

# A review of the distribution of the arterial and venous vasculature of the diaphragm and its clinical relevance

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*The diaphragm is the major respiratory muscle of the body. As it plays such a vital role, a continuous arterial and venous blood supply is of the utmost importance. It is therefore not surprising to find described in the literature a complex system of anastomoses that contributes to the maintenance of this muscle's life-preserving contraction. Understanding the anatomy of the diaphragm and any divergence in its vasculature is literally vital to humanity. In the light of this, we review the literature on the blood supply to the diaphragm, with specific emphasis on the recent description of the inferior phrenic vessels and the superior phrenic artery, summarize the clinical significance of the diaphragmatic vasculature and suggest future avenues of study to further expand on this current body of knowledge. (Folia Morphol 2008; 67: 159–165)*

**Key words:** diaphragm, hepatocellular carcinoma, inferior phrenic artery, superior phrenic artery

## INTRODUCTION

In view of the diaphragm's current standing as the primary muscle of inspiration, accounting for 67% of the vital capacity [33], it is easy to understand why its detailed anatomical structure and vasculature is a subject of scientific interest. Standard anatomical texts, in their topographical descriptions of the diaphragm, identify it as an arched musculo-fibrous entity separating the thoracic from the abdominal cavity. Its vasculature is predominantly supplied by two inferior phrenic arteries, five lower intercostal and subcostal arteries and two superior phrenic arteries. Other smaller vascular anastomoses have also been reported with specific clinical relevance. Recent publications [10, 20–22, 25, 35, 39] have expanded our understanding of the diaphragm, particularly of its vasculature, which is involved in various ways in serious conditions such as hepatocellular carcinoma (HCC), hepatic artery pseudo-

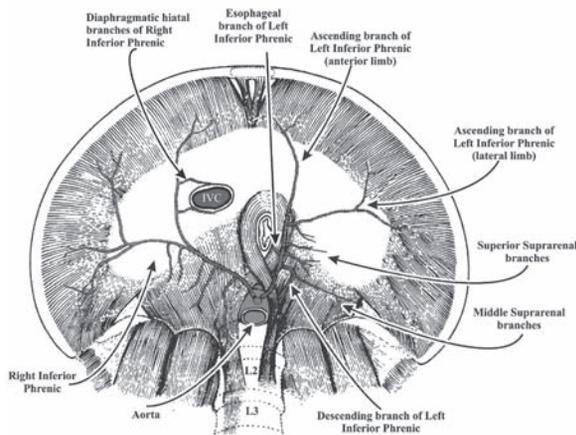
aneurysm, transcatheter arterial embolism, and digestive pathologies.

Despite the multitude of studies investigating various aspects of its anatomy and physiology, some features of the diaphragm's structure and function remain to be explored. The purpose of this review is to assemble an up-to-date report on the vasculature of the diaphragm with particular reference to its clinical significance. We also hope to propose areas for future investigation that may benefit clinicians in the therapeutic treatment of HCC, hepatic artery pseudo-aneurysms and gastric and biliary defects.

## LITERATURE REVIEW AND CLINICAL RELEVANCE

### Arterial supply

Standing [33], in "Gray's anatomy", describe the diaphragm as a fibromuscular dome-shaped cavity



**Figure 1.** Diagrammatic representation of the arterial distribution of the right inferior phrenic artery and the left inferior phrenic artery with their branches (with permission from Loukas et al., 2005); IVC — inferior vena cava.

partitioning the thoracic from the abdominal cavity. It is a continuous sheet composed of three parts, sternal, costal and lumbar, based on its circumferential attachment. Muscular fibers arise from these peripheral origins and converge medially and somewhat anteriorly to form a central tendon that underlies the pericardium. The blood supply to the diaphragm [11, 33] is from the last five intercostals and subcostal arteries which supply the costal margins from the phrenic arteries, which predominantly supply the central region of the diaphragm (Fig. 1), and from the musculophrenic and pericardiophrenic arteries.

The two phrenic arteries may originate from the aorta above the celiac trunk or from the celiac trunk itself. Rarely, they may arise from the renal artery. A recent study also found the left inferior phrenic artery (IPA) to originate occasionally from the left hepatic or left gastric artery [38]. From their point of origin, both the left and right IPA course anterior and lateral to the crus of the diaphragm along the medial boundary of the suprarenal gland. The left IPA continues posterior to the esophagus and then moves anteriorly and to the left of the esophageal diaphragmatic aperture. The right IPA continues behind the inferior vena cava (IVC) and to the right side of the same aperture. Near the posterior boundary of the central tendon each IPA gives off both medial and lateral branches. The left and right medial branches anastomose with each other, as well as with the musculophrenic and pericardiophrenic arteries, anterior to the central tendon. The lateral branches travel toward the thoracic wall, anasto-

mosing with the lower posterior intercostal and musculophrenic arteries. There is also a collateral branch between the left gastric artery and the IPA.

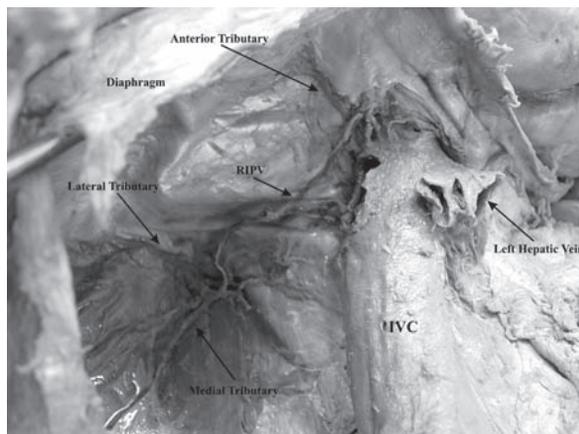
The pericardiophrenic artery is described as originating from the internal thoracic artery and accompanies the phrenic nerve between the pleura and the pericardium to supply the pericardium and diaphragm [26]. According to Singh, most pericardiophrenic arteries could not be traced to the diaphragm [32]. In a study by Kim et al. [14] pericardial and or mediastinal branches did not reach the diaphragm. This discrepancy could be explained by the fact that the pericardiophrenic artery is so small that angiography fails to detect it or because anatomists overestimate the diaphragmatic supply from the pericardiophrenic artery.

The musculophrenic artery usually arises at the fourth to sixth intercostal spaces as one of the terminal branches of the internal thoracic arteries. It gives rise to two anterior arteries at the level of 7–9<sup>th</sup> intercostal spaces [26]. Interestingly, it remains unknown to what degree the musculophrenic and pericardiophrenic arteries supply the diaphragm.

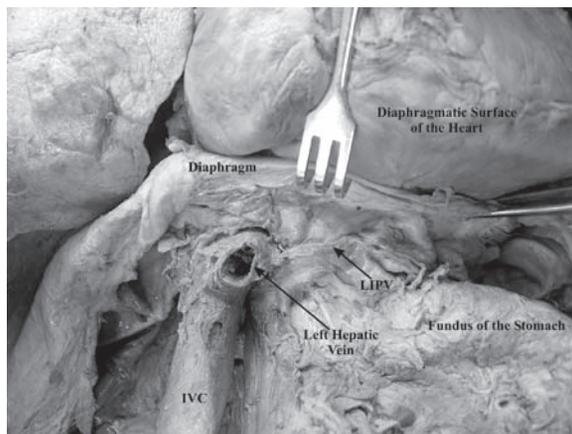
In addition, another artery the superior phrenic artery (SPA) has recently been shown to supply a significant portion of the diaphragm. The SPAs are generally small and arise from the lower part of the thoracic aorta and are distributed to the posterior part of the upper surface of the diaphragm. In addition, we observed the SPA arising from an alternative source in a significant number of cases as described below [22].

### Venous supply

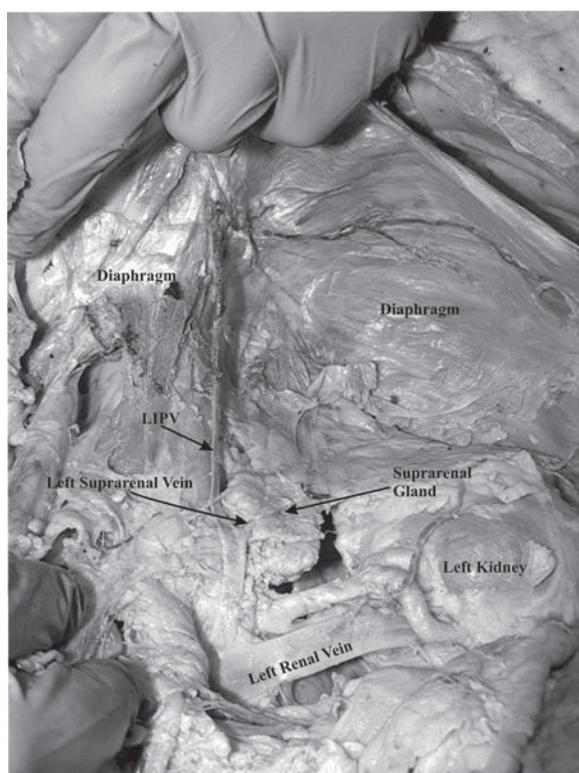
The venous supply corresponds to the arterial circulation on the inferior surface of the diaphragm. The right phrenic vein joins the IVC. The left phrenic vein commonly divides with one branch joining the left renal or suprarenal vein and the other passing anterior to the esophageal aperture to connect with the IVC (Fig. 2–4). Neither the ratio of blood supply to the muscular diaphragm in comparison with that of the central tendon nor the issue of whether this ratio varies with the size of these components has been explored in the literature. In fact, it is yet to be established if such a relationship even exists. We propose this topic as an area for further investigation. Diaphragmatic vasculature does not only supply the diaphragm but also participates in anastomoses that sustain blood supply to other organs. For example, the pericardiophrenic vein, a branch



**Figure 2.** A dissection demonstrating the right inferior phrenic vein (RIPV) draining into the infradiaphragmatic segment of the inferior vena cava (IVC). The liver has been removed as well as part of the right hemidiaphragm in order to better visualize the right inferior phrenic vein. Three of the four tributaries of the right inferior phrenic vein are also seen (with permission from Loukas et al., 2006).



**Figure 4.** A dissection figure demonstrating the left inferior phrenic vein (LIPV) draining into the left hepatic vein. The liver has been removed as well as part of the left hemidiaphragm in order to better visualize the left inferior phrenic vein (with permission from Loukas et al., 2006); IVC — inferior vena cava.



**Figure 3.** Dissection pictures demonstrating the left inferior phrenic vein (LIPV) draining into the left suprarenal vein. The liver, the spleen and the stomach have been removed in order to better visualize the left inferior phrenic vein (with permission from Loukas et al., 2006).

of the brachiocephalic vein, anastomoses with the inferior phrenic vein, providing an alternative route when either the superior or IVC is occluded [6].

### Collateral vasculature and disease

This comprehensive knowledge of the vascular supply to the diaphragm has raised some interesting questions in the clinical setting. In a study by Chung et al. [6], the authors investigated the safety of embolizing the inferior phrenic artery as a means of therapeutically treating HCC, a malignant tumor supplied by the hepatic arteries as well as collateral branches from other sources, among which the IPA is named as a culprit [5, 8, 10, 24, 28, 37]. Extrahepatic collaterals mainly develop as a result of surgical ligation or chemoembolization of the hepatic artery [5, 15, 24]. Consequently, for successful control of HCC, chemoembolization is required of the hepatic artery as well as any extrahepatic collaterals, such as the IPA, that supply this superfluous mass. Chung et al. [7] performed transcatheter oily chemoembolization on 82 HCC patients, documenting appreciable tumor remission initially in 31 patients. Continued observation found survival rates of 86% at 6 months, 78% at 1 year, 46% at 2 years and 30% at 3 years. Increasing reports of HCC in association with extrahepatic collateral arteries in the literature [3, 39] led Loukas et al. [20] to conduct an anatomical and comparative study of the distribution of the IPA in normal and HCC cadavers. The authors examined 300 adult cadavers with normal abdominal anatomy and 30 cadavers of HCC patients. In the normal cadavers, variation in the origin of the right IPA was classified as follows:

- 40% originated from the celiac trunk;
- 38% from the aorta;

- 17% from the renal artery;
- 3% from the left gastric artery;
- 2% from hepatic artery proper.

The left IPA originated as follows:

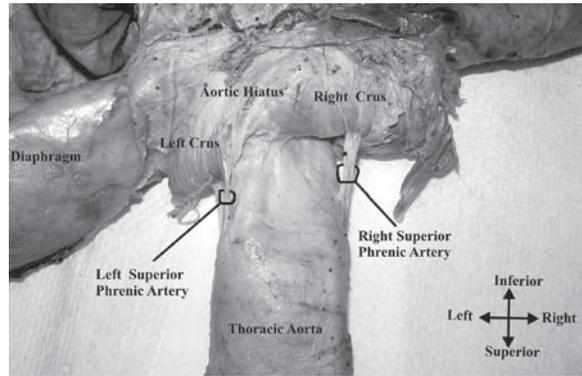
- 47% from the celiac trunk;
- 45% from the aorta;
- 5% from the renal artery;
- 2% from the left gastric artery;
- 1% from the hepatic artery proper.

The IPA projected eight notable branches: ascending, descending, IVC, superior suprarenal, middle suprarenal, esophageal, diaphragmatic hiatal and accessory splenic. Clinically noteworthy is the fact that the right IPA was always found to be associated with HCC and served as the major collateral artery adjunct to the hepatic artery.

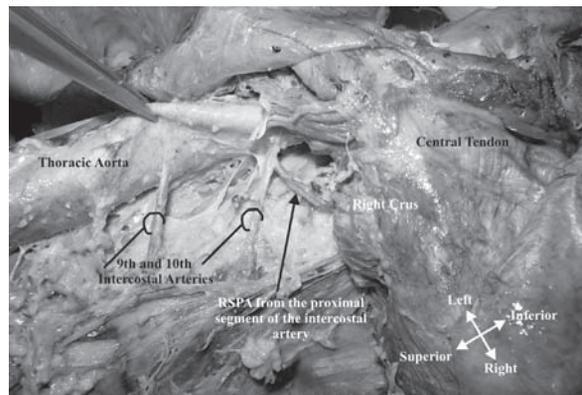
Interestingly, a clinical case reported the involvement of the left IPA in supplying blood to an adrenal cortical carcinoma [40]. The association of the IPA with abdominal carcinomas, including hepatic and adrenal, is another area for prospective investigation.

In another study by Loukas et al. [21] the authors examined the anatomical variations of the inferior phrenic vein (IPV), which may be applied to endoscopic embolization of esophageal and paraesophageal varices. The IPV was also found to be one of the major sources of collateral venous drainage in portal hypertension, retroperitoneal malignant disease and HCC [1, 18, 21, 23, 31, 41]. Loukas et al. [21] compared venous drainage between cadavers with no abdominal pathologies to those of HCC patients. The right IPV was found to drain as follows: into the IVC inferior to the diaphragm in 90%, into the right hepatic vein in 8% and into the IVC superior to the diaphragm in 2%. The left IPV drained as follows: into the IVC inferior to the diaphragm in 37%, into the left suprarenal vein in 25%, into the left renal vein in 15%, into the left hepatic vein in 14% and into both the IVC and the left adrenal vein in 1% of the specimens. The IPVs gave rise to four notable tributaries: anterior, esophageal, lateral and medial. The right IPV was found to be one of the major extrahepatic draining veins for all 30 cases of HCC. It is also of note that the IPV serves a surgical purpose in graft preparation for liver transplantation [16].

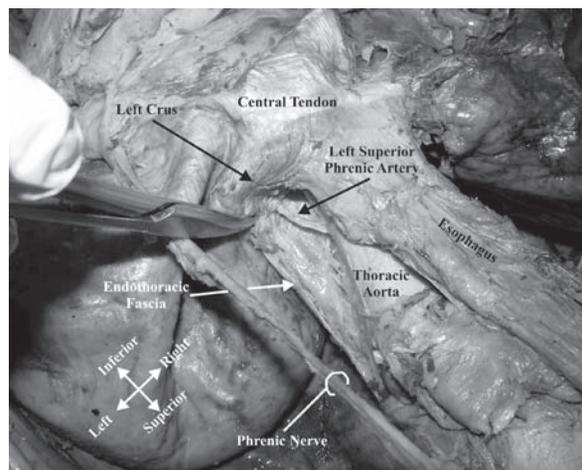
Yet another study that may be of relevance to HCC is that by Loukas et al. [22], which defines the anatomy and distribution of the SPA, another contributor of extrahepatic blood to liver cancers (Fig. 5–8). The right SPA originated from the follow-



**Figure 5.** Demonstrates a typical bilateral origin of the right superior phrenic artery and left superior phrenic artery from the aorta (with permission from Loukas et al., 2007).

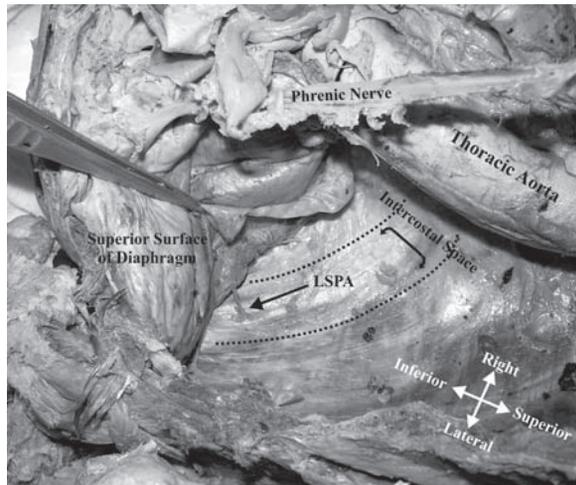


**Figure 6.** Demonstrates the origin of the right superior phrenic artery (RSPA) from the proximal segment of the 10<sup>th</sup> intercostal artery.



**Figure 7.** A typical origin of the left superior phrenic artery from the aorta.

ing: the aorta (R1) in 42%, as a branch of the proximal segment of the 10<sup>th</sup> intercostals artery (R2) in 33% and as a branch of the distal segment of the



**Figure 8.** Demonstrates a right superior phrenic artery to originating from the proximal segment of the 10<sup>th</sup> intercostal artery immediately after its exit from the aorta; LSPA — left superior phrenic artery.

10<sup>th</sup> intercostal artery (R3) in 25% of the specimens. The left SPA originated from the following: the aorta (L1) in 51%, from the proximal segment of the left 10<sup>th</sup> intercostal artery (L2) in 40% and from the distal segment of the left 10<sup>th</sup> intercostal artery (L3) in 9% of the specimens. The authors also found that in types R1, R2, L1 and L2 after a short distance the SPA terminated within the medial and posterosuperior surfaces of the thoracic diaphragm and diaphragmatic crura. Conversely, in types R3 and L3, the distribution of the vessels was restricted to the posterior surface of the diaphragm because of the lateral origin of the SPAs.

Case studies have also associated HCC with other conditions, such as complication in membranous obstruction of the IVC [12] and Budd-Chiari syndrome [19]. Budd-Chiari syndrome, which may occur secondary to invasive hepatic tumors, is a disorder caused by interruption of hepatic venous blood flow or the IVC above the origin of the hepatic vein [34]. Lin et al. [19] found left renal-inferior phrenic-pericardiophrenic collateral veins in 2 of 23 patients. Elucidating the cause and method of controlling blood flow to HCC may, therefore, serve not only in the treatment of HCC itself but in that of other associated conditions.

Several reports implicate the diaphragmatic vasculature in abdominal pathologies. A report by Tajima et al. [35] evaluated 9 patients who, after hepatobiliary pancreatic surgery, developed ruptured hepatic artery pseudoaneurysm and endured treatment via transcatheter artery embolization. The au-

thors specifically commented that extrahepatic collaterals, with special mention of the IPA, contributed to the prevention of liver necrosis following transcatheter arterial embolism. Kenji et al. [13] documented a case of gastric varix draining through the IPV, as opposed to the typical left suprarenal vein. This varix was treated by transfemoral balloon-occluded retrograde transvenous obliteration of the left IPV via the left hepatic vein. Northrop et al. [27] reported, in a patient with esophageal varices and erosions, a left IPA hemorrhage at the gastroesophageal junction, which may be misinterpreted on an arteriogram as recurrent gastric extravasation. Interestingly, two case reports indicated gastric toxicity as a result of perfusion of the stomach through the left IPA during hepatic arterial infusion chemotherapy [30]. In view in particular of the IPA and IPV supplying the falciform ligament, knowledge of the diaphragmatic vasculature may serve in the repair of bile duct defects, the formation of digestive anastomoses and the facilitation of homeostasis of parenchymal organs [4, 17, 29, 42].

In addition, imaging studies involving the arteries and veins supplying the diaphragm have provided dependable clinical input. Takahashi et al. [36] using multi-detector row computed tomography clearly visualized the right IPA in 92% of cases and the left IPA in 89%, making computed tomography a reliable method of diagnosing thrombosis and aneurysm of these vessels. Using selective angiography and digital subtraction angiography, a defect in hepatic artery perfusion was detected in 14 of 35 cases following surgical implantation of a pump and catheter system [2]. The cause of this defect was attributed to extrahepatic collateral flow, such as via the IPA.

Angiography was also employed to study the extrahepatic pathways to HCC, revealing that 83% of collaterals arise from the right IPA and 12% from the left IPA, among others [25]. Another report using angiography as a tool in reference to diagnosing submucosal gastric fundal varices detected shunted blood supply to the varices through the left IPV and the left pericardiophrenic vein in 35% of cases [42]. An interesting case [9] found the path of the IPV to influence the anatomy of the diaphragm. These researchers described a dilated left IPV that appeared on a chest radiograph of a patient with IVC obstruction as an irregularity of the left hemidiaphragmatic contour. On the basis of this case we propose the use of radiographic imaging of the diaphragmatic vessels in the diagnosis of certain

conditions such as IVC obstruction, a suggestion that may assist clinicians in assessing otherwise inexplicable vascular anomalies.

To date many reports have documented the vasculature of the diaphragm anatomically and clinically. However, current knowledge of these vessels is incomplete. Although the IPA, IPV and SPA have received attention in the recent literature, there is little information on the detailed distribution of the blood supply between the muscular and tendinous diaphragm. It will be interesting to note the association between the extent of the muscular in comparison to the tendinous portion of the diaphragm and the arterial supply [43]. It will also be interesting to note if the diameters of the arteries supplying the diaphragm are related to a more muscular or more tendinous diaphragm. All these data could potentially explain why in some patients transcatheter chemoembolization is not successful.

Furthermore, a deeper understanding is necessary of the smaller vasculature, such as the pericardiophrenic and musculophrenic vessels. In considering the seemingly innumerable clinical reports involving diaphragmatic vasculature, it is important to acknowledge the effort still required to fully educate scientists and clinicians in the implication and application of this vasculature to abdominal carcinomas, gastric and gastrointestinal junction varices, hepatic artery pseudoaneurysm, IVC obstruction, liver transplantation and other pathologies.

## CONCLUSIONS

A series of studies has made an extensive exploration of the vasculature of the diaphragm, macroscopically, histologically, radiologically and clinically. We hope that for the anatomist the bringing together of these studies has helped to expose the gap in current knowledge and to suggest avenues for prospective research. We hope that for the clinician or surgeon the information provided will assist in refining clinical knowledge and improving diagnostic and surgical procedures such as transcatheter arterial embolism. In conclusion, with this literature review and by highlighting the gaps in the current knowledge base, we hope to contribute to the arsenal of resources available to anatomists and clinicians alike.

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