THE ESOPHAGEAL ARTERIES

THEIR CONFIGURATIONAL ANATOMY AND VARIATIONS IN RELATION TO SURGERY*

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INTRODUCTION

THE ESOPHAGEAL ARTERIES have in the past two or three decades attained a surgical significance unforeseen to the classical anatomists. The conventional extremely brief descriptions of the circulation of the esophagus available in standard anatomic texts are based on the relatively few investigations conducted from the sixteenth through the nineteenth centuries. Few definitive studies of the arterial distribution of the esophagus, none of a scope commensurate with current surgery, or in the English language, have appeared in the past 75 years.

The usual anatomic test,[1-14, 58-79] treatise, or atlas description in entirety is somewhat as follows: "The arterial supply of the esophagus is derived from the inferior thyroid, the esophageal branches of the aorta, the intercostals, the inferior phrenic, and the left gastric arteries." Further informative detail is exceptional and meager at best. Almost no statement can be found concerning configurations and variational morphology.

Since Torek's[23] initial successful transthoracic esophagectomy in 1913, the esophagus, hitherto considered operatively inaccessible, has attained prominent status in the surgical domain. A total of several hundred esophageal operations have been reported to date in the literature from a number of clinics.[25, 55] It is well established that the viability of enteric segments involved in various surgical technical procedures is primarily dependent on maintenance of an adequate circulation.[11, 15-18, 26, 27] Consequently, accurate knowledge of the origin and distribution of the vasa propria of the foregut may prove an invaluable asset in the advancing field of esophageal surgery. This survey is, in the main, concerned with the surgically relevant and practical details of the arterial blood supply of the gullet.

HISTORICAL

The arteries of the esophagus are much less well described in the literature than are the esophageal veins. No pertinent specific arterial studies in the English language appear to have been published during the past century, although Kegaries[28] a decade and a half ago investigated the esophageal venous plexuses. A few random and incidental notes on the esophageal circulation, however, appear in scattered fashion in several monographs on thoracic surgery and anatomy.

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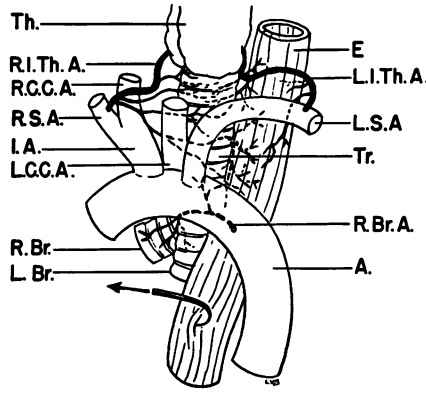
Gossart[29] and Demel[30] provide the only fairly comprehensive references during the past 50 years. Both authors, however, conducted their studies about a quarter of a century ago, long before modern resective approaches to the esophagus had become relatively popularized. Before this, Luschka,[31] Cruveilhier,[32] Sappey,[33] and Henle[2] among the older anatomists reported the first important findings concerning the esophageal branches of the aorta; subsequently Testut,[13] Poirer and Jonnesco,[4] and Rouviere[74] concerned themselves to a limited extent with this subject, adding several facts apparently from original sources. More recently, Leriche,[34] Hovelacque,[35] Gregoire,[36, 37] Vasconcelas,[38] and Sauerbruch,[39] individually contributed several notations concerning the surgical anatomical significance of these arteries. The exhaustive treatises of Adachi[10] and Do Rio Branco,[41] although primarily concerned with other vascular structures, yield brief original data. Lately, Horine,[42] Berry,[43] Hudson,[44] Cauldwell[45] and their co-workers, studying variously the pulmonary, coronary, and bronchial circulations have included several details concerning the esophagus. Parker and Brockington,[80] and others, utilizing experimental surgical procedures in animals, particularly dogs, have incorporated several conclusions concerning the esophageal circulation in their papers. However, Noer[81] has warned that comparisons between animals and human beings require close scrutiny as to their validity because of markedly varying arterial patterns in the alimentary systems of differing species.

METHODS

The following survey of the arteriae gulae is drawn almost entirely from our own dissection material. In a number of instances our accord or disagreement with previous authors in respect to specific details is cited. Fifty bodies were dissected, but some of our percentages are from a somewhat smaller number since, in certain instances, only one region under investigation was thoroughly worked out. The anatomic studies were performed during the course of complete necropsies on the refrigerated bodies of persons who had been dead less than two days. No bodies were included in which pathologic changes or extreme obesity existed of such a nature as to grossly obscure the cervical, thoracic, or upper abdominal structures. Arterial color mass was as a rule not utilized in following the course of proximal larger vessels. The detailed distribution of small branches of the arteriae propriae of the esophagus, trachea, bronchi, thyroid, and upper stomach, not easily and obviously identifiable by gross dissection, was generally determined by means of cannulation with blunted hypodermic needles and injection of India ink from a 5 cc. syringe. In several cases, for purposes of radiographic or three dimensional visualization, the larger arteries were injected with a thin barium sulfate suspension or a red vinylacetate plastic color mass. Almost all specimens were sketched and tabulated during dissection and discarded within one or two days, since facilities for preservation were seldom available.

FIG. 1



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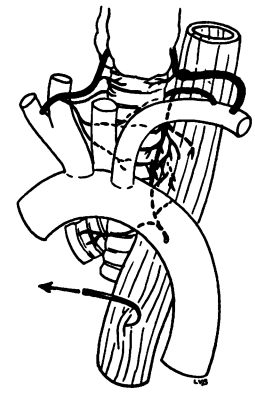

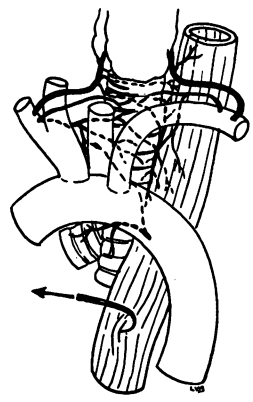

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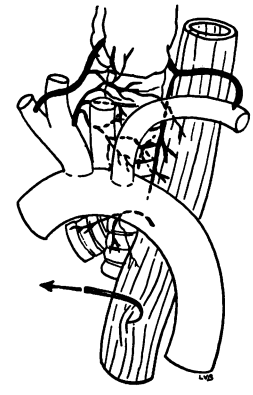


FIG. 4

FIG. 1.—Pars cervicalis, typical pattern: The right inferior thyroid supplies a greater number of branches than the left. Posterior esophageal twigs are relatively few and small. Many tracheal and esophageal twigs arise as bifurcations from the common tracheo-esophageal artery lying in the groove. Anastomosis with ascending branch of the right brachial artery is usual.

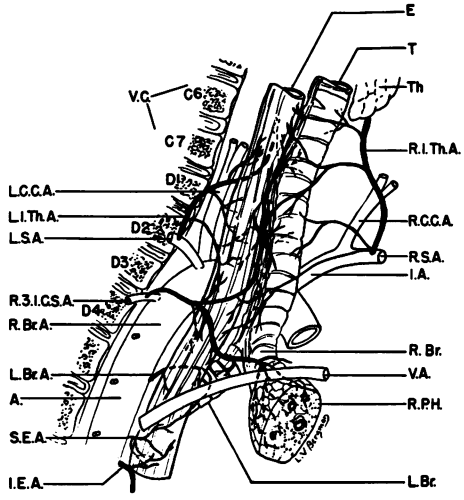
FIG. 2.—Pars cervicalis, common variant: The left esophageal arteries stem in the main directly from the left subclavian and are somewhat increased in number. Anastomosis between tracheo-esophageal arteries and right bronchial is present.

FIG. 3.—Pars cervicalis, common variant: The majority of esophageal branches to the pars cervicalis come from direct right and left branches of subclavian artery. A few upper twigs are contributed by the inferior thyroids.

FIG. 4.—Pars cervicalis, uncommon variant: The thyroid ima artery providing the majority of the right esophageal branches to the pars cervicalis. In this instance no gross anastomoses with bronchial arteries were observed.

Keys: Th. (thyroid), E. (esophagus), Tr. (trachea), L. Br. (left bronchus), R. Br. (right bronchus), A. (aorta), I. A. (innominate artery), R. CC. A. (right common carotid artery), L. CC. A. (left common carotid artery), R. S. A. (right subclavian artery), L. S. A. (left subclavian artery), L. I. Th. (left inferior thyroid artery), R. I. Th. A. (right inferior thyroid artery), R. Br. A. (right bronchial artery). (Note: Broken lines indicate course behind structures shown.)

FIG. 5



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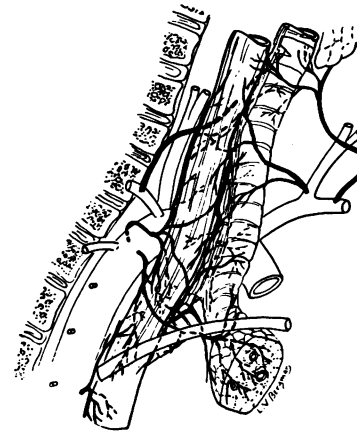

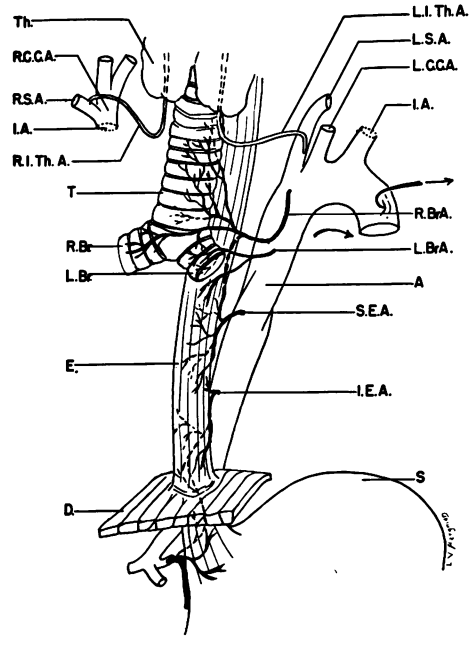

FIG. 7

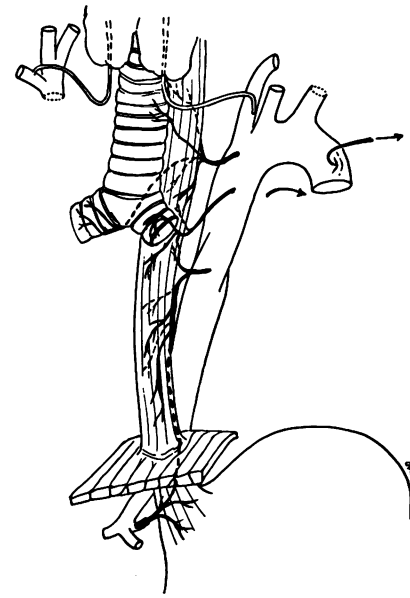

FIG. 8

FIG. 5.—Pars bifurcalis, usual pattern: The right bronchial artery, originating as it frequently does, from the right third intercostal artery, passes behind the esophagus. A vertical tracheo-esophageal artery in the tracheo-esophageal groove is formed by anastomosis between the descending branches of the right inferior thyroid artery and the ascending branches of the right bronchial. The right bronchial also anastomoses, in this specimen, with the superior esophageal artery.

(*Legend continued on opposite page*)

GENERAL CONSIDERATIONS

The esophagus in this study is described as divided from above downward into the following four segments, the names of which are essentially self defining: 1. Pars cervicalis; 2. Pars bifurcalis (that portion adjacent to the aortic arch and tracheal bifurcation); 3. Pars thoracalis; 4. Pars abdominalis.

The gullet differs from most other parts of the gastro-intestinal tract in that it is primarily a tubular musculo-membranous conduit, rather than a secretory, digestive, and absorptive organ.[20-22] As might therefore be expected, it is less liberally supplied with arteries of gross caliber and its intramural vascular plexuses are relatively sparse. Arteriae esophageae propriae, although essential for the viability of this structure, seldom exceed 3 mm. in diameter.

The circulation of these parts in the adult can be better understood after consideration of their development in the fetus. Embryologically the trachea, bronchi, and lungs, as well as the thyroid, are derived from the foregut, and as a consequence, an ultimate intimate relationship between their blood vessels and that of the esophagus ensues. Similarly, the dorsomedian part of the diaphragm originates from the cephalad segment of primitive dorsal mesentery, thus accounting for the intermingling of the esophageal and phrenic circulation.[46, 47]

The esophageal arteries proper are derivatives of the paired vitelline branches of the fusing embryonic dorsal aortae and, with the bronchial arteries, may be considered as in serial sequence with the ultimately unpaired fused coeliac, superior mesenteric, and inferior mesenteric trunks. Unlike the predominant pattern in the large and small intestines, in the absence of an adult mesentery, these arteries, as a rule, course longitudinally rather than radially, forming, to some degree, vertical anastomotic chains. The primary unbranched trunks are obscured in the connective tissue of the mediastinum and stand out clearly only when the aorta and esophagus are separated by dissection.

From a surgical point of view the esophagus is probably quite properly considered as analogous to gut elsewhere, in that the viability of segments

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FIG. 6.—Pars bifurcalis, uncommon variant: In a typical case the right bronchial artery provided only a few small twigs. Unlike the usual distribution, the larger and greater number of branches were left-sided in this instance, stemming in the main from a left-sided ascending tracheo-esophageal artery from the arch, and a left bronchial, from which an unusually small right bronchial artery springs. Several small twigs arose from the right common carotid near its origin.
Keys: V. A. (vena azygos), V. C. (vertical column), R. P. H. (right pulmonary hilum), R. 3 1. A. (right third intercostal artery).

FIG. 7.—Pars bifurcalis and pars thoracalis, typical pattern: The right bronchial artery contributes more to esophageal circulation than the left, via an ascending tracheo-esophageal artery and direct branches. The thoracic esophagus is supplied by two unpaired direct esophageal arteries, the uppermost anastomosing with the bronchials. As is characteristic, the inferior artery is larger in size.

FIG. 8.—Pars bifurcalis and pars thoracalis, common variant: A single direct thoracic esophageal artery of appreciable size is found, bifurcating into fairly large ascending and descending branches, the former rejoining the superior esophageal artery. A grossly discernible thoraco-abdominal anastomosis, found in over half the cases, exists.

involved in various surgical technical procedures must largely depend on maintenance of an adequate circulation. The numerous gossamer-thin twigs to the esophagus often encountered are, in all likelihood, of little value as collateral circulation after disruption of the sturdier esophageal arteriae propriae, although they may play an important part in the spread of infection and in metastases of malignant tissue. For this reason many fine arteriolar anastomoses that have been shown to exist between the esophageal vessels and the pericardium, heart, pulmonary veins, internal mammary arteries, and thymic vestiges are omitted from further detailed consideration in this study.

ANATOMIC FINDINGS

For the sake of brevity our observations, when possible, have been presented in statistical summary, or arranged in tabular form. Much of the descriptive material is given in association with the appropriate illustrations. The latter are semi-diagrammatic, drawn without reference to possible variations in the topographic visceral anatomy, which is schematized, since we are here concerned primarily with the regional vasculature.

I. *Pars Cervicalis:*

A. Primary supply-inferior thyroid artery (from the thyro-cervical trunk of the subclavian artery).

B. Origin of major arteries to pars cervicalis.

From inferior thyroid	34 cases
From subclavian	12 cases
From thyroid ima	3 cases
From common carotid	1 case

Almost invariably the anterior arteries are functional tracheo-esophageal vessels, coursing and bifurcating in the groove and giving branches to both structures. In about two-thirds they are more voluminous on the right. Posterior vessels are generally smaller and few in number, and are more apt to run transversely.

C. Anastomoses or collaterals (grossly traceable and presumably surgically significant).

	Left	Right
With sup. thyr. A. A.	1 case	.....
With bronchial A. A.	8 cases	2 cases
With aortic twigs	5 cases	33 cases
With each other	 5	.....

D. Accessory arteries.

From subclavian	9 cases
From aorta	4 cases
From carotid	2 cases
From vertebral	1 case

II. *Pars Bifurcalis:*

A. Primary supply-bronchial arteries (from aorta or the right third or fourth intercostal artery).

FIG. 9

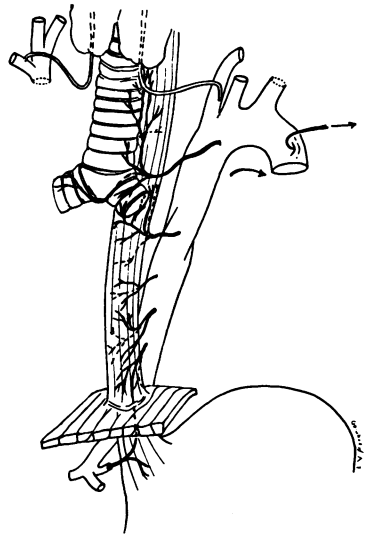
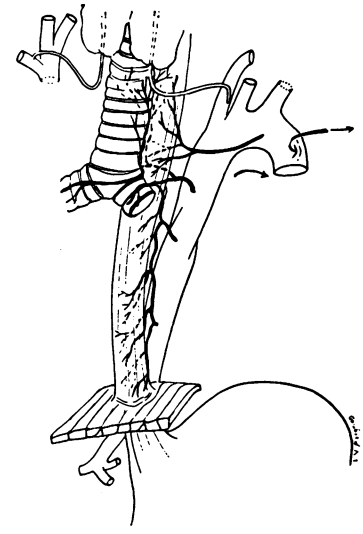
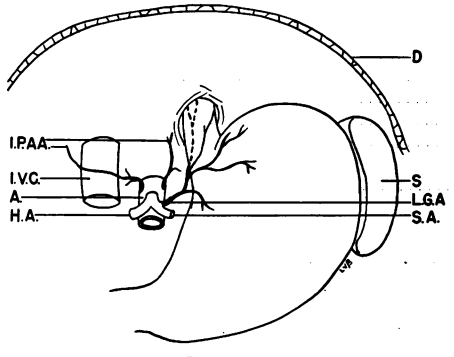


FIG. 10





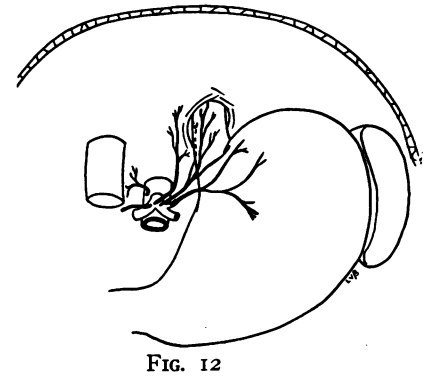


FIG. 11

FIG. 12

FIG. 9.—Pars bifurcalis and pars thoracalis, infrequent variant: A third primary esophageal artery of appreciable size stems directly from the thoracic aorta. In this instance the left superior bronchial artery has a common origin with the right, and a left inferior bronchial artery, supplying several fair-sized esophageal branches, is seen. This is a fairly common pattern for the bronchial arteries.

FIG. 10.—Pars bifurcalis and pars thoracalis, uncommon variant: A fairly large direct esophageal artery arises from the concavity of the aortic arch. The superior and inferior esophageal arteries proper are joined in an anastomotic arc lying alongside the aorta. From this, in an unusual radial pattern replacing the customary longitudinal anastomotic chain, numerous vasa propria branch to esophagus.

Key: C. A. (coeliac axis), S. (stomach), D. (diaphragm), R. and L. Br. A. (right and left bronchial arteries), S. and I. E. A. (superior and inferior esophageal arteries).

FIG. 11.—Pars abdominalis, typical pattern: A cardio-tuberous branch of the left gastric artery provides several branches to the infradiaphragmatic segment of the esophagus. A posterior ascending twig is seen, entering into an anastomosis with the inferior thoracic esophageal artery.

FIG. 12.—Pars abdominalis, common variant: The esophageal branches arise directly from the coeliac axis, adjacent in this instance to the origin of an accessory hepatic artery. The left inferior phrenic artery arising from the coeliac axis supplies a few twigs to the posterior wall of esophagus. No thoraco-abdominal anastomosis is seen.

B. Origin of major arteries to pars bifurcalis

From bronchial arteries	47 cases
From aorta and arch	3 cases

In over two-thirds of the cases, a greater number of arterial branches are directed along the left side of the esophagus in this region, those from the right bronchial most frequently passing behind the esophagus. Twigs are found, however, at both right and left esophageal borders, where they branch into ascending and descending limbs supplying both the intrathoracic trachea and bifurcation and the esophagus to as far as 5 to 8 cm. below the aortic arch. The importance of the bronchial contribution at this level is generally overlooked.[1-14, 58-79]

C. Anastomoses or collaterals: (Grossly traceable and presumably surgically significant).

	Left	Right
With inferior thyroid A	6 cases	29 cases
With subclavian A	2 cases	4 cases
With carotid A	3 cases	1 case
With intercostal, third	2 cases	.. cases
With aortic twigs	 12	.. cases
With thoracic esophageal A. A	6 cases	17 cases

D. Accessory arteries.

From aorta and arch	23 cases
From innominate artery	4 cases
From subclavian	5 cases
From carotid A. A	2 cases
From upper intercostal A. A	6 cases
From internal mammary A. A	7 cases

III. *Pars Thoracalis:*

A. Primary supply-superior and inferior esophageal arteries (from thoracic aorta).

B. Number of major arteries to thoracic esophagus.

		1 present	2 present
Superior	Found in 46 cases	in 43 cases	in 3 cases
Inferior	Found in 48 cases	46 cases	2 cases
Accessory (lowermost)	Found in 5 cases	3 cases	2 cases

The primary aortic branches to the thoracic esophagus *below the arch are generally described as from three to seven in number.*[1-14, 58-79] *In 90 per cent of these cases, only two were found,* in most instances as a smaller upper or lesser superior and a greater or inferior esophageal artery. These vessels are almost always unpaired and arise from the anterior aspect of the aorta slightly to the right of the midline. In a few instances only one somewhat enlarged aortic esophageal artery was found.

The superior artery generally arises at the level of the T6–7 intervertebral disc and seldom exceeds 3 to 4 cm. in length. The inferior comes off some 3 to 5 cm. lower at about the T7–8 disc level and is both thicker and longer, attaining possibly 6 to 7 cm. in length. Both course to the posterior surface

of the esophagus, dividing into right and left trunks, each giving ascending and larger descending branches. Terminal branches enter the pulmonary ligaments and pericardium. A variable number of additional delicate vascular strands, so fine as to appear inconsequential from a surgical standpoint, are always encountered. In about 7 per cent a radial pattern of vasa propria from an anastomotic arch between the superior and inferior arteries obtains.

C. Anastomoses (grossly traceable and presumably surgically significant).

	Superior		Inferior
With left bronchial A. A.	5 cases		1 case
With right bronchial A. A.	16 cases		3 cases
With inferior phrenic	.....		6 cases
With left gastric	1 case		28 cases
With each other	.....	19	.....

D. Accessory arteries.

From lower intercostal A. A.	3 cases
From coeliac axis	2 cases
From aorta	5 cases

IV. *Pars Abdominalis:*

A. Primary supply-left gastric artery (from coeliac trunk).

B. Origin of major arteries to pars abdominalis.

From left gastric	43 cases
From inferior phrenic	9 cases
From aorta	3 cases
From gastrohepatic (accessory hepatic)	9 cases
From splenic	1 case
From coeliac axis	8 cases

The left gastric artery, or its cardiotuberous branch, fairly constantly supplies a number of twigs, usually from two to four, to the infradiaphragmatic segment. The thoraco-abdominal anastomosis, present in grossly appreciable caliber in about two-thirds of cases, is generally between a posterior abdominal esophageal branch and the inferior thoracic esophageal artery. The central branches of the inferior phrenic arteries often form a circle about the hiatus, but these arteries appear to communicate directly with the esophageal vasculature in no more than 20 per cent of cases. A true infra-hiatal peri-esophageal arterial circle is seldom observed.

C. Anastomoses (grossly traceable and presumably surgically significant).

1. Left gastric, coeliac axis, or gastro-hepatic.

With superior esophageal	1 case
With inferior esophageal	28 cases
With gastric arteries	24 cases
With splenic	5 cases
With hepatic	8 cases
With renal, suprarenal	1 case
With each other	7 cases

2. Inferior phrenic.

With inferior esophageal	6 cases
With gastric arteries	4 cases
With splenic	2 cases
With hepatic	2 cases
With renal, suprarenal	5 cases

D. Accessory arteries.

From coeliac axis	11 cases
From hepatic, accessory hepatic A.	7 cases
From splenic	2 cases
From aorta	6 cases

CLINICAL AND SURGICAL IMPLICATIONS

The surgical applications of the foregoing observations may now be commented on briefly and several guarded conclusions drawn. The indications for esophageal surgery in accordance with current trends are primarily the several conditions here listed. Esophagectomy and esophagogastrostomy are carried out for carcinoma of the gullet and gastric cardia,[25, 55] benign tumors, extensive strictures,[52, 53] and, relatively recently, lower esophageal varices.[55] Esophagogastrostomy and esophagoplasty are performed, in the main, for congenital atresia and tracheofistula,[50, 51] diverticuli,[57] the narrower strictures, and in some instances of achalasia or cardiospasm.[54]

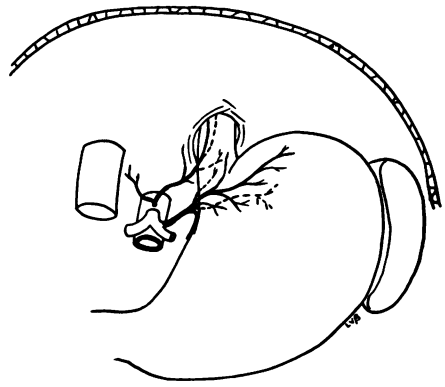


FIG. 13.—Pars abdominalis, infrequent variant: The left inferior phrenic artery, arising in a common stem with the right, largely replaces the left gastric in supplying the abdominal esophagus and enters into the thoraco-abdominal anastomosis.

The somewhat high operative mortality expected in this type of surgery may be partly attributed to impaired healing of suture lines; just as inadvertent devascularization of small intestinal or colonic segments may result in grave consequences in abdominal entero-anastomosis. The major direct complications secondary to surgically produced ischemia are diastasis and leakage leading to mediastinitis. Closely paralleling an occasional late complication in biliary and intestinal surgery, ischemic necrosis may also eventuate in delayed stricture formation rather than early perforation. This unsatisfactory outcome, now probably seen more often than early sloughing and anastomotic leakage, results in the late progressive obstruction frequently observed in patients surviving operation for several months in whom the recurrence of neoplasm is not found at necropsy.[84]

In the pars cervicalis the major blood supply is derived from below as bifurcating twigs from common tracheo-esophageal arteries in the tracheo-esophageal groove. Extensive separation of the upper esophagus from the

trachea results in the laceration of a large number of these. The collateral supply, via the superior thyroid, *etc.*, is meager. The frequent sloughing of the exteriorized cervical esophagus reported[25, 55] in the classical Torek esophagectomy and the notable failure of many attempted anastomoses with skin tubes may in large part be due to ischemic necrosis of this nature. In operating upon the higher diverticuli it is suggested that the esophagus be displaced from its bed as little as possible to preserve the circulation intact.

At the pars bifurcalis, extensive mobilization may lacerate both bronchial arteries, and, in a number of cases, the tracheo-esophageal anastomotic arc between the bronchial and inferior thyroid arteries. In about half the cases no appreciable compensatory collateral circulation appeared demonstrable. Consequently in operating for cancer in the mid-thoracic esophagus, mobilizing the

Esophageal Arterial Patterns in Relation to Surgical Procedures

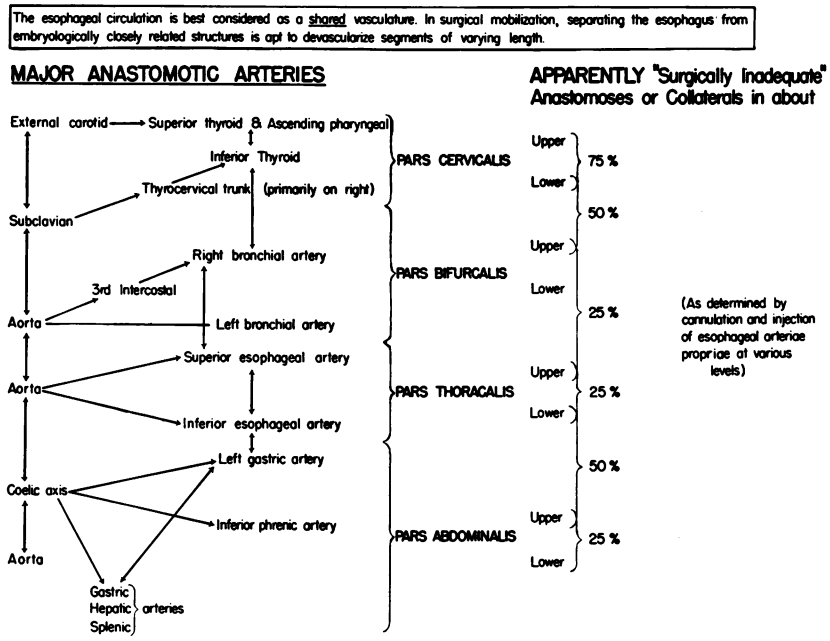


FIG. 14.—Key: S. (spleen), H. A. (hepatic artery), S. A. (splenic artery), L. G. A. (left gastric artery), I. V. C. (inferior vena cava), I. P. A. (inferior phrenic arteries).

esophagus and bringing it anterior to the arch strips it of its blood supply in a large number of cases, probably contributing to the high mortality (probably about 50 per cent) of this procedure. Later stricture formation and recurrent obstruction, an all too frequent, albeit delayed, complication, is probably attributable to partial devascularization and gradual necrosis with the familiar end result of obliterative fibrosis. An approach in which a high gastro-esophageal extra-thoracic or cervical anastomosis may be performed without greatly displacing the esophagus from the trachea may be preferable, and has recently been described by both Garlock[82] and Sweet.[83]

At the pars thoracalis, the aorta and esophagus may be gently separated for several centimeters, as a rule without marked devascularization. However, we believe that especial care should be taken to avoid tearing the two esophageal arteriae propriae coming off in the upper third, unless resection is intended. Simple dislocation of the lower thoracic esophagus from its bed, if these arteries are not avulsed, need not interfere greatly with the blood supply. Collateral circulation from above is fairly adequate for short segments left for anastomosis. In operating for stricture or infantile atresia, if an end-to-end anastomosis of esophagus is contemplated, minimal separation from the aorta is advisable. If this is not feasible without extensive mobilization, resection of the involved area and trans-thoracic esophagastrostomy would appear indicated.

At the pars abdominalis, if the left gastric artery is severed to facilitate gastric mobilization, and the complete length of the thoracic esophagus is extensively freed, the lower esophagus may be seriously devascularized. In the writers' judgment the inferior phrenic artery may not always be relied upon, since it contributes relatively little to the blood supply here and anastomoses between the bronchial and left gastric arteries are rare. For these reasons, in low esophagogastrostomy for cardiospasm or stricture, ligation of the left gastric artery would seem inadvisable if it can be avoided. In total gastrectomy via the abdominal approach, the esophageal branches arising from the coeliac plexus should be preserved, if possible. Many of the failures in attempted total gastrectomies of a decade or more ago, when adequate viable esophagus was not brought down, were quite possibly due to ischemic diastasis of the anastomotic suture lines. If the hiatus is opened widely and the esophagus dissected free without regard for the regional supplying arterial twigs, the lowermost segment of esophagus will have an impaired blood supply and should, we believe, often be resected rather than utilized for anastomosis.

SUMMARY

The arterial blood supply of the esophagus found in dissecting 50 bodies has been described. The anatomic configurations and variations are detailed with particular reference to their surgical significance. The premise is offered that the esophageal circulation is best considered as a *shared* vasculature, and that due care must be taken during surgical mobilizations in separating the esophagus from such embryologically related structures as the trachea, bronchi, and diaphragm, lest the freed segments be devascularized to a degree incompatible with reparative processes. The possible etiologic role of ischemic necrosis in early diastasis and leakage, or in delayed obliterative fibrosis and stricture, of reconstructive esophageal anastomotic suture-lines at various levels is considered. Methods of minimizing injury to the blood supply and thereby preventing devascularization during esophageal surgery are suggested.

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