend to facilitate blood flow. Conversely, branches arising from the vessel accompanying the bronchiole (centrolobular supply) must shorten on expiration and would tend to facilitate blood flow during this phase. Thus a maximal blood flow is assured during both phases of respiration. Whether this occurs in life remains to be demonstrated.

The fact that capillary networks of the pulmonary alveoli are so richly supplied with anastomoses connecting the network of one alveolus with another and also anastomosing the three different types of parent vessels in the secondary lobule, must be of physiologic importance.

An obstruction to one particular vessel supplying a secondary lobule is readily overcome by these anastomoses. It also may explain why after substantial pulmonary emboli scarring is usually insignificant. The rich anastomoses probably also play an important part in overcoming pulmonary consolidation in the pneumonias. On the other hand, opening up of all the anastomoses and capillaries as in shock can lead to extensive pulmonary edema in a matter of minutes.

**SUMMARY**

Microscopic dissection of corrosion models of normal human lungs permitted us to make the following observations:

1. The capillary networks of the alveoli of the secondary lobule derive their blood supply in one of three ways.
   
   (a) From branches of the arterial vessel entering the secondary lobule together with the bronchiole. These vessels supply primarily the central core of the lobule.
   
   (b) From branches of vessels on the surface of the secondary lobule. These branches may penetrate to the level of the respiratory bronchioles. They supply primarily the alveoli of the peripheral zone of the secondary lobule as well as alveoli on the surface of the lobule.
   
   (c) A variable number of alveoli on the surface of the secondary lobule are supplied directly from the vessels located in the
tissues between secondary lobules.

2. Extensive anastomoses exist between the capillary networks derived from the same parent vessel as well as between capillary networks derived from different types of parent vessels.

3. Several patterns used in the formation of capillary networks have been described.

4. The physiologic importance of the multiple blood supply to the secondary lobule and the richness of the anastomoses between vessels feeding the capillary networks and between the capillary networks themselves, has been discussed.

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Resumen

La diseción microscópica de modelos por cor-rosión de los pulmones humanos normales nos ha permitido hacer las siguientes observaciones:

1. La red capilar de los alveoles del lóbulo secundario deriva su provisión de sangre de una de tres maneras:
     (a) de ramas del vaso arterial que entra en lóbulo secundario juntamente con el bronquiolo. Estos vasos proveen primariamente el centro del lóbulo.
     (b) de ramas de los vasos de la superficie del lóbulo secundario. Estas ramas pueden penetrar al nivel de los bronquiolos respiratorios; pri-mariamente abastecen los alveoles de la zona periférica del lóbulo secundario así como los alveoles en la superficie del lóbulo.
     (c) un número variable de alveoles en la su-perficie del lóbulo secundario son provistos directamente por vasos ubicados en los tejidos entre los lóbulos secundarios.

2. Existen anastomosis extensas entre las redes capilares derivadas del mismo vaso de origen así como entre redes capilares de diferentes orígenes vasculares.

3. Se han descrito varios patrones en la formación de las redes capilares.

4. La importancia fisiológica de la provisión múltiple de sangre al lóbulo secundario y la riqueza de las anastomosis entre los vasos que alimentan las redes capilares y entre las redes mismas es motivo de disertación.

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Zusammenfassung

Die mikroskopiscliche Zerlegung von Corrosionsmo-dden normaler menschlicher Lungen erlaubt uns, folgende Beobachtungen anzustellen:

1. Das kapillare Gefäßnetz der Alveolen der sekundären Lobulie bekommt seine Blutzufuhr auf einem von drei Wegen:
   (a) Aus Ästen der arteriellen Gefäße, die in die sekundären Lobulie zusammen mit den Bronchiolen eintreten. Diese Gefäße versorgen in erster Linie den zentralen Kern der Lobulie.
   (b) Aus Ästen von Gefäßen an der Oberfläche der sekundären Lobulie. Diese Äste können bis zur ebene der respiratorischen Bronchiolen eintreten. Sie versorgen in erster Linie die Alveolen der peripheren Zone der sekundären Lobulie ebenso wie Alveolen an der Oberfläche des Lobulus.
   (c) Alveolen in verschiedener Zahl an der Oberfläche der sekundären Lobulie werden direkt versorgt aus Gefäßen, die in den Geweben zwischen den sekundären Lobulien liegen.

2. Ausgedehnte Anastomosen bestehen zwischen kapillaren Gefäßnetzen, die von den gleichen Stammgefäßen ausgehen, genauso, wie bei denen, die von verschieden Stammgefässen abweizen.

3. Beschreibung verschiedener Typen, die beim entstehen von kapillaren Gefäßnetzen aufzutreten pflegen.


References