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Visceral and renal artery aneurysms

EDIZIONI MINERVA MEDICA

1 The anatomy and its variants

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DEFINITION OF ANATOMICAL VARIANT

The term anatomical variant defines the morphology of a particular structure that differs from the anatomical configuration observed in most individuals. Unlike congenital anomalies, which are considered pathologic by definition, anatomic variants are considered to be within the normal range. However, it is understandable that anatomic variants can interfere with diagnostic and operative procedures, and thus significantly affect prognosis. For these reasons, they must be adequately recognized, observed, and studied.[1, 2] Although anatomical variants do not represent a pathological condition, it is likely that some of them may act as cofactors in conditioning the development of some pathological situations. Moreover, focusing on more operative aspects, it is undeniable that some peculiar anatomical conformations may increase the risk of complications during surgical procedures. It is clear that the knowledge of human anatomy and the study of anatomical variants represent an indispensable requirement for any medical practice.[3]

ORGANOGENESIS HINTS

The arrangement of the anatomical structures, the mutual relationships between the viscera, and the origin and course of the blood and lymphatic vessels, are the result of complicated processes of growth, rotation and migration that occur during the stages of embryonic and fetal development. Organogenetic movements, which are responsible for the final shape of the organs, can also be the cause of particularly frequent anatomical variants in arterial and venous vessels. Therefore, the rationale that explains the existence of anatomical variants must be traced back to the organogenesis level, in particular to the development of the main arterial vessels, of which some milestones must be kept in mind.[4] During organogenesis, leading to the final organization of the vascular system (genetically determined), anatomical variants are extremely frequent in both the arterial and venous systems and can lead to local changes in the abnormal development of certain organs.

The union of the two primitive dorsal aortas will give a single artery from which the uneven celiac, upper and lower mesenteric trunks will originate. Regarding the origin of the arteries from the abdominal aorta, it is necessary to take into account the existence of the two primitive vitelline arteries, which are parallel to the homonymous veins and which originate from the dorsal aortas in the abdominal tract of the embryo. The celiac trunk (tripod) generally originates from the right vitelline artery, while the upper and lower mesenteric arteries originate from the left vitelline artery; the vitelline arteries, initially a variable number of paired vessels supplying the yolk sac, gradually fuse and form the arteries located in the dorsal mesentery of the intestine. In adults, these vessels (*i.e.* celiac trunk, superior mesenteric artery, and inferior mesenteric artery) irrigate the organs that developed from the primitive anterior, middle, and posterior intestines, respectively.[5]

The presence of variants affecting the celiac trunk, hepatic artery, and superior mesenteric artery could be due to differences in the fusion by variability in the fusion of the right and left primitive vitelline arteries when they move to the root of the dorsal mesentery. Thus, the authors would like to stress that the knowledge of the normal anatomy as well as of the anatomical variants of the vessels originating from the abdominal aorta, and supplying the organs in the abdominal district, represents the indispensable starting point for the planning and execution of safe surgical operations in this sector.

DESCRIPTION OF THE ANATOMICAL VARIANTS OF THE VISCERAL BRANCHES OF THE ABDOMINAL AORTA

In the abdomen, the most commonly described vascular anatomical variants are related to the visceral branches (both uneven and even ones) and anastomotic circles derived from the aorta: celiac trunk (*i.e.*, tripod), mesenteric arteries, renal and gonadic arteries, as well as pancreatic-duodenal, gastro-duodenal, and colic anastomoses.

The *celiac trunk* is the first ventral branch of the abdominal aorta; it arises at the level of the twelfth thoracic vertebra and, usually at the level of the upper border of the pancreas, it trifurcates into the left gastric, the common hepatic and the splenic arteries[6] (**FIGURE 1.1**). It supplies blood to the esophagus, stomach, spleen, liver, biliary and part of the duodenum-pancreatic complex; for this reason, anatomical variations of the celiac trunk and hepatic arteries are of considerable importance in many surgical procedures, such as in upper abdominal surgery in order to avoid, or minimize, any ischemic complications.[7] The celiac trunk was described, for the first time, by Haller in 1756 (for this reason it is known as Tripus Halleri, whose trifurcation is considered the normal pattern).[8] In 75-90% of individuals, the celiac trunk runs horizontally forward for about 1.25 cm (the length can be variable, usually between 8 and 40 mm). Some studies have shown that the frequency of the normal celiac trunk branching pattern varies in populations with different geographical origins, ranging from approximately 72% (in Croatians), to 86% (in Indians), or even as high as 89.1% (in Koreans).[6, 9-13]

The second ventral branch of the abdominal aorta is the superior mesenteric artery arising at the level of first lumbar vertebra; its normal branches are the inferior pancreatico-duodenal, jejunal, ileal, ileocolic, right colic and the middle colic arteries.[14] In 1928, Adachi described the anatomical variations of both the celiac trunk and the superior mesenteric arter-

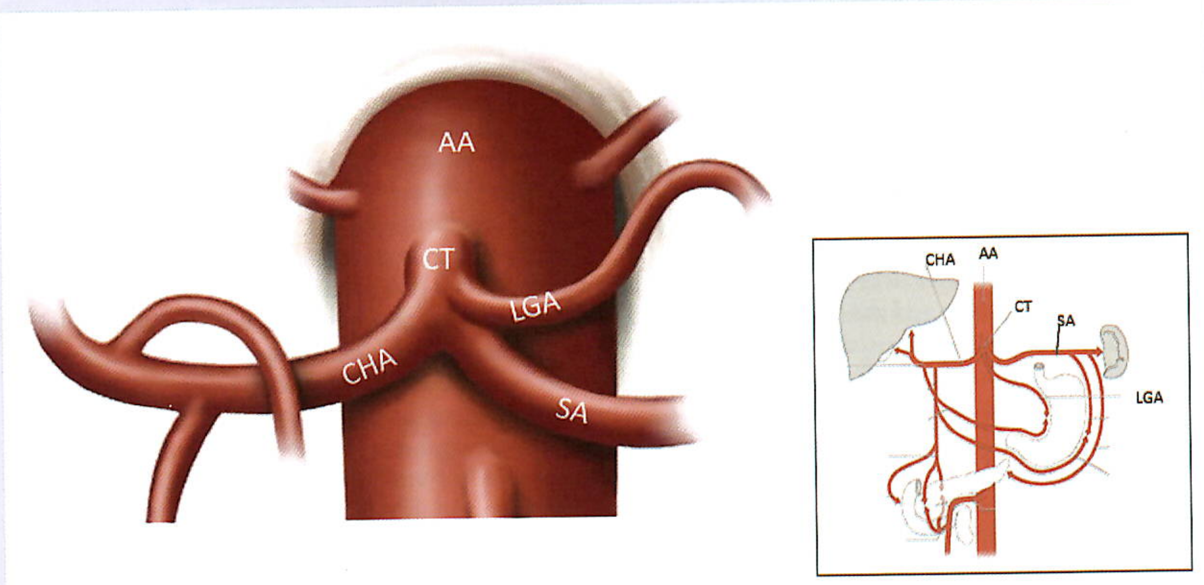

FIGURE 1.1. Common trifurcation of celiac trunk (CT) into the left gastric artery (LGA), the common hepatic artery (CHA) and the splenic artery (SA). Abdominal aorta (AA). In the insert is drawn part of the visceral compartment supplied by the branches of the abdominal aorta. *(Modified pictures from the Anatomy Atlas - Prometheus).*

ies.[15] Anatomical variations of the celiac trunk include the absence of one of its branches (bifurcation or incomplete celiac trunk), additional branches, a common origin with the superior mesenteric artery (celiac-mesenteric trunk), a common origin with the superior and inferior mesenteric artery (celiac-bimesenteric trunk) and total absence.[16, 17] An absent celiac trunk (not included in the Adachi classification,[15] but later included in Morita's classification[18]) is a rare anatomical variant: its incidence ranges from 0.1-0.4%[19, 20] to 2.6%.[21] In 2014, Iacob *et al.*[22] reported only 31 cases of absent celiac trunk across the world, some of which (about 1 out of 3) were detected by imaging studies and then others detected during anatomical dissection. More precisely, Morita proposed five types of variant for the celiac trunk: 1) celiac trunk; 2) hepato-splenic trunk; 3) gastro-splenic trunk; 4) hepato-gastric trunk, and 5) absent celiac trunk.[18] Celiac trunk components originating directly from the abdominal aorta are not uncommon; instead, those cases in which the three components originate as branches of the abdominal aorta without forming a relationship with the other vessels are rarer. Sometimes the celiac trunk originates together with the superior mesenteric artery, forming a common trunk known as the "*celiac-mesenteric trunk*".[23]

Chen *et al.*[6] studied the anatomical changes of the celiac trunk and hepatic artery in 974 cadavers: 89.8% of cases showed classic trifurcation of the celiac trunk, with no statistically significant difference between males and females. The common hepatic artery constituted a separate branch in 10% of cases; a common hepatosplenic trunk and a gastrohepatic trunk were seen in 4.4% and 0.3%, respectively. A common hepatic artery arising from the superior mesenteric artery or directly from the aorta was present in 3.5% or 0.5%, respectively. A hepatosplenomesenteric trunk and a celiomesenteric trunk were encountered in 0.7%.

Other authors[24] described, in several cadavers, anatomical variants considered gastrosplenic and hepatomesenteric trunks arising from the anterior wall of the abdominal aorta. Three optional conditions were recorded:

1) the gastrosplenic artery, after giving off the left inferior phrenic artery, divides into the left gastric artery and the splenic artery, also producing the left hepatic artery; the hepatomesenteric artery divides into the common hepatic artery (in turn dividing into four branches: the right gastric artery, the gastroduodenal artery, the cystic artery, and the proper hepatic artery) and the superior mesenteric artery.
2) The gastrosplenic artery divides into the left gastric artery and the splenic artery; the hepatomesenteric artery (longer than the previous condition) divides into the common hepatic artery (giving rise to the proper hepatic artery and the right gastric artery) and the superior mesenteric artery.
3) The gastrosplenic artery immediately divides into the left gastric artery and the splenic artery; the hepatomesenteric artery has a much longer course compared to previous conditions, before dividing into the same terminal branches.

Iacob *et al.*,[25] besides describing some anatomical variations in a case report (concerning the presence of gastrosplenic trunk, the common hepatic artery and superior mesenteric artery, arising independently from the abdominal aorta and one additional right renal artery), underline the concomitant presence of different tortuosity indexes and different endoluminal diameters of the various branches. The authors also refer to three types of association of the gastrosplenic trunk: 1) with the hepatomesenteric trunk;[6, 10, 15, 26] 2) with the right hepatic artery, arising from the superior mesenteric artery;[15, 27] and 3) with the common hepatic artery arising independently.[6, 10, 11, 21, 26, 28]

A further peculiar anatomical variation is the absence of the common hepatic artery described in a case reported in 2017.[29] The authors describe that the celiac trunk detached the left gastric artery and splenic artery, and a "replaced" gastroduodenal artery; moreover, the proper hepatic artery was derived from the superior mesenteric artery, which subsequently divided into a "replaced" proper hepatic artery (later branching into right and left hepatic arteries) and the right gastric artery.

Raikos *et al.*[30] described multiple arterial variations of the abdominal aorta (of both uneven and even abdominal branches) in a 45-year-old male cadaver; as far as uneven branches are concerned, a common phrenogastrosplenic trunk (arising from the left of the aorta anterior surface), including the left inferior phrenic, the left gastric and the splenic arteries were observed, instead of the typical trifurcation of the celiac trunk.

Moreover, the common hepatic artery originated separately from the midline of the anterior face of the aorta (above the superior mesenteric artery) as well as an accessory right hepatic artery on the right anterior face of the abdominal aorta, at the same level as the superior mesenteric artery. In a work by Prakash *et al.*,[13] from 50 cadavers of the Indian population, the following anatomic variants of the

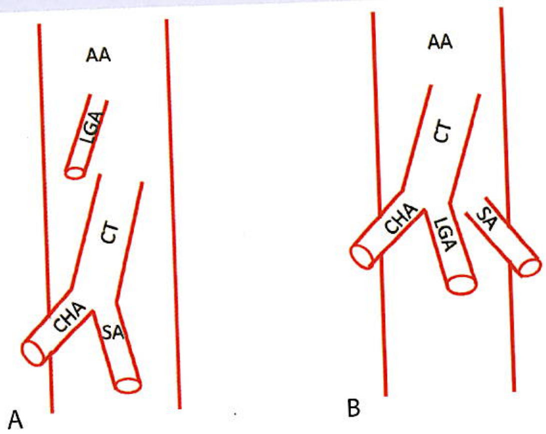

FIGURE 1.2. (**A**) Direct origin of the left gastric artery (LGA) from the abdominal aorta (AA), proximal to the celiac trunk (CT) terminally dividing into the common hepatic artery (CHA) and splenic artery (SA). (**B**) Direct origin of the splenic artery (SA) from the abdominal aorta (AA), distal to the celiac trunk (CT) terminally dividing into the common hepatic artery (CHA) and left gastric artery (LGA).

celiac trunk were found: 1) a direct origin of the left gastric artery from the aorta, proximal to the celiac trunk terminally dividing into the common hepatic and splenic arteries (n. 4 cases) (**FIGURE 1.2A**); 2) all three branches with a direct origin from the abdominal aorta (n. 2 cases); 3) a direct origin of the splenic artery from the aorta, distal to the celiac trunk terminally dividing into the common hepatic and left gastric arteries (n. 1 case) (**FIGURE 1.2B**). According to some observations reported in the literature, the splenic artery may have other origin variations; it can take its direct origin from: the abdominal aorta, the common hepatic artery, the left gastric artery or the superior mesenteric artery.[31] Moreover, other studies revealed that the splenic artery has variations in the tortuosity, course, position and number of branches.[32] The occurrence of other abnormalities is also reported,[33] such as congenital absence, total duplication, intrahepatic course and variations of the terminal branching pattern of the splenic artery. Ekingen *et al.*[32] reported different types of splenic artery origin (among 750 patients undergoing multi-detector computed tomography-MDCT angiography): 1) from the celiac trunk as a branch of the celiac trunk bifurcation into the splenic artery and common hepatic artery (68%); 2) from the quadrifurcation of celiac trunk (into the splenic artery, left gastric artery, gastroduodenal artery, and common root of the right hepatic artery-plus the middle colic artery; 0.40%) (**FIGURE 1.3A**); 3) from the pentafurcation of the celiac trunk (into the splenic artery, left gastric artery, right hepatic artery, middle colic artery, and common root of the left hepatic artery-plus gastroduodenal artery; 0.13%) (**FIGURE 1.3B**). In addition, the presence of an accessory splenic artery has been reported, which is quite rare, probably due to intra-parenchymatous anastomosis between the inferior polar artery of the splenic artery and the splenic branches of the left gastroepiploic artery.[33, 34]

Rarely, multiple anatomical variants are found concurrently, thanks to MDCT angiography, such as in the case reported by Bolintineanu *et al.*,[35] describing a triple anatomical variation concerning the presence of a hepato-spleno-mesenteric trunk in association with an accessory left hepatic artery and a common trunk origin of the right and left inferior phrenic arteries from left gastric artery arising independently from the abdominal aorta. Another rare variation of the hepato-spleno-mesenteric trunk arising from abdominal aorta has also been described,[36] including two classical branches of the celiac trunk (common hepatic artery and splenic artery) together with the superior mesenteric artery; in this case, the classical third branch of the celiac trunk (*i.e.* the left gastric artery) directly rose from the abdominal aorta.

In a very particular case, in a cadaver of a 79-year-old Japanese female,[16] instead of the usual

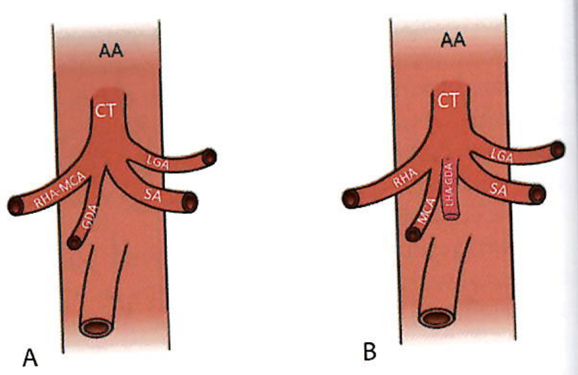

FIGURE 1.3. (**A**) Quadrifurcation of celiac trunk (CT) into the splenic artery (SA), left gastric artery (LGA), gastroduodenal artery (GDA), and common root of the right hepatic artery-plus the middle colic artery (RHA-MCA). (**B**) Pentafurcation of celiac trunk (CT), into the splenic artery (SA), left gastric artery (LGA), right hepatic artery (RHA), middle colic artery (MCA), and common root of the left hepatic artery-plus gastroduodenal artery (LHA-GDA). Abdominal aorta (AA). *(Modified pictures from the Anatomy Atlas – Prometheus).*

celiac trunk (totally absent), the left gastric artery, the splenic artery and the hepato-mesenteric trunk were found to have formed independently from the abdominal aorta; moreover, the hepatic artery arising from the hepato-mesenteric trunk ran behind the portal vein.

Even with regard to pairs of collaterals of the abdominal aorta, with visceral targets (*i.e.*, *renal* or *gonadic arteries*), anatomical variations can sometimes be found. In 75% of subjects, the renal arteries originate from the aorta immediately downstream of the origin of the superior mesenteric artery, approximately from first to second lumbar vertebrae; however, interindividual variability is known, with origins between the twelfth thoracic and second lumbar vertebrae. Two left renal arteries were observed on the same side of the abdominal aorta:[30] the superior renal artery, which is the main artery, is located below the superior mesenteric artery, whereas the inferior renal artery, which is an accessory branch, represents an accessory inferior polar renal artery, emerging from the left side of the abdominal aorta at an intermediate level between the origin of the right renal artery and of the inferior mesenteric artery. Such additional renal artery (also defined as accessory, aberrant, or anomalous) may arise from various portions of the aorta and terminate at different locations in the kidney. Moreover, according to other authors,[37] additional multiple bilateral arteries were observed in 10% of the population (with respect to multiple unilateral renal arteries, found in about 23%, and most commonly emerging from the left side of the aorta).

Besides the most common variants described, other conditions exist, more rarely, such as the one reported by Matusz *et al.*[38] in association with visceral abnormalities. They describe an atypical case of a right congenital solitary kidney with three renal arteries, one main renal artery and two additional renal arteries, in a 75-year-old woman with uterine didelphys. Other peculiar case reports are those describing: 1) three renal arteries observed on the right side and two on the left;[39] 2) four left renal arteries together with one right renal artery;[40] 3) six renal arteries (bilateral triple);[41] and 4) seven renal arteries (three right and four left).[42] Knowledge of such accessory arteries helps the surgeon during the renal region access and during the transplantation procedures, as well as the radiologist during the interpretation of renal angiograms.

A very special case is that described by Rossi and Stagni,[43] which refers to the right renal artery originating from a common trunk with the superior mesenteric artery and the hepatic artery (hepatic-mesenteric-renal tripod). Such a condition can be explained from an embryological point of view, not so much as an alteration of the normal development and involution of pronephros, mesonephros, and metanephros, but rather as a result of the persistence of vascular structures normally destined for involution or alternatively of a "vascular recall" of the dorsal aorta.

The same embryological alterations could be at the origin of some anatomical variations recorded for testicular arteries. Besides the typical testicular artery origin (incidence of 85.3%), anatomical variations were observed in 14.7% of cases in a study by Pai *et al.*:[44] 1) the testicular artery as a branch of the inferior additional polar renal artery; 2) the testicular artery as a branch of the main renal artery; 3) the origin of the testicular artery as high as the renal artery origin, which implies that the testicular artery arched over the ipsilateral renal vein; and 4) double testicular arteries: the lateral artery (from the upper pre-hilar right renal artery) and the medial artery (from the anterior surface of the abdominal aorta, as a common trunk along with the inferior suprarenal and renal capsular arteries).

As far as *anastomotic colic circuits* are concerned, various anatomical variations are described with respect to the frequent situation where the abdominal aorta usually gives rise to the superior mesenteric artery (which supplies structures derived from the midgut through the ileocolic, right colic and middle colic arteries) and the inferior mesenteric artery (which supplies structures derived from the hindgut, including the distal third of the transverse colon, descending and sigmoid colon and rectum, through the left colic, sigmoid and superior rectal arteries). In particular, variations in the pattern of origin, branching, and territory of vascularization are found more frequently in the superior mesenteric artery than in the inferior mesenteric artery;[45] both are worth considering due to their clinical significance, during various surgeries involving the colon, to avoid complications such as intraoperative hemorrhage and colonic ischemia.[46] Of particular interest is the variant artery recently described by Manyama *et al.*,[47] who reported a *middle mesenteric artery* arising from the ventral aspect of the aorta, between the superior and the inferior mesenteric arteries, and giving rise to several branches that supplied the distal part of the ascending colon, the transverse colon and the proximal part of the descending colon. Such a middle mesenteric artery gives rise to two branches, which have free anastomosis within the transverse mesocolon: the first branch ran transversal to the left to supply the proximal part of the descending colon, while the second branch ascended upwards between the layers of the transverse mesocolon, providing two branches to the distal part of the ascending colon and the transverse colon. The distribution of the second branch is similar to the distribution of the middle colic artery (normally originated from the superior mesenteric artery). In this case, the *marginal artery of Drummond* (*i.e.*, the anastomotic vessel running in the mesentery along the inner margin of the colon) is contributed by branches from the three mesenteric arteries. Variations in the vascular supply of the small and large intestines can best be understood by considering both their development and vascularization. During embryonic morphogenetic events, each of the two dorsal aortas gives rise to three sets of paired arterial branches.[48]

Subsequently, the dorsal aortas fuse, some ventral branches regress, and only three pairs of ventral vessels fuse to form the celiac artery and superior/inferior mesenteric arteries. Foregut-derived structures are supplied by the celiac artery, whereas the midgut and hindgut are supplied by the superior and inferior mesenteric arteries, respectively. The presence of an additional third mesenteric artery from the aorta, supplying the midgut and hindgut derivatives, could be due to the persistence of an extra ventral intersegmental artery.

At the end of this description, albeit partial, of the most frequent anatomical variants of the visceral branches of the abdominal aorta, it should be emphasized that the planning and execution of surgical interventions in the abdominal compartment cannot disregard preliminary in-depth preoperative investigations aimed at assessing the vascularization and relationships between the anatomical structures of interest, with the ultimate goal of highlighting any anatomical variants of the branches of the abdominal aorta that may represent opportunities for iatrogenic damage during surgical procedures, thus reducing morbidity, the risk of complications and mortality.

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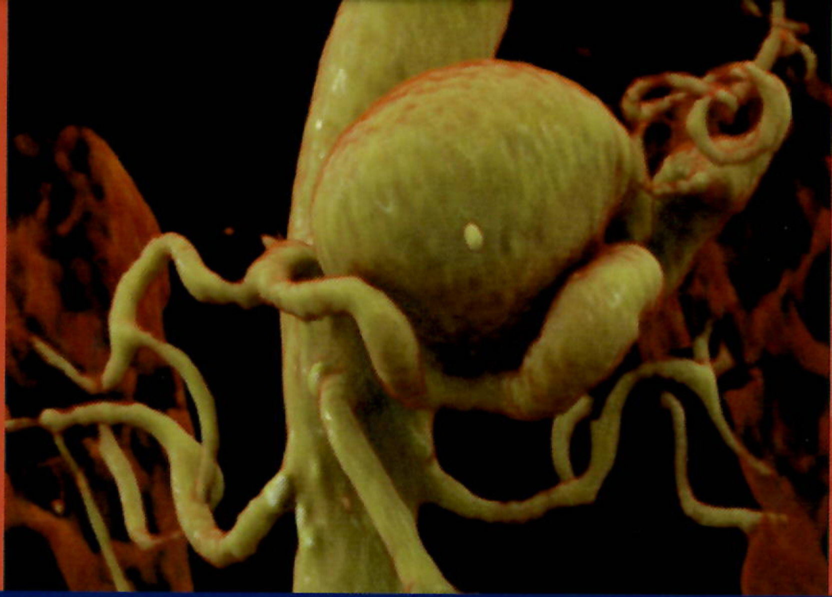

Visceral and renal artery aneurysms

Visceral and renal artery aneurysms are rare but life-threatening pathologies. Many techniques have been proposed for their treatment, and both open surgery and endovascular strategies have proven to be safe and effective. Many specialists can be involved in the treatment of these aneurysms, from vascular surgeons to interventional radiologists, and the knowledge of every different possible approach is fundamental to offer the patient the best outcome. In this book, all the aspects of visceral and renal artery aneurysms have been widely discussed, from epidemiology and anatomical variations to surgical approaches and materials. To conclude, the authors reported a large series of case reports from different experts in order to obtain a better vision of the real-world practice on this topic.

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