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ORIGINAL ARTICLE

Evaluation of the vascular anatomy of the right-sided colon using three-dimensional computed tomography angiography: a single-center study of 536 patients and a review of the literature

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Abstract

Purpose The requisite for a rigorous preoperative understanding of vascular branching continues to grow in parallel with the implementation of laparoscopic surgery. Three-dimensional (3D)-computed tomography (CT) angiography is a less-invasive modality than traditional angiographic examination. Therefore, we aimed to evaluate branching patterns of the superior mesenteric artery (SMA).

Methods In the present study, 536 consecutive patients who underwent preoperative 3D-CT angiography from April 2012 to March 2014 were prospectively enrolled. The branching pattern of the right colic artery (RCA) and the intersectional patterns of the RCA, ileocolic artery (ICA), and superior mesenteric vein (SMV) were evaluated.

Results The RCA existed in only 179 cases (33.4 %); the remaining 357 patients (66.6 %) lacked evidence of the RCA. The ICA was detected in all cases. The RCA ran ventral to the SMV in the majority of cases (89.4 %). Conversely, the ICA ran ventral to the SMV in only half of the cases (50.6 %). When the RCA was observed to pass dorsal to the SMV, the ICA also ran dorsal to SMV in all cases.

Conclusions 3D-CT angiography can aid surgeons in identifying and understanding the anatomical vascular variations and intersectional patterns of the RCA, ICA, and SMV. Developing awareness of these variations can aid in the prevention of unexpected vascular injury during laparoscopic right-sided colon surgery.

Introduction

Indications for laparoscopic colorectal surgery continue to grow as a product of the minimally invasive advantages of laparoscopy, including smaller incisions, less intraoperative blood loss and postoperative pain, and shorter hospitalization time than conventional open surgery [1–3]. However, identifying vascular bifurcation is frequently difficult during laparoscopic surgery owing to the limited field of view [4]; therefore, the requisite for a rigorous preoperative understanding of vascular branching continues to grow in parallel with the implementation of laparoscopic surgery.

The anatomy of the superior mesenteric artery (SMA) is particularly important during right-sided colorectal surgeries. Specifically, it is imperative to understand the branching pattern of the right colic artery (RCA), as substantial variation exists between individuals with respect to the location of the RCA and ileocolic artery (ICA), and whether these vessels are located ventrally or dorsally to the superior mesenteric vein (SMV). Although branching variations of the SMA have been previously investigated with cadaveric and angiographic studies [5–7], these methods are limited by temporality and invasiveness, respectively. Thus, intersectional patterns of the RCA, ICA, and SMV have previously been difficult to study in a rigorous fashion.

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Recently, through advances in computed tomography (CT) technologies, three-dimensional (3D)-CT angiography has been adequately well developed to provide an alternative modality for evaluating the branching pattern of the SMA. Importantly, 3D-CT angiography is less invasive than traditional angiographic examination and is useful for preoperatively evaluating the vascular anatomy of patients with gastric cancers, peripheral arterial disease, and middle rectal arteries [8–10].

Previous studies have reported on branching variations of the SMA using CT angiography prior to colorectal surgery [11–13]. However, these studies have typically included small study cohorts, and thus present considerably different results with respect to the frequency of the presence of the RCA and the relationship between the RCA and ICA. Therefore, in the present study, we aimed to evaluate the branching patterns of the SMA in a large number of patients ($n = 536$) and to demonstrate how 3D-CT angiography can be used in a clinical context to facilitate identification of bifurcation patterns of the SMA.

Materials and methods

Patient selection

In the present study, 536 consecutive patients (328 men and 208 women; median age 66 years [range, 21–91 years]) with

colorectal cancers who underwent preoperative 3D-CT angiography at the University of Tokyo Hospital from April 2012 to March 2014 were prospectively enrolled. Patients with left-sided colon cancer or those who underwent palliative surgery were also included. Informed consent was obtained from all patients prior to participation, and study approval was granted by the Ethics Committee of the University of Tokyo.

3D-CT angiography protocol

Patients underwent 3D-CT angiography using a 16- or 64-detector CT scanner. The tube potential was 120 kVp, and the tube current was adjusted by automatic exposure control with a noise index of ten and a slice thickness of 0.5–1 mm. Iopamidol (370 mg I/mL, iopamiron 370; Bayer, Osaka, Japan) was used as the contrast agent. Patients were injected with 0.7 g/kg iodine (upper limit, 37 g) for 30 s at a rate of 2.3–3.3 mL/s. The bolus tracking method was used to determine scan timing. The scan was initiated when the contrast in the abdominal aorta (above the renal arteries) reached 150 Hounsfield units. Ninety seconds after the injection of iopamidol, the venous phase image was acquired. Image processing analysis was performed using a 3D volume rendering technique with the ZIO station system (Ziosoft, Tokyo, Japan) (Fig. 1). All CT images were reviewed using a picture

Fig. 1 The patterns of the bifurcation of superior mesenteric artery (*RCA*). **a** Presence of the RCA ($n = 179$, 33.4 %), **b** absence of the RCA ($n = 357$, 66.6 %)

a)

MCA   SMA

RCA

ICA

n=179
(33.4%)
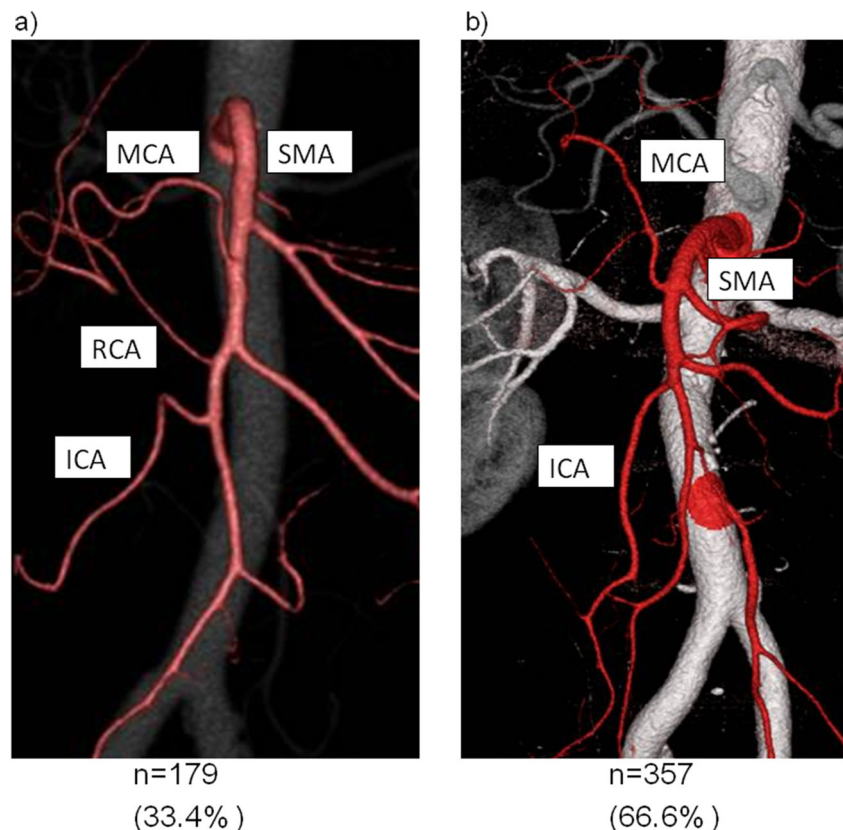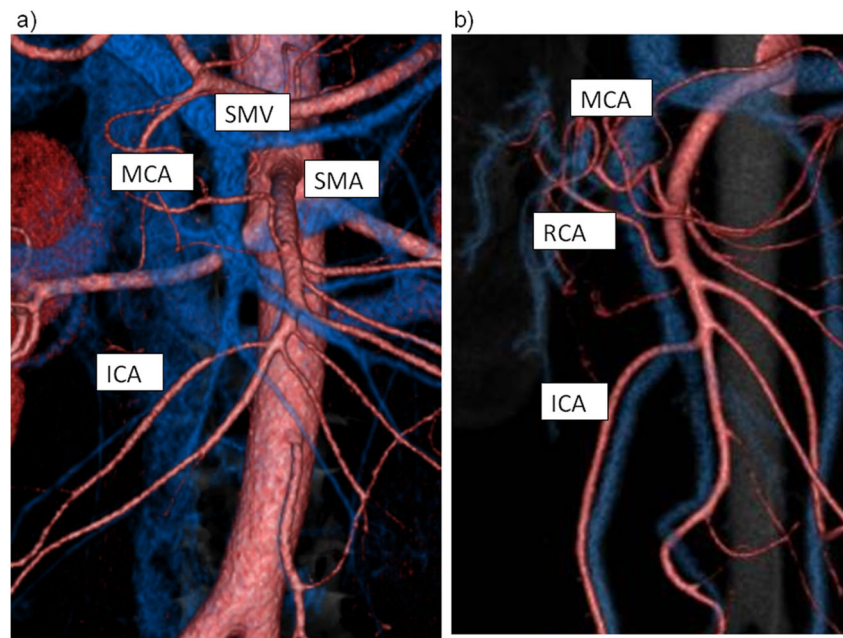
b)

MCA

SMA

ICA

n=357
(66.6%)

Fig. 2 The 3D image of the SMA and SMV. **a** Absence of the RCA and the ICA ran dorsal to the SMV. **b** The RCA ran ventral to the SMV and the ICA ran dorsal to the SMV

archiving and communication system workstation (General Electric Medical Systems, Milwaukee, WI).

Definitions of the middle colic artery, right colic artery, and ileocolic artery

The middle colic artery (MCA) and ICA were defined as the arteries arising from the SMA that approximated the transverse colon and ileocecal valve, respectively, at their distal ends. The right colic artery (RCA) was defined as the artery arising from the SMA that ran ventral to the pancreas toward the ascending colon. In the present study, cases in which the RCA diverge from the MCA or ICA were excluded. These definitions were developed according to 3D-CT images and an axial CT scans.

Intersectional patterns of the RCA, ICA, and SMV

Whilst the RCA and ICA run across the SMV, they exhibit variability in whether they are located dorsal or ventral to the SMV. Therefore, we evaluated the relative frequency of each type of relationship between the RCA, ICA, and SMV. The intersectional patterns of these vessels were assessed using a combination of the results obtained from sequential axial 2D- and reconstructed 3D-CT scans (Fig. 2).

Evidence acquisition

An electronic literature search was performed via PubMed to identify studies that have evaluated the presence of the RCA and intersectional patterns of the RCA, ICA, and SMV. Our search included all English language entries from inception until November 2015, and incorporated 'right colic artery' as the only keyword. Case reports, editorials, letters, commentaries, and studies that only validated previously published reports were excluded. The initial search gave 200 publications; after title and abstract screening, 15 studies remained. After full text screening, 11 studies remained, and a further two were added after reviewing the references of the 15 studies; thus, 13 studies were included in the final review.

Results

Frequency of varying SMA bifurcating patterns

The frequencies of the various bifurcation patterns of the SMA are shown in Fig. 1. The RCA existed in only 179 cases (33.4 %); the remaining 357 patients (66.6 %) lacked evidence of the RCA. The ICA was detected in all cases.

Intersectional patterns of the RCA, ICA, and SMV

We evaluated the anteroposterior positional relationship of the RCA, ICA, and SMV (Table 1). The RCA ran ventral to the SMV in the majority of cases (89.4 %). However, in contrast, the ICA ran ventral to the SMV in only half of the cases (50.6 %).

Table 1 The positional relationship between the RCA, ICA, and SMV

	Ventral to SMV	Dorsal to SMV	Total
RCA	160/179 (89.4 %)	19/179 (10.6 %)	179
ICA	271/536 (50.6 %)	265/536 (49.4 %)	536

Subsequently, we evaluated the intersectional patterns of the RCA and ICA together (Fig. 3). When the RCA was observed to be ventral to the SMV, the ICA was also ventral in almost half of the cases (14.9 vs. 14.9 % for the ICA dorsal to the SMV). Conversely, when the RCA was observed to pass dorsal to SMV, the ICA also ran dorsal to the SMV, in all cases. In cases without the RCA, the ICA ran ventral to the SMV in almost half of the cases (35.6 vs. 31.0 % for the ICA dorsal to the SMV).

Discussion

Preoperative 3D-CT angiography is associated with a significant reduction in the operative time and incidence of complications related to difficult or erroneous identification of mesenteric vessels [4]. During right-sided

Fig. 3 Intersectional patterns of the RCA, ICA, and the SMV. **a** The RCA and the ICA crossed the SMV ventrally. **b** The RCA crossed the SMV dorsally and the ICA ventrally. **c** Defect of the RCA and the ICA crossed the SMV ventrally. **d** The RCA crossed the SMV ventrally and the ICA dorsally. **e** The RCA and the ICA crossed the SMV dorsally. **f** Defect of the RCA and the ICA crossed the SMV dorsally. *Bold line* indicates artery, and *grey line* vein

hemicolectomy with D3 lymph node dissection, it is necessary to skeletonize the SMV and ligate the root of the ileocolic vessels. Subsequently, it is also necessary to ligate the origin of the right colic vessels and right branches of the middle colic vessels [14, 15]. Therefore, it is important to evaluate whether the RCA branch from the SMA is present or absent. In cases that lack the RCA, it is possible to misidentify the MCA as the RCA. Moreover, when dissecting lymph nodes around the SMV, a lack of information regarding the dorsal or ventral course of the RCA and ICA can result in damage to these arteries. Thus, preoperative identification of SMA branching variations is crucial in obtaining optimal surgical outcomes.

A primary goal of this study was to evaluate the frequency of RCA diversion from the SMA. The RCA was observed in only 179 cases (33.4 %), whilst 357 patients (66.6 %) lacked evidence of the RCA. Although the branching patterns of the RCA have previously been investigated in cadaveric and angiographic studies, the literature remains inconsistent with respect to the relative incidence of the RCA (Table 2) [7, 12, 13, 16–24]. For example, the RCA has been reported to branch from the MCA or ICA at rates of 19–52 % and 8–66.9 %, respectively; this constitutes a substantial range of reported incidences. In some part, this may be due to difficulty in distinguishing the RCA from peripheral arteries branching from the MCA and ICA. Furthermore, as it is important to obtain an overall understanding of the arteries diverting from the SMA for D3 lymph node dissection, we evaluated the frequency of the RCA branching from the SMA. Previously, the frequency of the RCA branching from the SMA has been reported between ranged from 28.3 to 41 % in reports that included more than 200 patients [7, 13, 16, 21]. These results are consistent with the results of 3D-CT angiography observed in the present study.

Subsequently, we evaluated the anteroposterior positional relationship of the RCA, ICA, and SMV, which is important when dissecting lymph nodes around the SMV. The ICA ran ventral to the SMV in almost half of the cases (50.6 %). Conversely, the RCA ran ventral to the SMV in the majority of cases (89.4 %). Intersectional patterns evaluated in cadaveric studies and 3D-CT angiography are shown in Table 3. Previously, the ICA has been shown to lie ventral to the SMV in 20.8–59.1 % of cases (average 46.4 %), whilst the RCA has been reported to lie ventral in 63–92.6 % of cases (average 86.8 %); these findings are consistent with the results of the present study [12, 13, 18–20, 22–24].

Interestingly, when the ICA was observed to run ventral to the SMV, the RCA was also observed to run ventrally, in all cases (Table 4). To date, only three reports exist regarding the correlation between the intersectional
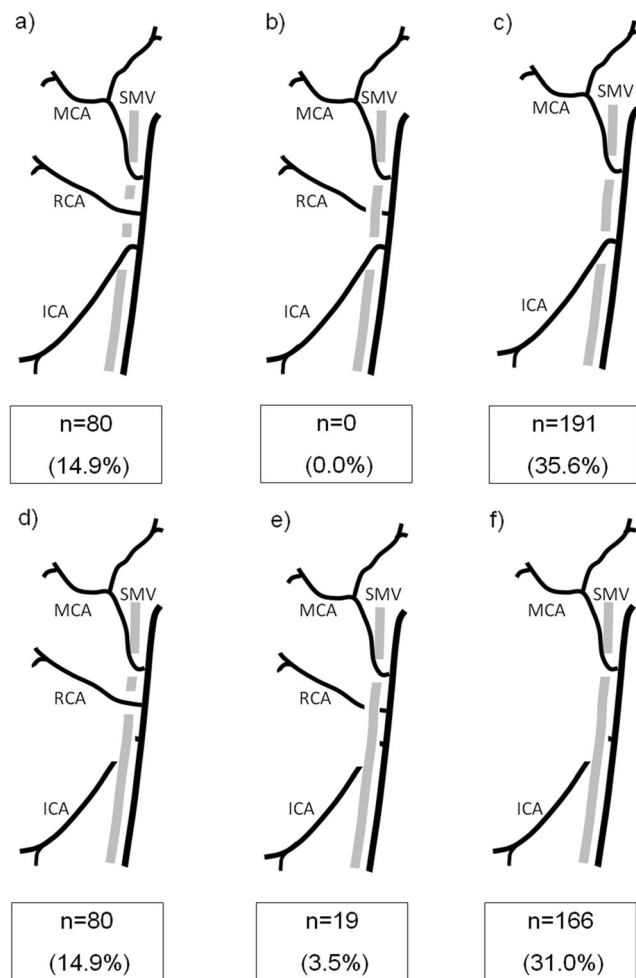
Table 2 The branching pattern of the RCA

	Diverge from SMA	Diverge from MCA	Diverge from ICA	Absent	Total
Dissecting cadaver					
Michels et al. [7]	152 (38 %)	208 (52 %)	32 (8 %)	8 (2 %)	400
Sonneland et al. [16]	170 (28.3 %)	182 (30.4 %)	201 (33.5 %)	76 (12.6 %)	600
Garcia-Ruiz et al. [17]	6 (10.7 %)	13 (23.3 %)	37 (66.0 %)	0 (0.0 %)	56
Shatari et al. [18]	8 (29.6 %)			19 (70.4 %)	27
Ignjatovic et al. [19]	19 (63.3 %)			11 (36.7 %)	30
Spasojevic et al. [20]	5 (19 %)			21 (81 %)	26
Angiographic examination					
Yada et al. [21]	121 (41 %)	52 (19 %)	38 (14 %)	71 (26 %)	273
3D-CT angiography					
Spasojevic et al. [12]	27 (54 %)			23 (46 %)	50
Tajima et al. [13]	69 (32.1 %)			146 (67.9 %)	215
Hirai et al. [22]	37 (37 %)			63 (63 %)	100
Nesgaard et al. [23]	17 (12.2 %)			122 (87.8 %)	139
Kaye et al. [24]	36 (23.8 %)			115 (76.2 %)	151
Present study	179 (33.4 %)			357 (66.6 %)	536
Total	846 (32.5 %)				2603

Table 3 The intersectional pattern of the RCA and SMV, and the ICA and SMV

	RCA ant.	RCA post.	Total	ICA ant.	ICA post.	Total
Cadaver						
Shatari et al. [18]	5 (63 %)	3 (37 %)	8	9 (33 %)	18 (67 %)	27
Ignjatovic et al. [19]	16 (84.2 %)	3 (15.8 %)	19	11 (36.7 %)	19 (63.3 %)	30
Spasojevic et al. [20]	4 (80 %)	1 (20 %)	5	7 (27 %)	19 (73 %)	26
3D-CT						
Spasojevic et al. [12]	25 (92.6 %)	2 (7.4 %)	27	10 (20.8 %)	38 (79.2 %)	48
Tajima et al. [13]	54 (78.3 %)	15 (21.7 %)	69	127 (59.1 %)	88 (40.9 %)	215
Hirai et al. [22]	33 (89 %)	4 (11 %)	37	52 (52.0 %)	48 (48.0 %)	100
Nesgaard et al. [23]				58 (41.7 %)	81 (58.3 %)	139
Kaye et al. [24]	33 (91.6 %)	2 (5.5 %)	36	50 (33.6 %)	98 (65.8 %)	148
Present study	160 (89.4 %)	19 (10.6 %)	179	265 (50.6 %)	271 (49.4 %)	536
Total	330 (86.8 %)	49 (12.9 %)	380	589 (46.4 %)	680 (53.6 %)	1269

patterns of the RCA and ICA. However, the finding of a dorsally located RCA in the context of a ventrally located ICA, with respect to the SMV, has only been noted in one study, with a total pattern rate of 0.6 % [13, 18, 22].

Table 4 The intersectional pattern of the RCA, ICA, and the SMV

	RCA ant. ICA ant.	RCA post. ICA ant.	No RCA ICA ant.	RCA ant. ICA post.	RCA post. ICA post.	No RCA ICA post.	Total
Cadaver							
Shatari et al. [18]	1 (3.7 %)	0 (0 %)	8 (29.6 %)	4 (14.8 %)	3 (11.1 %)	11 (40.7 %)	27
3D-CT							
Tajima et al. [13]	44 (20.5 %)	5 (2.2 %)	78 (36.3 %)	10 (4.7 %)	10 (4.7 %)	68 (31.6 %)	215
Hirai et al. [22]	21 (21 %)	0 (0 %)	31 (31 %)	12 (12 %)	4 (4 %)	32 (32 %)	100
Present study	80 (14.9 %)	0 (0 %)	191 (35.6 %)	80 (14.9 %)	19 (3.5 %)	166 (31.0 %)	536
Total	146 (17 %)	5 (0.6 %)	308 (35 %)	106 (12 %)	36 (4 %)	277 (32 %)	878

Therefore, when the ICA runs ventrally to the SMV, surgeons should be aware that the RCA is also likely to run ventrally, and should thus be careful to prevent injuring the RCA.

In the current study, we were unable to determine the accuracy of 3D reconstruction with the software used. However, 3D-CT has been reported to have accuracies of 100 and 90.6 % when assessing the hepatic artery and stenoses of the lower extremity arteries, respectively [25, 26]. Therefore, we conclude that 3D-CT angiography is accurate and reliable for evaluating the SMA.

In conclusion, 3D-CT angiography can aid surgeons in identifying and understanding the anatomical vascular variations and intersectional patterns of the RCA, ICA, and SMV. Developing awareness of these variations can aid in the prevention of unexpected vascular injury during laparoscopic right-sided colon surgery.

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