

# Branching Pattern Variations of the Celiac Trunk and Superior Mesenteric Arteries in a 94-Year-Old White Female Cadaver

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## ABSTRACT

Recognizing the presence of abdominal vascular anatomical variations in patients is imperative for surgeons who perform major abdominal surgeries, vascular interventionalists performing ablations or embolizations, and oncologists administering targeted chemotherapies. Neglecting to identify such variations can lead to significant patient morbidity and mortality. It is similarly important to anatomical instructors in the education of future medical providers. During cadaveric dissection of fifty-six cadavers, we observed several unique anatomical variations occurring within the major enteric vessels of the abdomen of a 94-year-old white female cadaver. These variations included a celiac trunk that gave rise to bilateral inferior phrenic arteries, the splenic artery, and a gastrohepatic artery that gave off the left gastric artery, an accessory left hepatic artery, and then continued as a common hepatic artery. Shortly from its origin, the common hepatic artery then trifurcated into a large gastroduodenal artery, the right hepatic artery, and the left hepatic artery. There was no definitive proper hepatic artery present. The accessory left hepatic artery gave off an accessory left gastric artery. The cystic artery derived directly from the superior mesenteric artery, and the middle colic artery arose from the gastroduodenal artery. The middle colic artery also had an accessory aberrant left colic artery branching from it. These anatomical variations described herein are of both clinical significance and academic consequence. While single anatomic variations are well described, the presence of multiple, complex variations in a single patient, such as those described here, is less common in the literature. To our knowledge, there are no other reports of this combination of variations in the literature to date. Operating surgeons and vascular interventionalists should be aware of these variants as they occur both individually and in combination while treating diverse patient populations. Accordingly, the developmental and clinical significance of these anomalous vessels is discussed here.

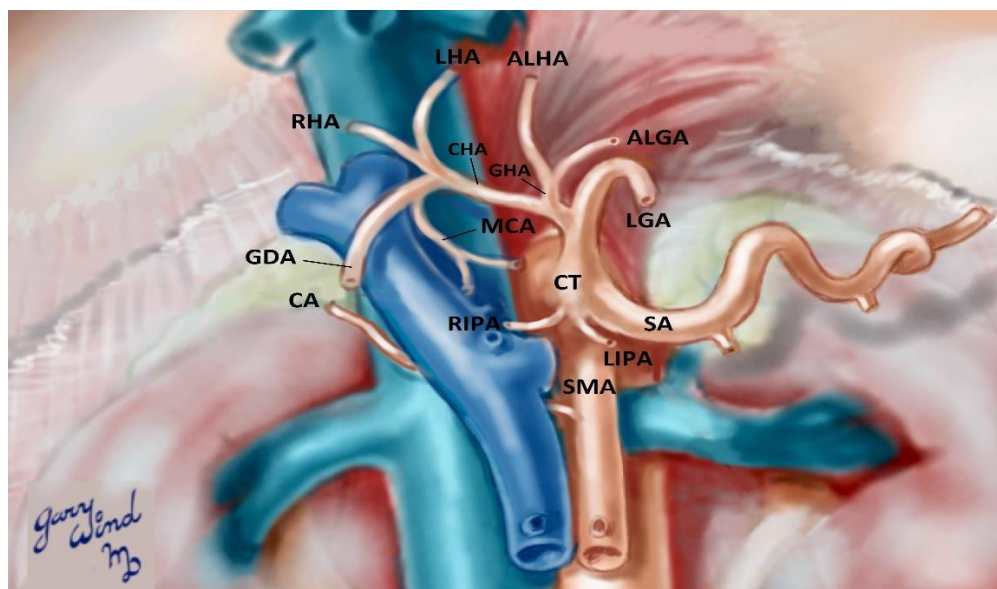
**Keywords:** Celiac trunk variations; Cystic artery variations; Superior mesenteric variations; Arterial branching variations; Replaced or aberrant left colic artery; Inferior phrenic artery variations; Accessory left hepatic artery; Accessory left gastric artery; Accessory aberrant left colic artery; Anatomical variations; Gastrointestinal anatomical variations

## INTRODUCTION

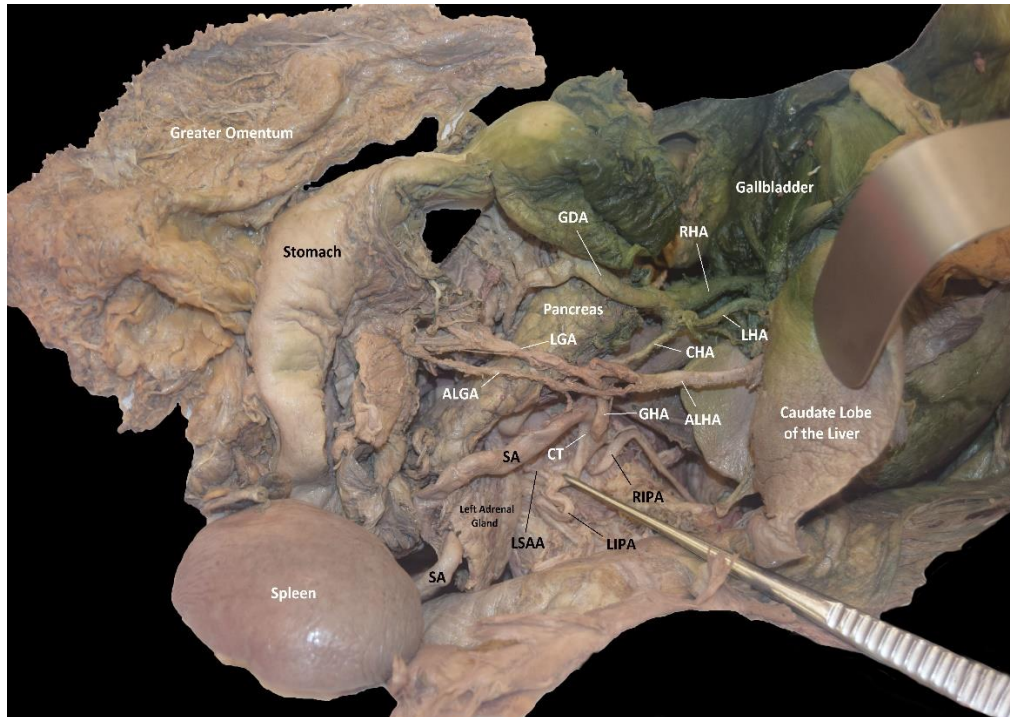
Variations in the arterial anatomy supplying the liver, gallbladder, and gastrointestinal tract have been well described as occurring individually. The coexistence of multiple variations in a single individual, however, is less observed. This article highlights numerous, simultaneous potential celiac trunk (CT) variations and superior mesenteric artery (SMA) variations. Clinical implications of aberrant or variant arterial anatomy have consequences for both abdominal surgery and chemoembolization of malignant lesions. Case studies of variations are of great importance to training surgeons and the instruction of anatomists alike to avoid iatrogenic complications and further compile demographic data to guide clinical decision-making. This case highlights the importance of the embryologic development of the ventral abdominal arterial system, knowledge of both common and uncommon variants by anatomical instructors and interventionalists, and potential implications on patient morbidity and mortality. During anatomical dissection of fifty-six cadavers in the 2019-2020 undergraduate medical and graduate nursing anatomy courses at the Uniformed Services University of the Health Sciences (USUHS), we found numerous, simultaneous potential celiac trunk (CT) and superior mesenteric artery (SMA) variations present in a preserved 94-year-old white female cadaver donated to the USUHS.

## CASE DESCRIPTION

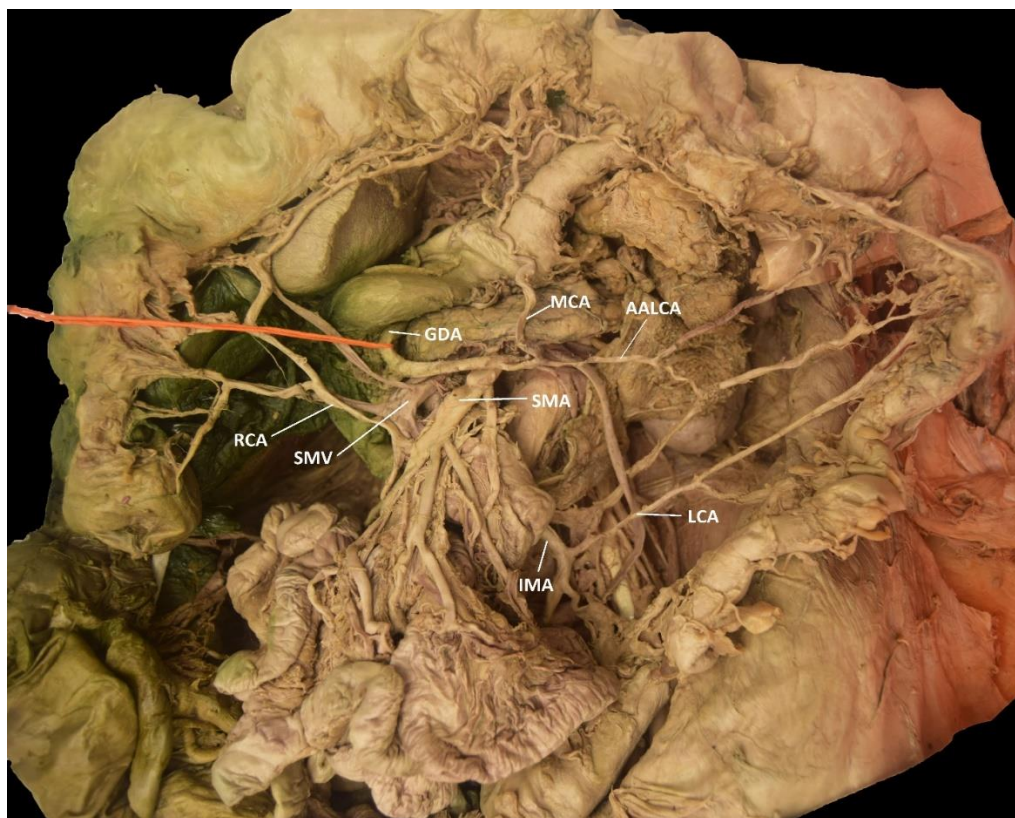
The branching pattern variations observed in the 94-year-old white female (listed cause of death of ischemic stroke) were as follows. The branches of the CT included the right inferior phrenic artery (RIPA), the left inferior phrenic artery (LIPA), a common trunk that gave rise to an accessory left hepatic artery (ALHA) and the left gastric artery (LGA), and a common trunk giving rise to the splenic artery (SA) and common hepatic artery (CHA). The ALHA also had an accessory left gastric artery (ALGA) branching from it. As the CHA became the proper hepatic artery (PHA), it gave off the following branches: the left hepatic artery (LHA), the right hepatic artery (RHA), and the gastroduodenal artery (GDA). The GDA had a common trunk branching from it that included the middle colic artery (MCA) and an accessory aberrant left colic artery (AALCA) (**Figures 1-3**). The AALCA assisted the marginal artery (MA) in supplying the distal third of the transverse colon and splenic flexure. The SMA gave rise to the cystic artery (CA), right colic artery (RCA), ileocolic artery (ICoA), and the ileal-jejunal arteries (I-JAs) (**Figure 4**).



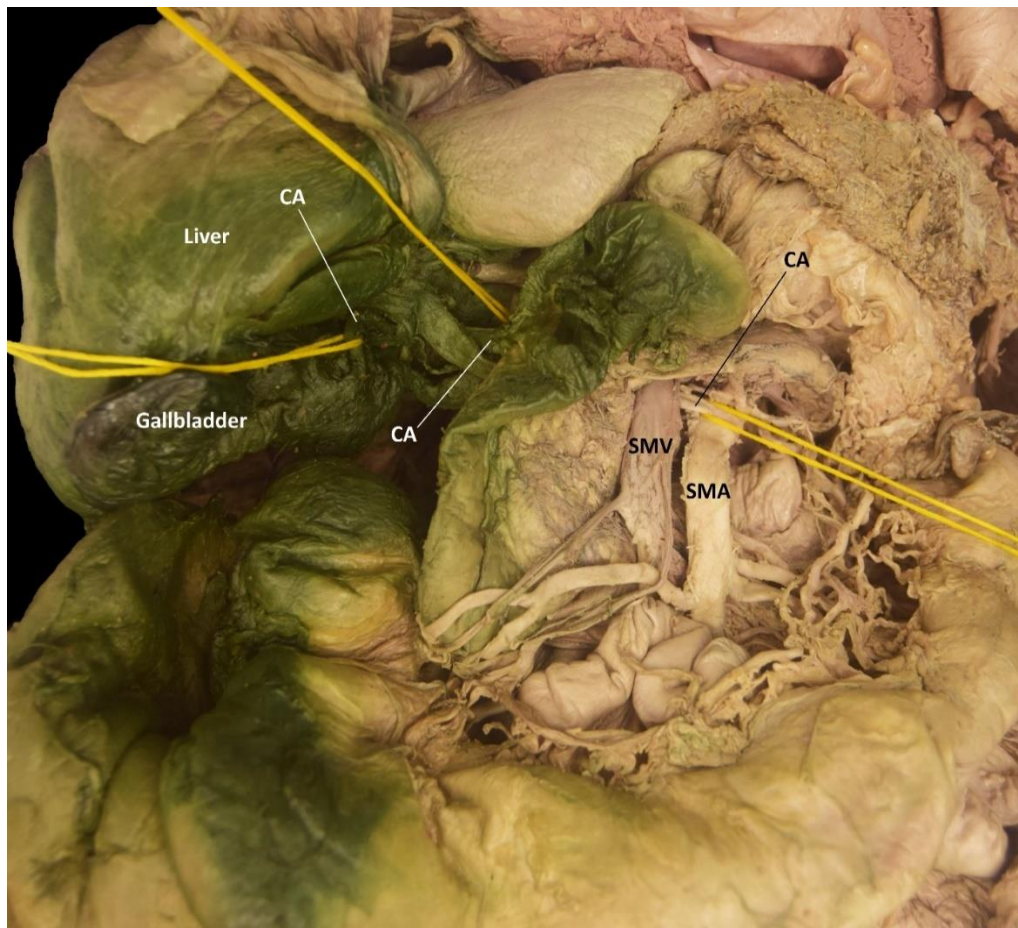
**Figure 1:** Illustrative schematic of the vascular variations found with the celiac trunk and superior mesenteric arteries. ALGA = Accessory Left Gastric Artery; ALHA = Accessory Left Hepatic Artery; CA = Cystic Artery; CHA = Common Hepatic Artery; CT = Celiac Trunk; GDA = Gastroduodenal Artery; GHA = Gastrohepatic Artery; LGA = Left Gastric Artery; LHA = Left Hepatic Artery; LIPA = Left Inferior Phrenic Artery; MCA = Middle Colic Artery; RHA = Right Hepatic Artery; RIPA = Right Inferior Phrenic Artery; SA = Splenic Artery; SMA = Superior Mesenteric Artery.



**Figure 2:** Facilitated display highlighting the celiac trunk variations. ALGA = Accessory Left Gastric Artery; ALHA = Accessory Left Hepatic Artery; CA = Cystic Artery; CHA = Common Hepatic Artery; CT = Celiac Trunk; GDA = Gastroduodenal Artery; GHA = Gastrohepatic Artery; LGA = Left Gastric Artery; LHA = Left Hepatic Artery; LIPA = Left Inferior Phrenic Artery; LSAA = Left Superior Adrenal Artery; RHA = Right Hepatic Artery; RIPA = Right Inferior Phrenic Artery; SA = Splenic Artery.



**Figure 3:** Facilitated display highlighting the superior mesenteric artery variations. AALCA = Accessory Aberrant Left Colic Artery; GDA = Gastroduodenal Artery; IMA = Inferior Mesenteric Artery; LCA = Left Colic Artery; MCA = Middle Colic Artery; RCA = Right Colic Artery; SMA = Superior Mesenteric Artery; SMV = Superior Mesenteric Vein.



**Figure 4:** Facilitated display of the branching pathway of the cystic artery as it branched from the superior mesenteric artery. CA = Cystic Artery; SMA = Superior Mesenteric Artery; SMV = Superior Mesenteric Vein.

## DISCUSSION

Variations in the number and branching patterns of the celiac-mesenteric arterial system have been described extensively. These variations typically occur independently and are described as single entities. The coexistence of multiple variations in a single individual, however, is less common in the literature. Here, we have described variations in branching of the CT and SMA that occurred in a single case study.

The importance using anatomical landmarks to identify the arterial vessels supplying abdominal organs was emphasized by J.F. Calot in 1891 [1]. He highlighted in particular those of the CA during cholecystectomy. Since then, variations in enteric circulation have been characterized to inform clinical decision making and guide surgical approaches. In-depth knowledge of branching patterns of these arteries is important for surgeons and anatomists alike.

### CELIAC TRUNK (CT) BRANCHING VARIATIONS

The CT classically arises as the first ventral branch of the abdominal aorta at the level of the T12 and L1 vertebrae and inferior to the esophageal hiatus of the diaphragm. The CT typically supplies the foregut, comprising the stomach, spleen, pancreas, liver, and part of the duodenum [2-28]. In order to supply these organs, the trunk travels forward in a horizontal plane and trifurcates into the LGA, CHA, and SA.

This branching pattern, however, can vary. Multiple authors have classified potential variations [2,14,27,29-34], with patterns ranging from two to six distinct branches [35]. When these variations occur in lieu of the typical branches, they are known as replaced or aberrant branches [4]. They are known as accessory branches when they occur alongside the usual LGA, CHA, and SA [4]. Variations in branching patterns include the inferior phrenic arteries [36], and superior adrenal arteries, while left or right middle adrenal, dorsal pancreatic, RHA, accessory hepatic, and MCA have also been described [4,5,26,37,38]. Clinical awareness of the variant origins of these arteries is important for surgeons approaching the stomach, duodenum, pancreas, hepatobiliary region, liver transplantation, and chemoembolization of pancreatic and hepatic tumors [37].

Vascular variations as a whole are understood to correlate with embryologic development. The arterial supply for the abdominal alimentary organs develops segmentally with paired ventral splanchnic arteries diverging from the paired dorsal aortae [2,4,5,10-12,14,22,34,37,39-46].

These paired ventral splanchnic arteries fuse into unpaired trunks after the fusion of the dorsal aortae, ultimately supplying the primitive digestive tube. Dorsal and ventral splanchnic anastomoses connect these trunks longitudinally along the dorsal and ventral aspects of the tube. The arterial supply to the digestive tube is simplified and transformed in the later stages of development into three systems of arteries. These supply the foregut, midgut, and hindgut as the CA, SMA, and inferior mesenteric arteries respectively [45].

However, abnormal fusion of the ventral branches of the dorsal aortae may result in variations including formation of celiaco-mesenteric, celiaco-mesentericophrenic, or hepatomesenteric trunks [3-5,37,47]. These variations of the celiac trunk were classified by Michels into six key types [47]. The variation described in this article most closely resembles Type V given the presence of an accessory left hepatic artery. However, this classification does not account for the accessory right and left inferior phrenic arteries arising from the CT in this case (**Figures 1 and 2**). The presence of bilateral inferiophrenics has been described in 13-51% of cases, as described by Toro and colleagues in 2017 [36].

Furthermore, the case reported here describes the presence of an ALGA arising from an ALHA, which is likewise not accounted for in Michels' classification schema. In 2006, Ishigami and colleagues detected the presence of a LGA originating from the LHA in 21% of patients receiving in a cohort study comparing the diagnostic accuracy of multiphase contrast-enhanced CT and CT during angiography with intra-arterial injection of contrast (n=118) [48]. This is in contrast with the incidence reported by Nakamura (14.2%) and Michels (3.0%) [49,50]. An awareness of these reports is clinically significant because an ALGA may mistakenly be identified as an intrahepatic branch of the LHA during prophylactic embolization prior to hepatic arterial infusion chemotherapy [48,49,51]. Additionally, Kim and colleagues (2016) noted that identification and preservation of large diameter (>5 mm) ALHA during laparoscopic gastrectomy correlated with improved hepatic function in the postoperative period, suggesting further clinical implications for the study and recognition of these variations [52].

Additional variations in CT anatomy noted in this case include the MCA, which is usually a branch of the SMA, arising from the GDA. Further discussion of this variation is included below.

## REPLACED CYSTIC ARTERY

The SMA classically originates at the lower third level of L1 vertebrae as the second branch of the abdominal aorta and branches into the inferior pancreaticoduodenal artery, MCA, right colic artery and ileocolic artery. With these branches, the SMA supplies blood to parts of the duodenum and pancreas, the small intestines, and the left third of the transverse colon [31,38,53]. Like those of the CT discussed above, the SMA can present with variations in location, number, and branching patterns [2,3,5,6,18,21,25,31,34,35,50,54-66].

Indeed, the classic branching pattern was only found to occur in 22-33% of cadavers assessed by various researchers [3,33,56]. Variations can potentially include normal branches or sub-branches of the CT as well as accessory branches such as a dorsal pancreatic artery that typically arises from other abdominal arteries [33,67,68].

The variation described in this article is the presence of the CA from the SMA (**Figure 4**). The CA classically originates from the RHA in Calot's triangle, reaching the gallbladder by traversing posterior to the cystic duct. Variations in the origin of the CA have been described, however, with the CA arising from the PHA in 22% of cases and GDA in 8% [69] and 3% of cases [70]. Pushpalatha (2010) noted the CA to arise from the SMA in 2% of cases, while Anson (1963) and Michels (1965) found no occurrences of such variation in their separate studies [50,71,72].

During embryogenesis, the extrahepatic biliary system arises from an intestinal diverticulum, which carries a supply of blood vessels from the aorta, CT, and SMA. The majority of these vessels are later absorbed, thereby leaving behind a mature vascular system. However, the pattern in which these blood vessels are absorbed can vary. Recognition of the possible variations in CA anatomy is important for the approach to surgical resection of the gallbladder.

During laparoscopic cholecystectomy in particular, dissection is limited to a field visible by a laparoscope magnified on a video monitor. Therefore, detailed understanding of possible CA variations and variations in its branches is critical for proper identification and ligation of the vessel intraoperatively.

## REPLACED MIDDLE COLIC ARTERY (MCA)

The MCA typically originates from the SMA in 78-99% of cases and supplies the transverse colon [2,3,42,50,56,73-77]. Despite this, there are numerous reports in the literature of variations in course, origination, and number. The MCA derives from the SMA, with the uncinat process of the pancreas superiorly, the third part of the duodenum posteriorly [2,12,44,73,74,76,78]. It divides into left and right branches after traversing the transverse mesocolon inferiorly.

As discussed above, celiacomesenteric anatomy variations are well documented in the literature. However, we were only able to identify three previously reported cases of MCA arising from the GDA [44,79]. Our case presented a MCA that arose from the GDA (**Figures 1 and 2**).

Previously described MCA variant anatomy includes: replaced MCA arising from the SA, CHA, inferior mesenteric artery, inferior pancreaticoduodenal artery, and aorta [77,79-81]; absent MCA [77]; and accessory MCA [77].

Indrajit et al. (2013) detailed two cases similar to our case study, in which the MCA arose directly from the GDA [44]. In the first case, the researchers noted the GDA supplied the right and middle part of the transverse colon in addition to its usual branches. In the second case, the GDA likewise supplied the hepatic flexure and right part of the transverse colon in addition to its normal branches. Kwong et al. (2019) reported a similar finding intraoperatively during a Whipple procedure, which further emphasizes the clinical importance of recognizing vascular anomalies and careful technical dissection intraoperatively [79].

Notably, the cases reported by Indrajit et al. (2013), Kwong et al. (2019), and our case study all involved female cadavers [44,79]. The rarity of this anatomical variant in combination with the concurrence of reported female cases serves as mounting evidence that female sex may be a predilection for this condition. Knowledge of anomalous foregut and midgut vasculature is necessary to prevent injury to these vessels during surgical and intravascular intervention on these regions.

Our case study also had an AALCA that derived from the replaced MCA. In our review of the literature, there is a discordance of nomenclature surrounding this structure as evidenced by Ito et al. (2019) [82]. These researchers asserted that the terms ‘superior left colic artery,’ ‘left accessory aberrant colic artery,’ and ‘accessory left colic artery’ are different terms for accessory middle colic arteries. The term “superior left colic artery” was first coined by Koizumi et al (1990) [83]. Koizumi and colleagues observed this artery in 32 of 65 specimens studied (49.2%) [83]. They proposed, in the presence of a superior left colic artery, referring to the LCA by the name “inferior left colic artery” [83]. Koizumi et al. (1990)’s description of this variance mimics the anatomical relationship of the MCA and the additional artery present in our case study.

Rusu and colleagues (2008) challenged this designation after surveying seven similar studies in comparison to their own superior left colic artery, which derived from the SMA [3,56,80,83-85]. Rusu et al. (2008) suggests that if the artery derives from an origin other than the IMA or its network, it ought to be called “aberrant” [84]. They termed their discovered variant “left accessory aberrant colic artery.” In light of these recommendations, we agree with Rusu et al. (2008)’s designation since our additional artery does not derive from the IMA, but provides blood supply to the distal third of the transverse colon and the splenic flexure.

This necessitates that the superior left colic artery discovered in our case study, which derives its origin from a common trunk with the MCA that arose from the GDA, rather than directly from the SMA, should be called “accessory aberrant left colic artery (AALCA).” We believe this to be the most accurate description of this variant anatomy, as the hindgut receives its vascular supply from foregut vasculature.

## CONCLUSION

The presence of several vascular anomalies a 94-year-old white female cadaver emphasizes the importance of anatomical study for future health care providers, preoperative diagnostic imaging before surgical intervention, and intraoperative awareness of the array of vascular anomalies that can be present. The frequency for these variations to occur independently in one individual is estimated to be extremely low. It is more likely, then, that these variations are due to disruptions in the embryonic development of the enteric circulation, causing the combination of rare arterial variations presented in the current case. Accordingly, the case described herein further adds to the growing list of existing complex variations in the celiac-mesenteric arterial system.

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