Pulmonary Circulation — Vertebral Venous Interconnections in the Chicken [1]

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ABSTRACT Injections of India ink colored blood, latex, and plastic followed by study of corrosion casts and dissections were used to determine the interconnections of the vertebral venous system and pulmonary circulation in the chicken. Multiple, minute connections are found to the intercostal veins, small mesenteric veins and others connected to the vertebral venous system. Thus, blood can flow in quantities between the vertebral venous system and the pulmonary circulation depending upon pressure gradients.

Recent discussions of the anatomy of the avian lung (King, '66; Dunker, '72) and the theory and determination of avian gas exchange (Scheid and Piiper, '70; Piiper and Scheid, '72) have not included consideration of the interconnections between the pulmonary circulation, the venous system and the vertebral venous plexus.

The mammalian vertebral venous plexus is a valveless longitudinal network with its terminus in the cranial dural sinuses and caudal vertebrae, parallel to and communicating with the superior and inferior vena cavae. Besides functions in storage and as primary drainage vessel for intercostal veins and some pelvic organs for example, clinically important functions include an auxiliary route for dissemination of metastasis and a by-pass around the inferior vena cava when abdominal pressure is high as in pregnancy or clearing the bowels (Batson, '57, '58; Herlihy, '47).

The avian venous system has been described in the pelvic region (Akester, '67, '71; Julien and Brauer, '65). The femoral vein sends a major branch through the parenchyma of the kidney to terminate in the vertebral plexus. Thus, the vertebral plexus and the hepatic portal connection to the renal portal veins form routes by which renal portal blood can by-pass the kidney. These connections do not have morphologically distinguishable valves. However, radiographic evidence indicates the lumina are often completely occluded, separating individual venous systems (Akester, '71). Many of the thoracic and abdominal interconnections of the venous system have not been described. In the present work a description of interconnections between the pulmonary circulating systemic venous system, and the vertebral venous plexus was sought.

METHODS

Single comb White Leghorn roosters ranging in age from 14 weeks to over a year were studied. In nine specimens, the distribution of India ink (Pelikan C11/143a, Gunther Wagner) was studied. Connections were verified in five by corrosion casts (Batson's plastic, Polysciences, Inc., Rudall, New Jersey) or dissection after fixation following infusion of India ink labelled blood in three and latex in six (Parke et al., '63). Maceration isolation of plastic casts was done in warm 0.5–1% NaOH solution, preserving bones.

RESULTS

The original impetus for this study was the observation of significant systemic effects produced after injection of sodium cyanide into a presumably isolated left pulmonary circulation accomplished by ligation of the pulmonary artery and vein on that side. The immediacy of the sys-

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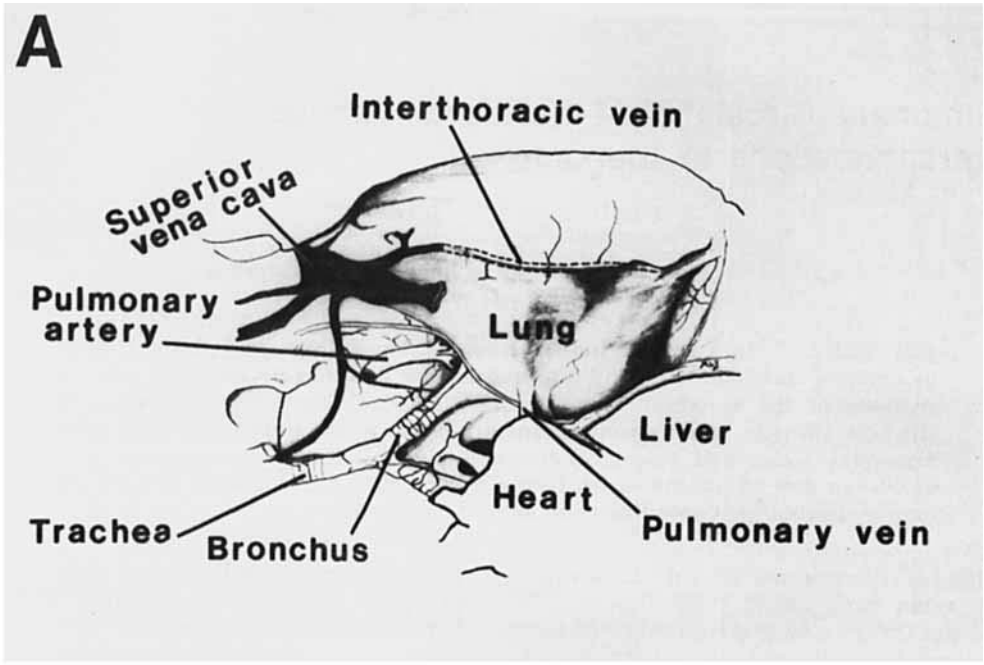
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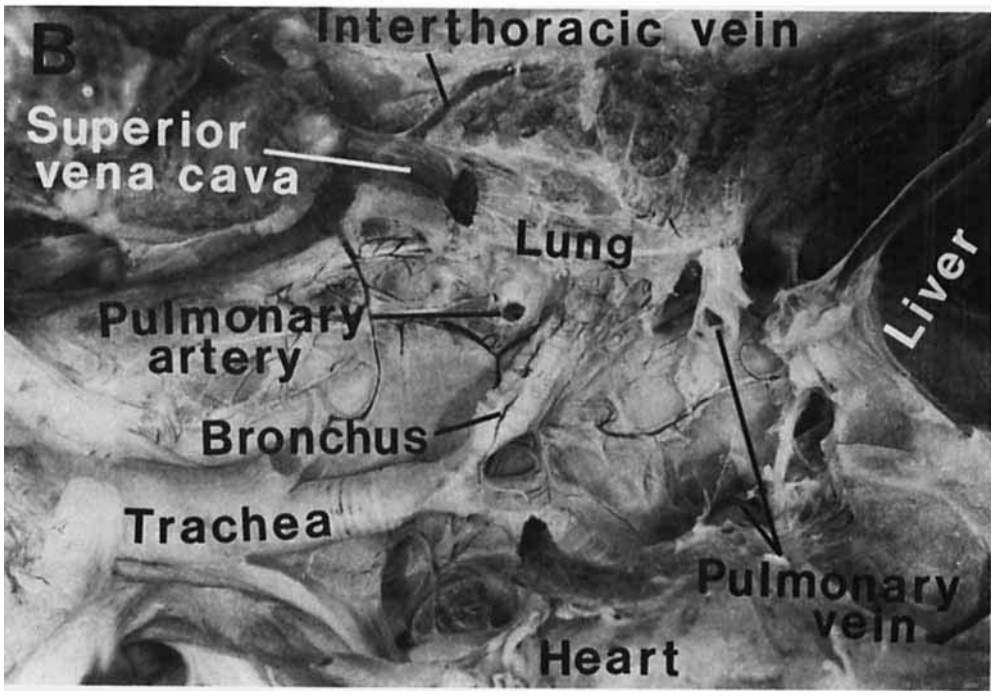
Superior vena cava
Pulmonary artery
Lung
Liver
Heart
Trachea
Bronchus
Pulmonary vein


B
Interthoracic vein
Superior vena cava
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Pulmonary artery
Bronchus
Trachea
Pulmonary vein
Heart

Figure 1

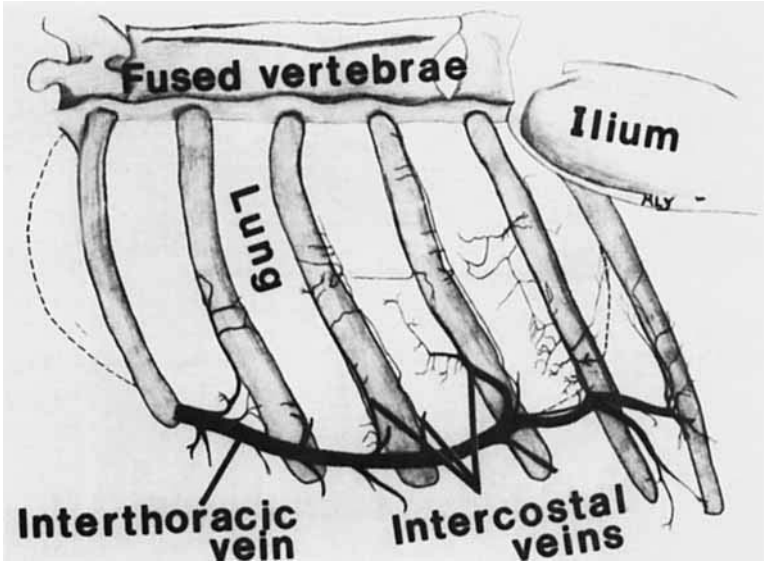

Fig. 2 Lateral schematic view of the interconnection between small branches from the lung paranchyma and intercostal veins and internal thoracic vein. The ribs have been removed, but their positions are indicated. Note the increase in branching of the intercostal veins in a cranial caudal direction. Most of the branching of the last intercostal vein is on the caudal, dorsal surface of the lung and is not shown. Lung outline indicated by dotted line.

temic effects was suggestive of a low resistance connection between the isolated pulmonary and systemic circulations. Injections of a few milliliters of India ink into similarly prepared animals produced rapid darkening of the entire animal. When India ink was injected into the brachial vein of other identical preparations, the lung slowly darkened. If the pulmonary vein was then severed on the pulmonary side of the ligature, blackened blood welled out leading to a rapid esanguination of the animal. If the ligated pulmonary artery was cut first, the blood slowly issuing from the lung became darkened after some time; subsequent severing of the pulmonary vein produced a rapid flow of dark blood. Thus, blood can flow in volume either into the systemic from the pulmonary circulation or *vice-versa*. The main connections appear to be venous-venous as bronchial artery connections cannot account for the transfer of blood from the pulmonary to the systemic circulation.

Corrosion casts showed essentially a vertebral venous system with major connections at all ages that have been described in mammals. The internal plexus in the region of the fused thoracic and sacral vertebrae was, however, a continuous longitudinal sinus. Connections to other veins included those previously described in mammals, i.e., vertebral, costocervical and femoral veins. Small, numerous twigs connected the internal plexus in the synsacrum to the dorsal surface of the kidney. In addition, the vertebral veins show connections to the internal thoracic veins which originate at the point of formation of both superior vena cavae and run caudally at the ventral borders of the lungs and appear to provide the most direct channels for ink injected into the pulmonary circulation to spread throughout the thoracic cavity (figs. 1 A,B). At the caudal border of each lung, the internal thoracic vein ter-

Fig. 1A Schematic drawing of the left lung and associated structures presented in a ventral-medial view following ink labeled latex injections into the pulmonary artery. (Relationships of the internal thoracic vein, dashed line to lung and superior vena cava are shown.) The heart, aortic arch and its branches and the liver have been retracted medially to expose the pulmonary artery, pulmonary vein, primary bronchus and small veins.

B. Injected specimen in a ventral-medial view. Note the perfusion of the ink-latex medium along the bronchus and planes of connective tissue. The heart, aortic arch and liver have been retracted medially.

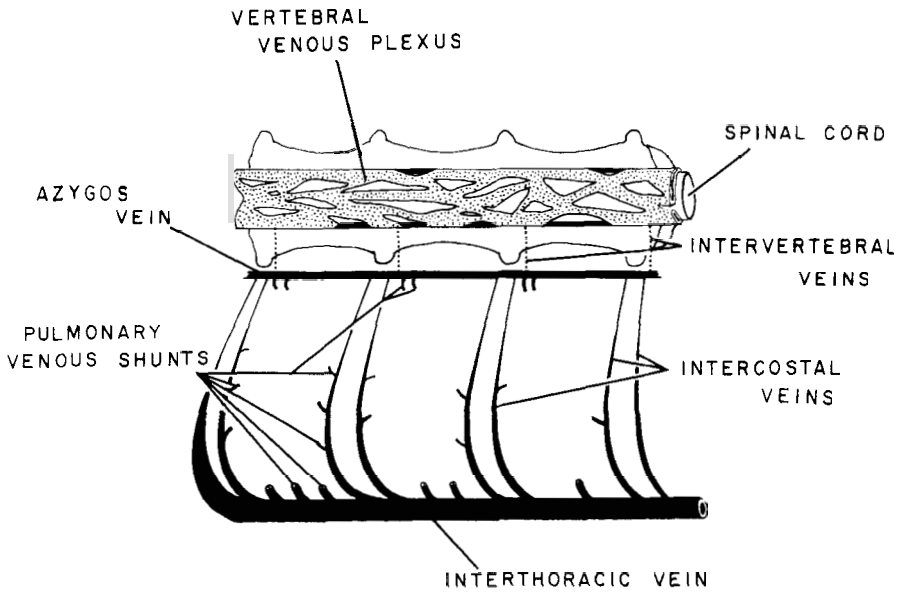

Fig. 3 Schematic view of vertebral venous plexus and connecting vessels of left thoracic area. Azygos vein represents external vertebral plexus. Pulmonary venous shunts are shown greatly enlarged in order to indicate positions. Actual number of shunts is not shown. Dashed lines indicate the segmental connection between internal and external venous plexus.

minates in the largest of the intercostal veins which courses along the caudal border of the lung next to the body wall (fig. 2). This intercostal vein also communicates with the ipsilateral adrenal capsule before entering into the vertebral venous plexus. This system of internal thoracic and intercostal veins provides a by-pass around the entire group of central veins.

The connections between the pulmonary and systemic circulations are small and multiple. They were always poorly perfused in Batson's plastic casts, despite thorough washing out of blood from vessels with vasodilator-containing solutions. In these casts, the external vertebral venous plexus could be seen sending fine branches into the parenchyma of the lung at each thoracic vertebra. Injections of India ink-labelled blood as well as latex indicated three other communications. A diffuse series of connections was seen between the pulmonary parenchyma and each intercostal vein, increasing in number cranial to caudal. The most caudal intercostal vein had many more connections to the lung than any other intercostal vein (fig. 2). Many small interconnections between the lung and small veins running in mesentery and other tissues, ventral and medial to the lungs, were also seen as a diffuse network with India ink injections (fig. 1B). These small veins generally terminated in the external vertebral venous plexus (fig. 3). Small quantities of blood were also transferred through the external and internal vertebral venous plexuses to the contralateral lung where the lungs are in juxtaposition across the mediastinal region.

DISCUSSION

The size of each individual connection between the pulmonary circulation and vertebral venous plexus was small, yet their number were such that large flow rates could occur back and forth with small pressure gradients. The functional significance and stability of this potential blood "shunt" around the respiratory exchange area is unknown. One obvious implication is in the anomalously low arterial saturation of hemoglobin, about 88% in the chicken (Sturkie, '65). Thus a rather large venous admixture to arterial blood exists. However, the low arterial saturation is primar-

ily caused by a ventilation-perfusion abnormality, not by an anatomical shunt, as inhalation of oxygen by the rooster leads to an immediate increase in arterial saturation.

These interconnections could contribute to pulmonary congestion of roosters following bilateral vagotomy. As venous blood pressure increases significantly following this operation, venous blood could pour into the pulmonary circulation directly, unaffected by any regulatory mechanism of the right heart. The peculiar spotty development of pulmonary congestion in vagotomized chicken, particularly in older males, confined to the dorso-medial aspect of the lungs and along the intercostal ridges (Burger and Fedde, '64) may indicate the importance of this mechanism. No significant changes with age was seen, however, in either distribution or density of connections to other vessels. Thus, the intensification of this pathological shift in venous blood in older chickens is not correlated with an anatomical change.

In all other respects, the vertebral venous plexus in the chicken is similar anatomically to that of the mammal. It runs in a longitudinal pattern within and around the vertebral column, sending out branches to the systemic circulation along its length. Functional studies will be needed to determine the significance of the observed multiple, minute connections to the parenchyma of the lungs and kidney.

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