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REVIEW ARTICLE

Vascular anatomy of the splenic flexure: a review of the literature

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Abstract
Surgical treatment of the transverse colon is difficult because of the many variations of blood vessels. We reviewed the patterns of vascular anatomy and the definition of the vessels around the splenic flexure. We searched the PubMed database for studies on the vascular anatomy of the splenic flexure that were published from January 1990 to October 2020. After screening of full texts, 33 studies were selected. The middle colic arteries were reported to arise independently without forming a common trunk in 8.9–33.3% of cases. The left colic artery was absent in 0–7.5% of cases. The accessory middle colic artery was present in 6.7–48.9% of cases and was present in > 80% of cases without a left colic artery. The reported frequency of Riolan's arch was 7.5–27.8%. The frequency was found to vary widely across studies, partially due to the ambiguous definition of Riolan's arch. A comprehensive preoperative knowledge of the branching patterns of the middle colic artery and left colic artery and the presence of collateral arteries would be helpful in surgery for colon cancer in the splenic flexure.

Keywords Accessory middle colic artery · Left colic artery · Riolan's arch · Anatomy · Splenic flexure

Introduction

Laparoscopic surgery for colon cancer has been widely adopted following the demonstration of comparable survival and complication rates between laparoscopic and open colectomy by several randomized control studies [1–4]. However, surgery for the transverse colon was excluded from these studies because of technical challenges, including the many variations of blood vessel branching patterns and the close proximity of the transverse mesocolon to the pancreas and duodenum. Complete mesocolic excision and central ligation are important for improving overall survival after colectomy [5]. Therefore, it is critical to have a comprehensive understanding of the anatomy of area of interest before laparoscopic surgery, which requires a narrow field of view.

The vascular anatomy for splenic flexure varies among individuals. The blood flow of the splenic flexure is usually supplied by the left colic artery (LCA) and the left branch of the middle colic artery (MCA).The mesentery around the splenic flexure is known as the avascular area, and the blood flow from the marginal artery around the splenic flexure, called Griffiths' point, is sometimes insufficient [6]. There are several collateral arteries, such as the marginal artery of Drummond, the Moskowitz artery, and Riolan's arch. Riolan's arch is a well-known artery that connects the inferior mesenteric artery (IMA) to the superior mesenteric artery (SMA). The accessory MCA (AMCA), which has been recently recognized as an important source supplying the splenic flexure, typically originates from the SMA, running below the pancreas and toward the splenic flexure [7]. Central ligation of the AMCA may contribute to reduced cancer recurrence because indocyanine green fluorescence shows lymphatic flow along the AMCA [8]. These arteries are also important for supplying blood flow to the sigmoid colon after the high ligation of IMA. However, the anatomy of these arteries varies among individuals. The AMCA sometimes originates from the celiac, splenic, or first jejunal arteries. The LCA is absent in some individuals, and the left and right MCA branches sometimes originate separately from the SMA without forming a common MCA trunk. The definition of Riolan's arch is also confusing because of varied definitions used across studies.

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A complete understanding of the anatomy of these vessels is critical to prevent intraoperative injury and postoperative intestinal ischemia. In the present study, we review the patterns of vascular anatomy and the definitions of the vessels around the splenic flexure.

Literature search

We conducted an electronic literature search using the PubMed database to identify studies discussing the vascular anatomy of the splenic flexure that were published between January 1990 and October 2020. The following keywords were used: "anatomy" and "middle colic artery," "left colic artery," or "Riolan's arch". Case reports, editorials, letters, and commentaries were excluded. The initial search identified 243 publications; after title and abstract screening, 37 studies remained. After full-text screening, 33 studies that remained were included in the present study, which was conducted in accordance with the PRISMA guidelines (Fig. 1). Written informed consent was obtained from the subjects to use their 3D-CT angiography images. This study was approved by the ethics committee of the University of Tokyo (Approval No. 3252-10).

Left colic artery

The LCA, the first branch of the IMA, runs toward the descending colon. The reported branching patterns of LCA, as summarized in Table 1 and shown in Fig. 2, are as follows:

Type 1: LCA arising independently from the sigmoid artery (SA).

Type 2: LCA and SA arising from the same point of the IMA.

Type 3: LCA and SA sharing a common trunk.

Type 4: Absence of the LCA.

Type 1 was the most frequently reported pattern, but the LCA and SA shared a common trunk with nearly the same frequency. The LCA was absent in 0–7.5% of cases [6, 9–22]. One reason for the varying frequency of the absence of the LCA among studies was differences in the definition of the LCA. The LCA was present in all cases where it was defined as the first IMA branch. When the LCA was defined as an artery that originated from the IMA and supplied the descending colon, the frequency of its absence ranged from 2.8 to 7.5% (mean, 5.0%).

In many cases, the LCA ran along the inferior mesenteric vein (IMV) and supplied the splenic flexure. The part of the LCA running toward the splenic flexure was sometimes termed the ascending branch of the LCA (ALCA), whereas the LCA branch to the descending colon was termed the descending branch (Fig. 3a). Multiple branches were often recognized (Fig. 3b) [23]. Michels et al. referred to the other

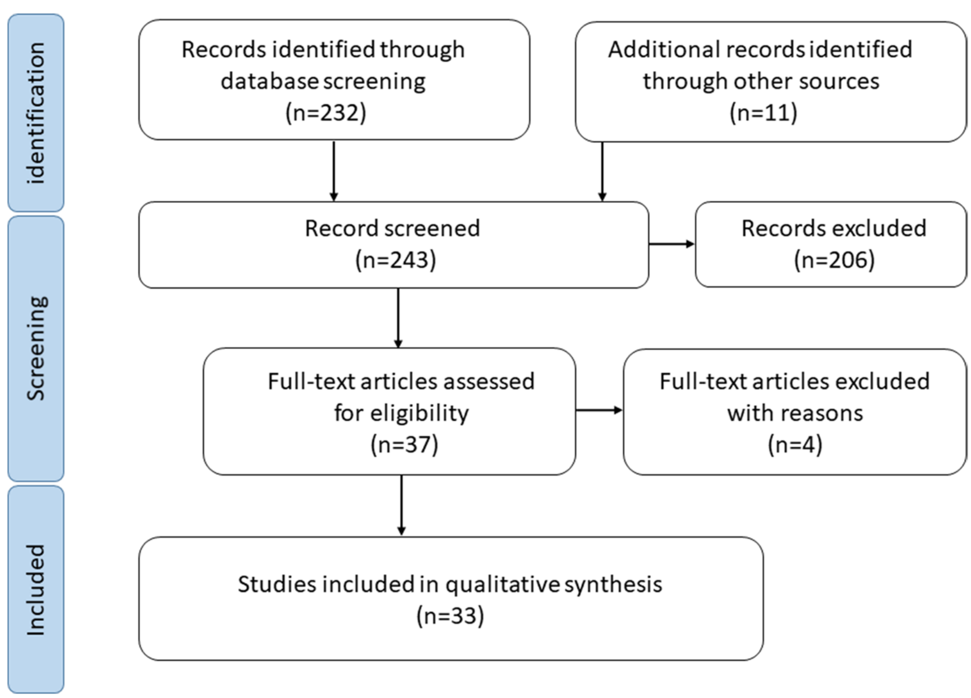


Fig. 1 Flow diagram for the selection of articles

Table 1 Branching patterns of the left colic artery

	Number	Type 1	Type 2	Type 3	Type 4
Dissecting cadaver					
Griffiths et al. 1956 [6]	100	41 (41%)	8 (8%)	45 (45%)	6 (6%)
Kahn et al. 1964 [9]	142	57 (40%)	85 (60%)		
Balcerzak et al. 2020 [10]	40	24 (60%)	10 (25%)	6 (15%)	0
Intraoperative finding					
Wang et al. 2018 [11]	110	51 (46.4%)	26 (23.6%)	33 (30.0%)	
Zhang et al. 2020 [12]	106	63 (59.5%)	9 (8.5%)	31 (29.2%)	3 (2.8%)
Angiographic examination					
Yada et al. 1997 [13]	260	151 (58%)	39 (15%)	70 (27%)	0 (0%)
Predescu et al. 2013 [14]	49				
Zhang et al. 2020 [15]	154	68 (44.2%)	26 (16.9%)	54 (35.1%)	6 (3.9%)
3D-CT angiography					
Kobayashi et al. 2006 [16]	82	27 (32.9%)	10 (12.2%)	45 (54.9%)	
Bertrand et al. 2014 [17]	93	44 (47.3%)	17 (18.3%)	25 (26.9%)	7 (7.5%)
Murono et al. 2015 [18]	468	193 (41.2%)	42 (9.0%)	209 (44.7%)	24 (5.1%)
Patroni et al. 2016 [19]	113	80 (71%)	33 (29%)		
Miyamoto et al. 2016 [20]	46	20 (43.4%)	5 (10.9%)	21 (45.6%)	
Ke et al. 2017 [21]	188	89 (47.3%)	39 (20.7%)	51 (27.1%)	9 (4.8%)
Iguchi et al. 2020 [22]	96	19 (19.8%)	77 (80.2%)	0 (0%)	
Total	2047	927	1016		55

Type 1: the left colic artery (LCA) arises independently from the sigmoid artery (SA); Type 2: the LCA and SA arise from the IMA at the same point; Type 3: the LCA and SA have a common trunk; Type 4: deficit of the LCA

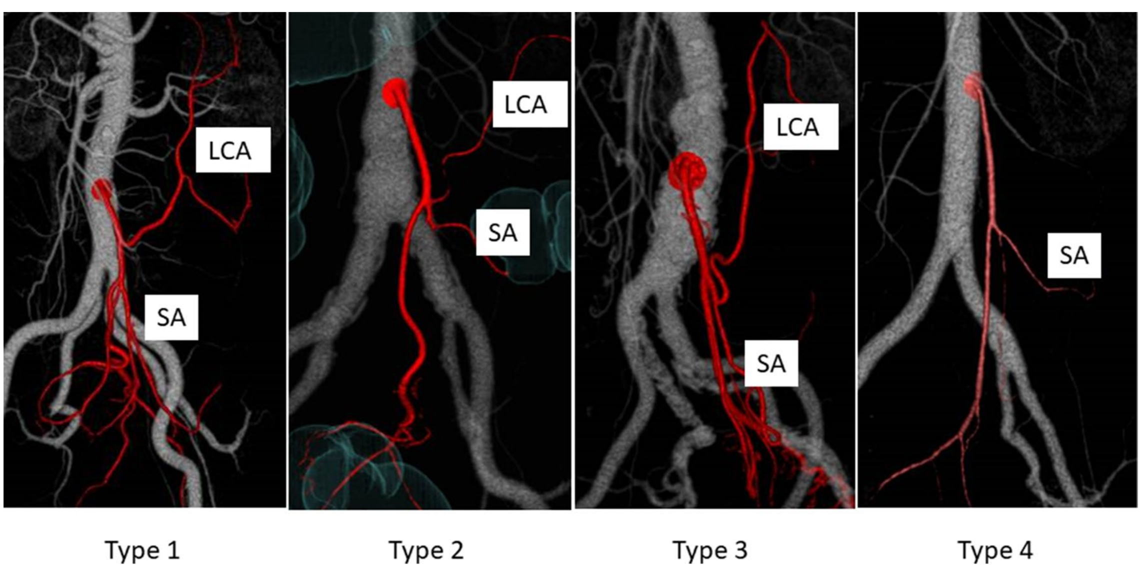
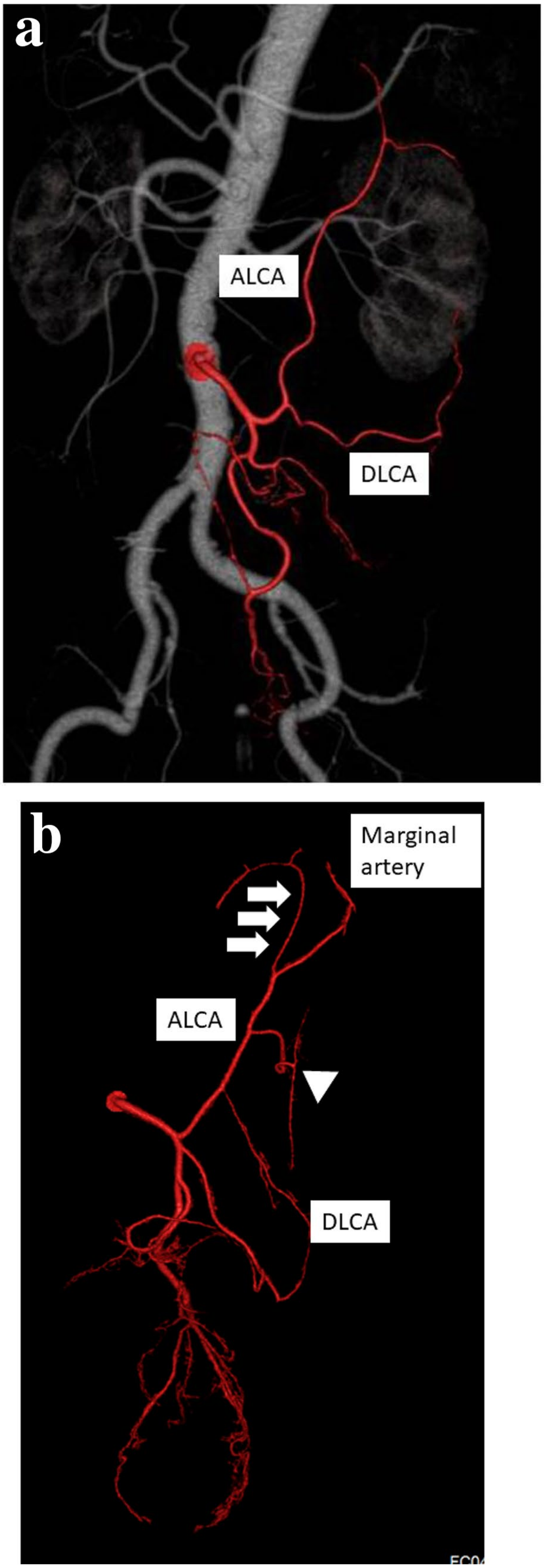


Fig. 2 Branching patterns of the left colic artery (LCA). Type 1, the LCA arises independently from the sigmoid artery (SA); type 2, the LCA and SA arise from the same point of the inferior mesenteric artery (IMA); type 3, the LCA and SA share a common trunk; type 4, absence of the LCA

LCA branch as the middle branch of the LCA, which was reported in 38% of cases [24].

The ALCA, which usually supplies the splenic flexure, sometimes terminates in the marginal artery of the transverse colon. Yano et al. reported that the frequency of the ALCA was 14.7% (Table 2) [25]. The LCA accompanied the IMV to the cranial side of the origin of IMA in 53.7–80.3% of cases, and the LCA supplied the splenic flexure in 76–86% of cases (Table 2) [21, 24–28]. The LCA, not the MCA, was the main lymphatic flow from the splenic flexure according



◂**Fig. 3** The anatomy of the left colic artery (LCA) **a** The LCA typically runs along with inferior mesenteric vein and supplies the splenic flexure. The branch to the splenic flexure is called the ascending branch of the LCA (ALCA). The branch of the LCA connecting to the marginal artery of the descending colon is called the descending branch of the LCA. **b** Multiple branches of the LCA. The second branch (triangle) is sometimes called the middle branch of the LCA. Distinguishing the terminal branch of the ALCA (arrow) from Riolan's arch is difficult

Table 2 The watershed of the left colic artery

	Number	ALCA present	ALCA supply to T/C* or SF*
Dissecting cadaver			
Sinkeet et al. 2013 [26]	57	32 (55.5%)	44 (76%) (SF)
Michels et al. 1965 [24]	127		109 (86%) (SF)
3D-CT angiography			
Yano et al. 2020 [25]	143	113 (79.0%)	21 (14.7%) (T/C)
Ke et al. 2017 [21]	188	151 (80.3%)**	
Fukuoka et al. 2017 [27]	191	103 (53.7%)	
Miyake et al. 2018 [28]	734	483 (65.8%)**	

ALCA ascending branch of left colic artery, *T/C* transverse colon, *SF* splenic flexure

**The ALCA was defined as the left colic artery running toward the upper level of the origin of the inferior mesenteric artery

to a study using ^{99m}technetium [29]; therefore, central ligation of the LCA is important during surgery for cancer in the splenic flexure.

Middle colic artery

The MCA is the first branch of the SMA and supplies the transverse colon. The MCA usually divides into right and left branches, with the right branch usually running toward the hepatic flexure. The right and left branches of the MCA were reported to arise independently from the SMA without forming a common trunk in 8.9–33.3% of cases [7, 13, 22, 30] (Table 3); this difference might be related to differences in the definition of MCA among the reports. In some studies, the AMCA was included in the determination of the MCA frequency. The origin of the MCA is often separate from the root of the middle colic vein (MCV). Typically, the right MCV flows into the gastrocolic trunk of Henle and the left MCV flows into the superior mesenteric vein (SMV) [30].

Table 3 The branching pattern of the middle colic artery

	Number	Left branch originate independently	Presence of AMCA	Deficit of left branch of MCA
Dissecting cadaver				
Sonneland et al. 1958 [7]	600	50 (8.3%)	52 (8.6%)	
Koizumi et al. 1990 [34]	65		32 (49.2%)	
Intraoperative finding				
Watanabe et al. 2017 [8]	31		12 (38.7%)	
Ueki et al. 2019 [30]	42	14 (33.3%)	6 (14.3%)	
Angiographic examination				
Yada et al. 1997 [13]	273	113 (41.3%)		
3D-CT angiography				
Fukuoka et al. 2017 [27]	191		13 (6.7%)	
Miyake et al. 2018 [28]	734	65 (8.9%)	267 (36.4%)	34 (4.6%)
Tanaka et al. 2019 [35]	88	8 (9.1%)	27 (30.7%)	5 (5.7%)
Ito et al. 2019 [36]	112		31 (27.7%)	
Iguchi et al. 2020 [22]	96	16 (16.7%)	33 (34.4%)	4 (4.1%)
Yano et al. 2020 [25]	143		70 (48.9%)*	
Murono et al. 2020 [37]	205		74 (36.1%)	9 (4.4%)

AMCA accessory middle colic artery

*Including the AMCA branched from inferior mesenteric artery

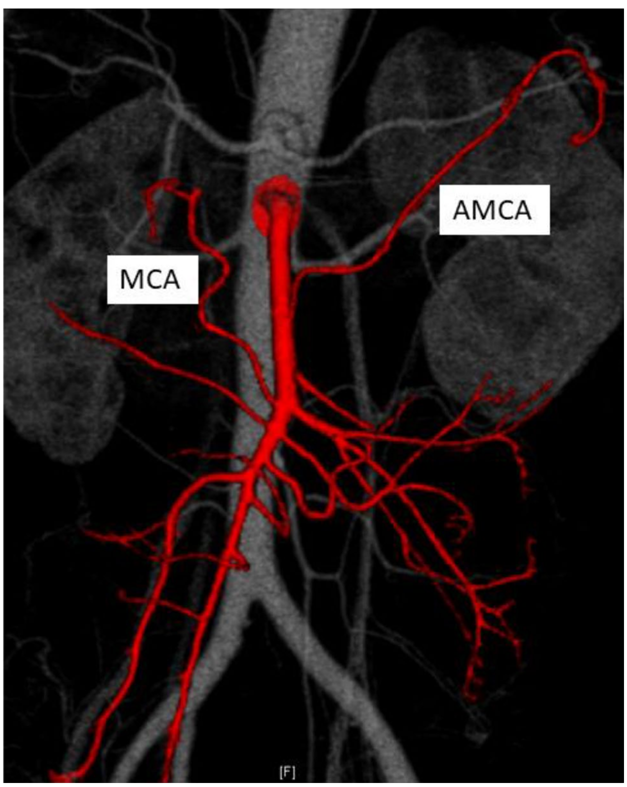


Fig. 4 The accessory middle colic artery (AMCA). The AMCA typically originates from the superior mesenteric artery proximal to the middle colic artery and runs below the pancreas toward the splenic flexure

The association of the first jejunal vein and SMA should be evaluated when dissecting lymph nodes around the root of MCA, given that the first jejunal vein was reported to be located ventrally to the SMA in 21% of cases [31].

Accessory middle colic artery

Typically, the AMCA originates from the SMA proximal to the MCA and runs below the pancreas toward the splenic flexure (Fig. 4). However, the AMCA was rarely reported to originate from the celiac, splenic, and first jejunal arteries [13, 25, 28, 32]. One study reported that the AMCA originated from the IMA [25]; however, distinguishing the AMCA from the LCA was difficult in that case (Fig. 5). The AMCA is sometimes called the accessory LCA or left accessory (aberrant) colic artery [8, 31–33]. The AMCA was present in 6.7–48.9% of cases (Table 3) [7, 8, 25, 27, 28, 34–37]. The AMCA and LCA might be complementary arteries, because the AMCA was present in more than 80% of cases without an LCA [28]. The AMCA shared a common trunk with the pancreatic artery in 8.9–20.2% of cases [28, 36], and the root of the AMCA was hidden behind the pancreas in 7.3% of cases [37]. Therefore, it is necessary to perform imaging studies to determine the positional relationship between the AMCA and the pancreas to avoid injury during surgery.

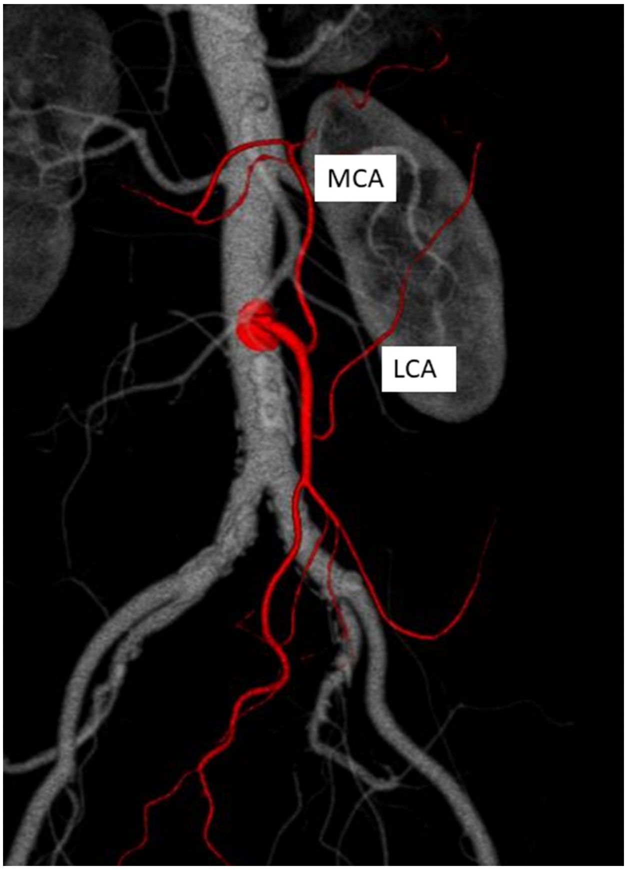


Fig. 5 A rare case of a middle colic artery branching from the inferior mesenteric artery

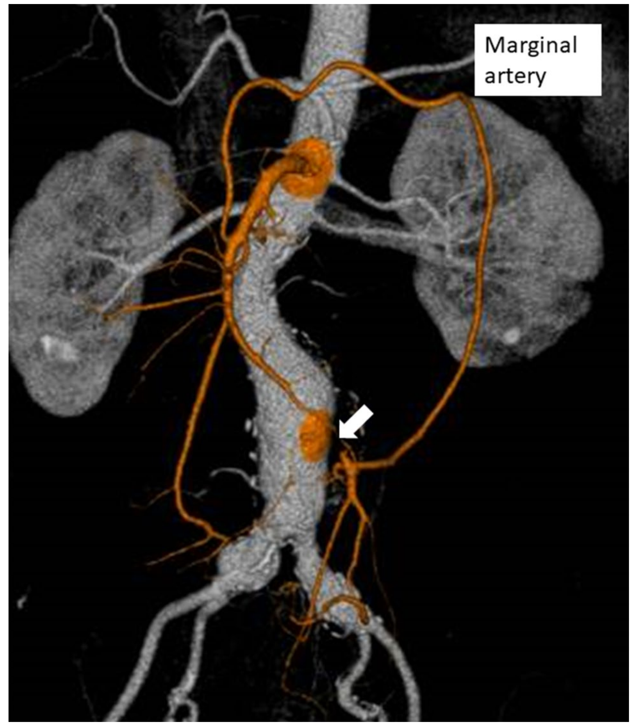


Fig. 6 Hypertrophy of the marginal artery. The origin of the inferior mesenteric artery (triangle) was occluded in this case. Hypertrophy of the marginal artery or left colic artery is often observed in cases of occlusion/stenosis of the inferior or superior mesenteric artery

Distinct from the MCA, the vein accompanying the AMCA flows mainly into the IMV, not the SMV. Therefore, understanding the anatomy and branching patterns of the IMV is necessary to perform central vessel ligation. The IMV was reported to flow into the SMV in 29.2–47.6% of cases and into the splenic vein in 48.5–70.8% of cases [22, 31, 37, 38]. Arimoto et al. defined the drainage vein from the splenic flexure running below the pancreas as the splenic flexure vein (SFV) [38], which usually accompanied the AMCA. The SFV was present in 75.0–86.3% of cases, which was much higher than the frequency of AMCA [22, 37, 38] (Table 4). In most cases without the AMCA, the ALCA was the companion artery [37]. Therefore, the IMV should be dissected immediately below the pancreas to include the section where the SFV joins the IMV and the entire length of the ALCA [37].

Riolan's arch

Riolan's arch is defined as the structure providing the communication between the SMA and IMA [39]. The connection of the SMA and IMA by the marginal artery is sometimes

Table 4 The branching pattern of the inferior mesenteric vein and splenic flexure vein

	Number	IMV returned to SMV	IMV returned to splenic vein	SFV present	SFV returned to splenic vein
3D-CT angiography					
Hamabe et al. 2018 [31]	105	50 (47.6%)	53 (50.5%)		
Murono et al. 2019 [37]	205	94 (45.9%)	111(54.1%)	177 (86.3%)	
Arimoto et al. 2019 [38]	66	27 (40.9%)	32 (48.5%)	64 (97%)	2 (3.1%)
Iguchi et al. 2020 [22]	96	28 (29.2%)	68 (70.8%)	72 (75.0%)	3 (3.1%)

IMV inferior mesenteric vein, *SMV* superior mesenteric vein, *SFV* splenic flexure vein

Table 5 The connective artery between the left colic artery and middle colic artery

	Number	Drummond	Riolan	ALCA(Moskowitz)	Any connective artery
Cadaver					
Garcia-Granero et al. 2017 [42]	27	27 (100%)	5 (18%)	3 (11%)	
Angiographic exam					
Zhang et al. 2020 [15]	154	154 (100%)	38 (24.7%)	35 (22.7%)	104 (67.5%)
Intraoperative finding					
Toh et al. 2018 [43]	Unknown		17.8%		
3D-CT					
Xie et al. 2015 [41]	626		47 (7.5%)		
Yano et al. 2020 [25]	143			21 (14.7%)	
Karatay et al. 2020 [44]	115	115 (100%)	32 (27.8%)		

ALCA ascending branch of left colic artery

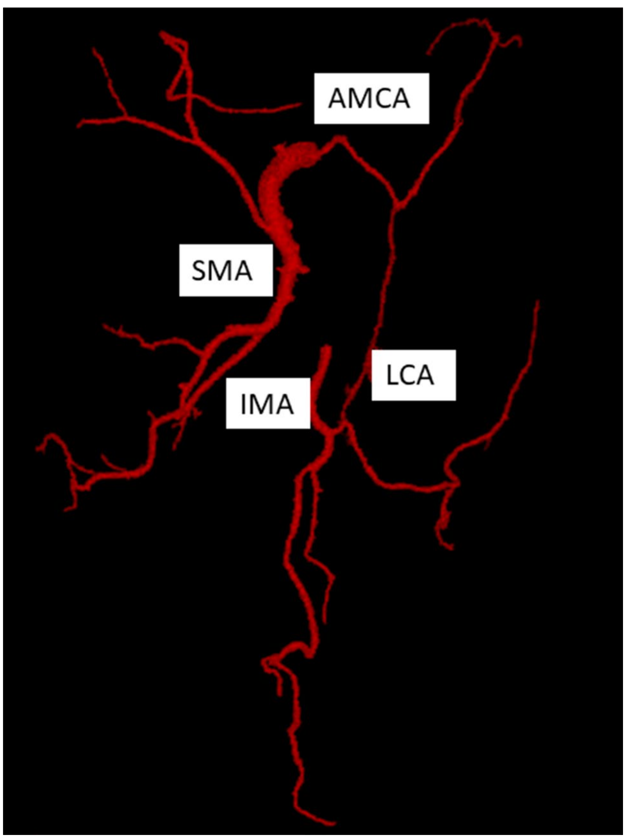


Fig. 7 A connective artery between the accessory middle colic artery and the left colic artery

insufficient at the splenic flexure, which is called Griffiths' critical point [6]. Riolan's arch, which is also called the meandering mesenteric artery, is an important collateral artery in these cases [40]. However, the definition remains confusing. Hypertrophy of the marginal artery is often observed in patients with IMA occlusion (Fig. 6). Although sometimes recognized as Riolan's arch, the marginal artery is usually called the marginal artery of Drummond, whereas Riolan's arch runs more centrally than the marginal artery.

The reported frequency of Riolan's arch is 7.5–27.8% [15, 41–44] (Table 5). The frequency varies widely across studies, partially due to the ambiguous definition of Riolan's arch. The ALCA or AMCA appears to have been included in Riolan's arch in some studies [41, 43]. In reality, it is difficult to distinguish the ALCA from Riolan's arch in cases where the LCA has multiple branches to the marginal artery (Fig. 3b).

Similarly, it is difficult to distinguish the AMCA from Riolan's arch when there is an artery connecting the AMCA and LCA (Fig. 7). Specifically, the artery connecting the ALCA and the origin of the MCA, which is more central than Riolan's arch, is called the artery of Moskowitz [45].

In a study, angiographic examination revealed that stenosis or occlusion of the mesenteric artery was present in 8.4% of elderly patients [15]. Moreover, Griffiths' critical point was observed in 48.1% of cases. In these cases, Riolan's arch and the ALCA were important as collateral arteries. Especially, the terminal bifurcation of the ALCA at the splenic flexure should not be damaged, which may be important to supplement the blood flow of Griffiths' point [6, 40]. In patients exhibiting ALCA hypertrophy, stenosis/occlusion of the SMA or IMA should be considered.

Conclusion

We reviewed the anatomy of the MCA and LCA. Given the increasing utility of computed tomographic angiography, a comprehensive preoperative knowledge of the branching patterns of the MCA and LCA and the presence of collateral arteries would be helpful in surgery for colon cancer in the splenic flexure.

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Declarations

Conflict of interest The authors declare no conflicts of interest in association with the present study.

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