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ARCHITECTURE OF SUBPLEURAL MICROVESSEL OF THE LUNG IN BACTRIAN CAMEL (*Camelus bactrianus*)

Shi-Yuan Yu[2], Xiao-Hua Du[3], Hai-Yan Li[1], Jian-Lin Wang and Zi-Ren Wang

School of Life Science, Lanzhou University, Lanzhou, Gansu, 730000, P.R. CHINA

[1]Department of Veterinary Medicine, Gansu Agricultural University, Lanzhou, Gansu, P.R. China 730070.

[2]School of Life Science, Northwest Normal University, Gansu, P.R. China, 730070.

[3]School of Veterinary Medicine, Gansu Agricultural University, Gansu, P.R. China 730070.

ABSTRACT

The subpleural microvessel of the lung in the bactrian camel (*Camelus bactrianus*) was studied with the replica scanning electron microscopic method. The results showed that the microvessels of the lung arranged densely, branched and coursed regularly, of which the corrosion casts revealed a complex three-dimensional network completely. According to the microvascular architecture, the subpleural microvessel mainly comprised the arteriole, terminal arteriole, precapillary arteriole, and capillary. Sometimes, the terminal arteriole directly gave rise to large number of capillaries which anastomosed with each other, forming the subpleural capillary network. The network was loose, in which the diameter of the mesh was larger than that of the capillary, and the mesh was often hexagon and pentagon in appearance. There are obvious impressions of the smooth muscles on the surface of the casts of the arteriole, the terminal arteriole and the precapillary arteriole. On the surface of the casts of the precapillary arteriole and the capillary, there are obvious impressions of the endothelial nuclei as well.

Key words : Bactrian camel, lung, scanning electron microscopy (SEM), subpleural microvessel

Many researchers have studied the microvessels of the lungs in various animals by vive microstructure observation, radioautodevelopment, transmission electron microscopy and cast scanning electron microscopy. Weibel and Gomez (1962) studied the morphology of the lung capillaries of the human by scanning electron microscopy. Hijiya and Okada (1978), Kendall and Eissmann (1980), Hou *et al* (1983), and Liao *et al* (1993) studied microvessels of lungs in rat, dog, monkey and human, respectively by cast scanning electron microscopy and obtained solid images of the relationships between the alveolus and its surrounding capillaries. Smith and Campbell (1976) and Smith and Rapson (1977) compared microvessel of the hoptoad lung with those of other animals. West *et al* (1977), Brackenbury and Akester (1978) and Fujii and Okamoto (1981) observed the microvessels of the lungs of the duck, pigeon and chicken by SEM, respectively. Shiyuan Yu (1997d, 1998b) studied the arrangement of pulmonary microvessels of some reptiles. This study was conducted to describe the microvessel of the lung of the bactrian camel and to probe into adaptability of the camel to drought and arid environment.

Materials and Methods

The whole lungs of 6 adult and healthy bactrian camels (4 castrated and 2 female) were collected from the slaughterhouse of the Right Alasan Banner Food Company in the Inner Mongolia Autonomous Region, China. Ten per cent ABS solution in butanone (ternary co-polymer of acrylonitrile, butadiene and styrol; Chaoyou Zhang, 1988) was injected immediately completely through the pulmonary artery. The specimens were then put in flowing water for 24-72 hours to harden the ABS completely.

Scanning Electron Microscopy (SEM) : Proper small pieces of specimens were collected from different lung lobes, which were cut into SEM specimens with a sharp blade after being iced. The specimens were put in 10% hydrochloric acid at room temperature for 1-2 weeks and then washed in flowing water in net box slowly. After all the

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residues being washed out, the casts were selected, dried and sputter-coated with gold-palladium and examined in a Hitach S520 Stereoscan scanning electron microscope.

Results

Results of present study did not reveal evident differences among camel lungs or lung lobes. The pulmonary microvessels were dense in arrangement and regular in branch and course. The subpleural, interlobular septulum, alveolar and interstitial microvessels were observed with SEM.

Branch and supply of subpleural microvessel

It clearly displayed the microvessel of the subpleural lung under low power SEM, in which there were two large arterioles which curved on the surface of the lung and gave off lots of branches on their way. These branches gave off many thin and small twigs which all extended into capillaries to communicate with each other to form the subpleural microvascular network which surrounded the pulmonary lobule.

Subpleural microvessels were recognised into four grades of vessels: arteriole, terminal arteriole, precapillary arteriole and capillary by their continuous branches. The arterioles were 100-150 µm in diameter, which firstly gave off many terminal arterioles to continue as lots of precapillary arterioles, at last, the later branched into capillaries to form capillary network here. The terminal arterioles, precapillary arterioles and capillaries were 29 - 40 µm, 11-18 µm and 4-10 µm in diameter, respectively (Table 1). Basical branch form of the microvessel was as follows :

Arteriole → terminal arteriole → precapillary arteriole → capillary

Sometimes, the terminal arteriole directly gave rise to capillary to unite with the subpleural capillary network, of which the branch form was as follows :

Arteriole → terminal arteriole → capillary

Therefore, the subpleural capillary network was supplied by two class of capillary sources, one being the capillary from each grade of branches, other being the capillary from the terminal arteriole. The former was main source and the later was secondary source.

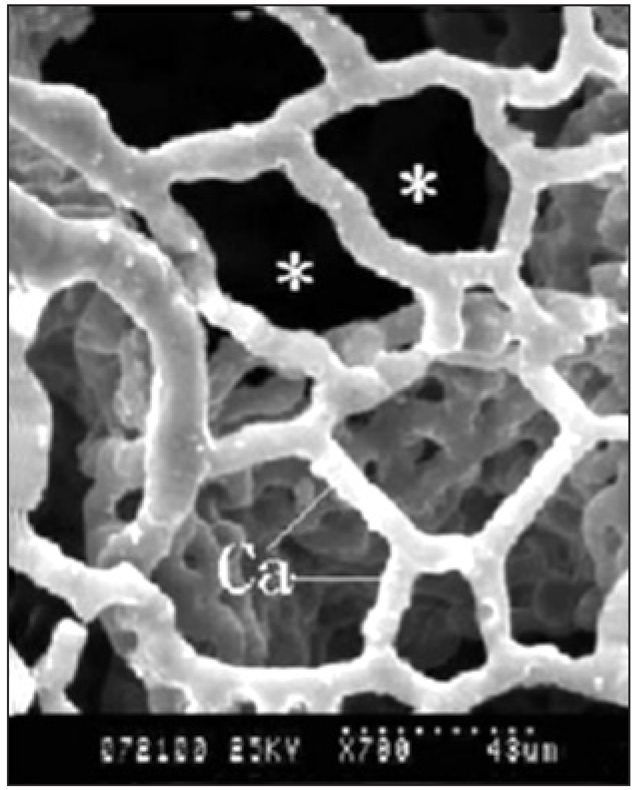

Fig 1. Subpleural capillary network. The capillaries (Ca) communicated with each other, forming the circle. The stars(*) were the meshes of the capillary network.

Table 1. Diameters of subpleural microvessels (µm).

	Terminal arteriole	Precapillary arteriole	Capillary
Right accesory lobe	36.59±1.30	14.21±1.15	6.90±0.96
Right apical lobe	38.14±2.08	13.84±1.57	6.86±0.78
Left diaphragmatic lobe	36.73±1.96	14.63±1.09	6.74±1.01
Lfet middle lobe	37.65±1.57	14.56±1.21	6.88±0.98
Total**	37.28±1.73	14.31±1.26	6.58±0.93

* Fifty branches of each kind of vessel were measured in each lung lobe.

** There were no evident difference among lung lobes on t test ($P>0.05$).

Generally, each pulmonary lobule of the bactrian camel lung was supplied by 2-3 arterioles which branched repeatedly to form the microvessel network on the pulmonary lobule. Meanwhile, as the interspaces among the pulmonary lobule were a little large, many independent microvessel network masses of the pulmonary lobule could be observed under the

Table 2. Comparison of subpleural microvessel branches in some mammals.

Experimental objects	Peculiarity of subpleural microvessel branches
Human	Microvessels: small artery • samll precapillary artery • capillary; subpleural capillaries all from small precapillary artery.
Golden monkey	Subpleural capillaries all from small precapillary artery; In addition, terminal branch of small artery also directly to unitewith capillary network.
Dog	Microvessels: Arteriole • terminal arteriole • precapillary arteriole • capillary; subpleural capillaries all directly from small precapillary artery.
Laboratory rabbit	Same as dog
Mouse	Same as golden monkey
Bactrian camel	Microvessels: Arteriole • terminal arteriole • precapillary arteriole • capillary; Besides, subpleural capillaries not only from precapillary arteriole but also terminal arteriole.

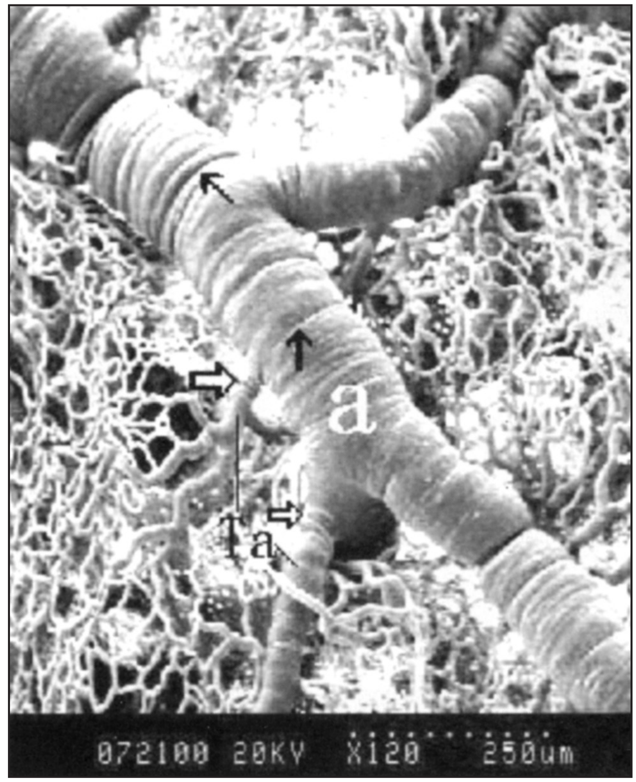

Fig 2. The impressions of the smooth muscle cell on the microvascular cast. The arrows (↑) showed the impressions of the smooth muscle cells on the cast of the arteriole (**a**). The circular impression (→) was on the cast of the junction of the arteriole with terminal arteriole (**Ta**).

lower power SEM, which formed whole pulmonary microvessel cast.

Every grade of the subpleural microvessels were curved on their ways, which seemed to be squeezed or to have extensive space.

Peculiarity of subpleural capillary network architecture

The subpleural capillary was not uniform in its diameter, part of which bulged as capsuliform and part of which contracted as neck of bottle. Its diameter was from 4 μm to 10 μm (Table 1). The capillaries united with each other into hexagon and pentagon meshes and formed the subpleural capillary network (Fig 1). As the diameter of the mesh was larger than of the capillary, whole network was loose. Besides hexagon and pentagon meshes in the subpleural capillary network, the oval, elliptical and irregular ones were also noticed, which were commonly formed by the capillaries at an obtuse angle to each other and curved gently but a few acute angles curved sharply too.

In addition, the blind terminal ends of the subpleural capillaries (Hijiya and Okada, 1978; Kendall and Eissmann, 1980) were not observed in the bactrian camel lung.

Peculiarity of surface of subpleural microvascular cast

Under SEM, there were clear and circular-diagonal impressions of the smooth muscle cells on the surfaces of the subpleural arteriole, terminal arteriole and precapillary arteriole casts (Figs 2 and 3), of which there were the most, widest and densest impressions of the smooth muscle cells on the surface of the arteriole cast. With branching of the microvessel gradually, the impressions on the surfaces of the microvessels decreased in number. There were no impressions of the smooth muscle cells on the surface of the capillary. Otherwise, the circular impression of the smooth muscle cells could be found at joint among the arteriole, terminal

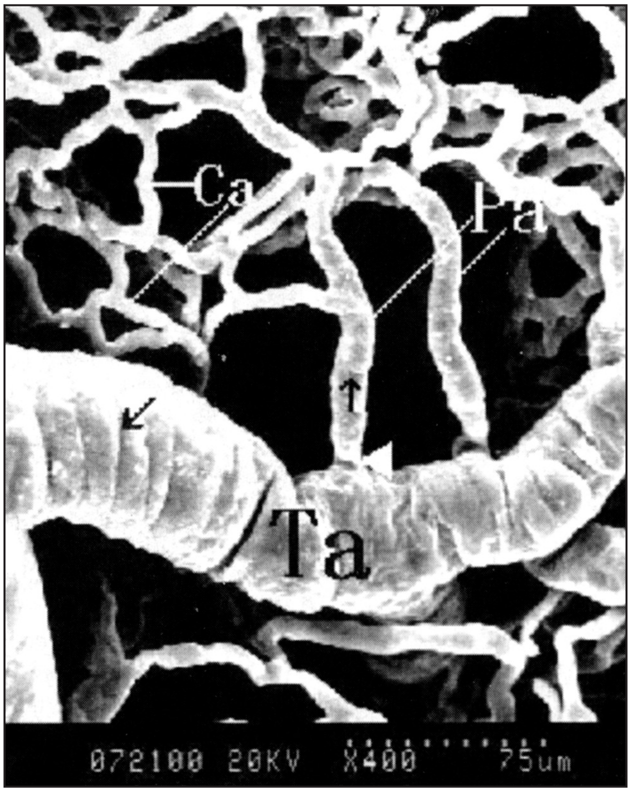

Fig 3. The arrows(↑) showed the impressions of the smooth muscle cells on the cast of the arteriole(a). The black triangle(□) showed the circular impression at the origin of the microvessel.

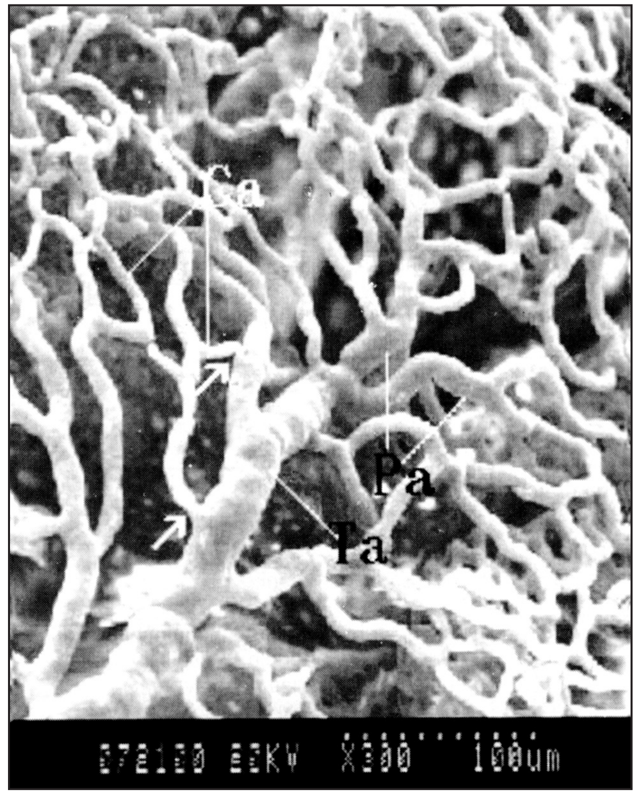

Fig 4. Branch of subpleural arteriole. The arrows (↑) showed the circular impressions at the origin of the capillary (**Ca**) which was directly given off by the terminal arteriole (**Ta**).

arteriole and precapillary arteriole casts. There were also the circular impressions formed by precapillary sphincter at the origin of the capillary casts (Figs 2 and 4).

The oval impressions of the endothelium nucleolus clearly appeared on the surface of the subpleural arteriole and capillary casts (Figs 5 and 7), which arranged longitudinally along the microvessel and did not appear on the surface of the arteriole and terminal arteriole casts.

Peculiarity of interlobule septum micro-vasculatural architecture : The interstitial substance of the camel lung was very abundant, the dividing line between the lung lobes was clear and interlobule septum was much more wide. It was clearly observed that the microvessels in the interlobule septum communicates with subpleural microvessels to form a whole microvascular network on the surface of one lobule. Therefore, they were primarily alike on morphology, supply and architecture. As both were not on same plane, the microvessels in the interlobule septum was deeper than the subpleural microvessels in position, the former was clearly not observed (Fig 7).

Discussion

Branch of subpleural pulmonary microvessel

After entering the lung, generally, the pulmonary artery accompanied with bronchial tree and branched again and again to continue as the arteriole, terminal arteriole and capillary. The capillaries spread and communicated with each other to form reticular sheath-like alveolar capillary network around the alveolus and alveolar capsule. While studying the pulmonary microvessel architecture in dog and human lung by SEM,

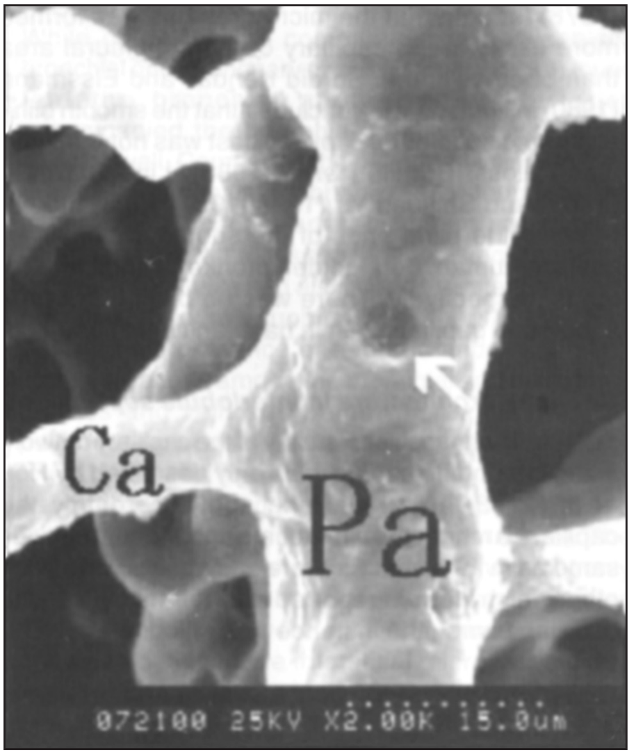

Fig 5. Subpleural precapillary arteriole. The arrows (↑) showed the impressions of the endothelial nucleoli of the precapillary arteriole (**Pa**).

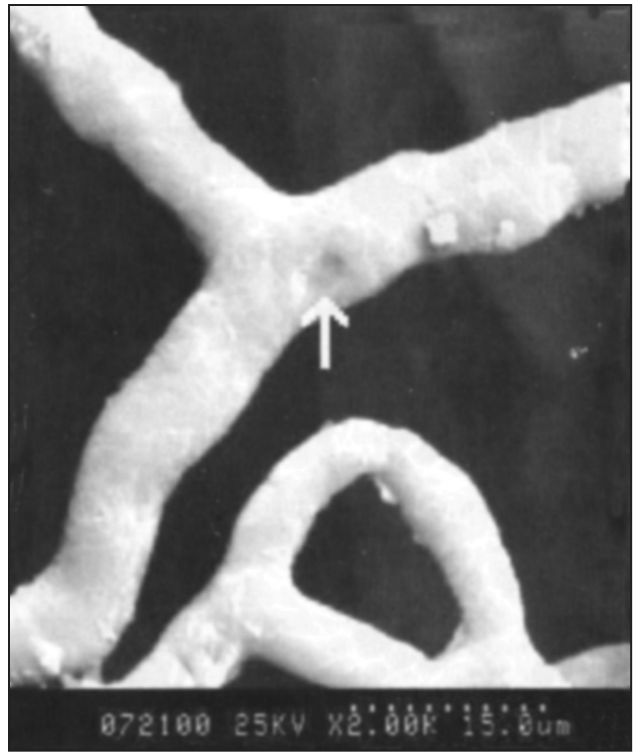

Fig 6. Subpleural capillary. The arrows (↑) showed the impressions of the endothelial nucleus.

Hou *et al* (1983) distinguished arteriole into three grades: small artery, small precapillary artery and capillary, of which the small precapillary artery directly derived from small pulmonary artery and end was cluster-like and gave off many capillaries. The subpleural capillaries emerged from the small precapillary artery. In the bactrian camel, the pulmonary microvessels were distinguished into four grades: arteriole, terminal arteriole, precapillary arteriole and capillary, which was basic in branch form. The subpleural capillaries in the camel mainly come from the precapillary arteriole and communicate with each other to form the subpleural capillary network, which is similar to the findings of Hou *et al* (1983). In addition, it was also found that the terminal branch of the small artery directly gives off the capillary branch to unite with the capillary network. After that, Shiyuan Yu (1997b, 1998a) described that the terminal branch of the small artery directly unites with the capillary network in golden monkey and rat lungs. In the bactrian camel, besides that the pulmonary microvessel branched grade by grade, the terminal arteriole directly gave off capillary branch to unite with the subpleural capillary network, which was same as in the golden monkey and rat (Table2).

Architectural peculiarity of subpleural capillary network

Early at the beginning of the twenteeth century, the scientists took note of the subpleural alveolar capillary network being large and rough and made sure that the mesh of the subpleural alveolar capillary network was 3-4 times larger than of other areas. Hou *et al* (1983) found that the meshes of the subpleural alveolar capillary networks in dog and human lungs was wider and broader than of other areas with SEM. Liao Rui *et al* (1993) observed that the density of the mesh of the

Fig 7. Microvessels in interlobule septum. The subpleural microvessel communicated with the microvessel in the interlobule septum. The arrows (↑) showed the junction of the interstitial microvessel (**Bca**) with the subpleural microvessel.

capillary network in the alveolar septum was bigger than in the subpleural under SEM, which was also seen by Shiyuan Yu (1995, 1996, 1997a, b, c, d and 1998a, b) and Shiyuan and Chongyang (1995) and Shiyuan and Qibing (1996) in laboratory rabbit, pika, golden monkey and mouse. It was obvious that the speed of the blood flow was faster in rough and loose capillary network than in dense one when the diameter of the artery was fundamentally same. Thus, in the progress of the subpleural capillary continuing as the alveolar septum capillary network, the blood flow entered the alveolar septum capillary at the faster speed, took part in gas exchange and accelerated the blood circulation, which was likely to be one of the physiological reasons for the subpleural capillary architecture to be different from the alveolar septum one.

In the architecture of the lung subpleural capillary in the bactrian camel, the meshes of the capillary network were mainly enclosed by the capillaries which formed acute angle to each other, part of them was also at an obtuse angle. By means of the fact that the blind end of the subpleural capillary cast was observed in the rat lung, Hijiya and Okada (1978) thought that the microthrombus was formed more easily in the capillary of the subpleural area than of other areas. So did Kendall and Eissmann (1980) in human, who concluded that the smooth blind end of the subpleural capillary cast was not the man-made gloss. But Hou *et al* (1983), Liao Rui *et al* (1993) and Shiyuan Yu (1995, 1997, 1998) did not observe the blind ends of the subpleural capillary casts in human, dog, golden monkey, rabbit and rat lungs, respectively. There was no blind end of the subpleural capillary cast in bactrian camel lung, too.

Capillary architecture in interlobule septum

The branch and supply of the capillary network in the interlobule septum was only described by Hou *et al* (1983) in human lung and accordingly the capillary architecture in the interlobule septum was same as in the subpleural area and united with each other which was not reported in other animals. In the bactrian camel, the instance was allied to above.

Communicating form between lung and bronchial circulations

The scientists proved that the bronchial artery, after entering the lung in mammal, gave rise to branches to supply the mediastinum pleura, pericardium, lymphatic node, pulmonary pleura and subpleural connective tissues besides the wall of each grades of bronchia, pulmonary artery and vein (Miller, 1947; Verloop, 1948; Zuobin and Zhou, 1985). Therefore, the lung interstitial microvessels were actually branches of the bronchial artery beneath the pulmonary pleura and in the interlobule septum. Now, it was affirmed that the communicating branch occurs between the vessels of the bronchial and pulmonary circulations. The position where communication took place and the level of the communication of vessel, still remains inconclusive. Lapp (1951) thought that bronchial artery supplied the bronchia as far as the alveolar duct where it separated into the capillary network and communicated with the alveolar capillary. But

Verloop (1948) and Tobin (1952) reported that the supply of the bronchial artery was only as far as upto the respiratory bronchiole where communication occurred with the pulmonary artery. Pump (1963) observed that the bronchial artery gave rise to the bronchial pulmonary branch before the terminal bronchiole appeared and supplied the alveolar wall where it communicated with the terminal branches of the pulmonary artery forming the capillary network. While observing the communication between the bronchial and pulmonary arteries, Yongqi (1958) found that the bronchial and pulmonary arteries accompanied the bronchial tree and supplied the alveolar wall. Comparing the pulmonary microvessels in several mammals, Richhand (1961) found that the supply of the bronchial artery in human was same as in horse, except that it supplied the alveoli along the terminal bronchiole and also along the interlobule and pulmonary pleura. Zuobing and Zhou (1985) also reported the presence of end-end and end-branch communications among the bronchial and pulmonary arteries and vein and before the capillary in the pulmonary pleura of human. The present research found that broad and different level communications were present among the pulmonary interstitial and subpleural microvessels in the bactrian camel. The interstitial microvessels communicated with not only the subpleural capillaries but precapillary arterioles directly and there were also the communicating branches between the interstitial microvessels and terminal arterioles. By studying the communicating vessels, Lapp (1951), Verloop (1948) and Hayek (1953) found that there was the muscular tissue in the vessels, which was suggestive of likely active regulating ability of the vessels. There were circular impressions on the casts of the junctions of the communicating branches or the microvessels became slender suggesting the contractile ability of the vessels. On the casts of the junctions of the pulmonary interstitial vessels and pulomonary artery in the bactrian camel, the authors also found similar circular impressions formed by the smooth muscle cells, which showed that the communicating branch between the pulmonary microcirculation and bronchial circulation also had active regulating ability.

The salient finding of this study could add to the possible physiological explanation of the endurance ability of bactrian camel in cold climates.

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