BACKGROUND: The branching of the inferior mesenteric artery and vein varies among individuals. Three-dimensional CT angiography is a less invasive modality than traditional angiographic examination to assess the artery and vein.

OBJECTIVE: We aimed to demonstrate the clinical applicability of CT angiography by evaluating bifurcations of the inferior mesenteric artery and the positional relationship between the inferior mesenteric artery and vein.

DESIGN: This was a prospective observational study of patients undergoing preoperative CT angiography.

SETTINGS: This study was conducted at a single tertiary care institution in Japan.

PATIENTS: A total of 471 consecutive patients who underwent preoperative CT angiography from April 2012 to December 2013 were prospectively enrolled.

MAIN OUTCOME MEASURES: The branching pattern of the inferior mesenteric artery, the positional relationship between the inferior mesenteric artery and vein, and the associations between inferior mesenteric artery length and clinical features were evaluated.

RESULTS: The length of the inferior mesenteric artery varied widely, from 10.1 to 82.2 mm. In 41.2% patients, the left colic artery arose independently from the sigmoid artery, and in 44.7% of the patients, the left colic artery and sigmoid artery had a common trunk, whereas the left colic artery did not exist in 5.1%. The left colic artery was located lateral to the inferior mesenteric vein at the level of the origin of the inferior mesenteric artery in 73.0% of the patients. The incidence of a short inferior mesenteric artery was significantly increased in men with high BMIs (75.0%).

LIMITATIONS: Three-dimensional reconstruction was performed by the use of a single software, and angiographic examination was not performed. Therefore, accuracy and reliability of the 3-dimensional reconstruction could not be established for each modality.

CONCLUSIONS: Using 3-dimensional CT angiography, preoperative understanding of the anatomic vascular variations can be easily obtained, which would help surgeons to safely perform laparoscopic surgery in the left-side colon and rectum.

KEY WORDS: Anatomy; Inferior mesenteric artery; 3-dimensional computed tomography angiography.

The branching of the inferior mesenteric artery (IMA) and vein (IMV) varies among individuals, and understanding individual variations preoperatively would be very helpful during left-sided colorectal surgeries. Although variations in IMA branching have been historically investigated by dissecting cadavers, this cannot be performed in a live patient; furthermore, although angiographic examination of this topic has been reported, this is an invasive method, and it is not capable of depicting the positional relationship among arteries, veins, and other organs. Recently, through advances in CT technologies, 3-dimensional (3D) CT angiography has been developed as an alternative modality for evaluating vascular branching. Three-dimensional CT angiography is a less invasive modality than traditional angiographic
examination and is useful for preoperatively evaluating the vascular anatomy of patients with breast and gastric cancers. Previous studies have reported on the position of the superior mesenteric and middle rectal arteries using CT angiography before performing colorectal surgery; however, to our knowledge, no study has investigated the anatomy of the IMA using CT angiography. Thus, in the present study, we aimed to demonstrate the clinical applicability of 3D-CT angiography by evaluating bifurcations of the IMA, the 3D positional relationship between the IMA and IMV, and the associations between IMA length and clinical features.

**MATERIALS AND METHODS**

**Patient Selection**

A total of 471 consecutive patients with colorectal cancers, including those with right-sided colon cancer or those who underwent palliative surgery, at the University of Tokyo Hospital from April 2012 to December 2013 were prospectively enrolled in the study. Patients who had previously undergone left-sided colorectal surgeries were excluded; thus, 468 patients (294 men and 174 women) were included in the analyses. Informed consent was obtained from all of the patients for participation in this study, and all of the patients underwent preoperative 3D-CT angiography. The median age of the patients was 66 years (range, 21–91 years). This study was approved by the ethics committee of the University of Tokyo.

**Three-Dimensional 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 10 in a section thickness of 0.5 to 1.0 mm. Iopamidol (370 mg/mL; Iopamiron 370, Bayer, Osaka, Japan) was used as the contrast material. The patients were injected with 0.7 g/kg of body weight of iodine (upper limit, 37 g) for 30 seconds at a rate of 2.3 to 3.3 mL/s. The bolus tracking method was used to determine the scan timing. The scan was initiated when the abdominal aorta (above the renal arteries) had reached 150 Hounsfield units. Image processing analysis was performed using a 3D volume rendering technique with the ZIO Station System (Ziosoft, Tokyo, Japan; Fig. 1). All of the CT images were reviewed using a picture archiving and communication system workstation (General Electric Medical Systems, Milwaukee, WI).

**Definitions of the Left Colic Artery and IMA, Evaluation of the Bifurcating Patterns of the IMA, and Measurement of IMA Length**

The left colic artery (LCA) was defined as the artery arising from the IMA and running to the descending colon. Typically, the LCA runs to the splenic flexure ascending along the IMV.

The IMA was considered from its origin at the aorta to its first branch (the origin of the superior rectal artery), and the length of the IMA was measured at the angle where the IMA appeared the longest on the 3D images. Moreover, the height of lumbar vertebrae at which the IMA originated from the aorta was investigated. These data were determined by using 3D images.

Bifurcations of the IMA were divided into 4 patterns based on the definition reported by Yada et al with minor modifications: 1) in type 1, the LCA arose independently from the sigmoid artery (SA); 2) in type 2, the LCA and SA arose from the IMA at the same point; 3) in type 3, the LCA and SA had a common trunk; and 4) in type 4, there was a deficit of the LCA (Fig. 1). Bifurcations were evaluated by using 3D images.

**Intersectional Patterns of the LCA and IMV**

The positional relationship between the LCA and IMV at the level of the origin of the IMA, which is very important for left-sided colon surgery, was evaluated in the axial 2D view (Fig. 2). The intersectional patterns of the LCA and IMV were divided into the following 3 types: 1) type A, the LCA was located just medial to the IMV; 2) type B, the LCA was located just lateral to the IMV; and 3) type C, the LCA was located laterally distant from the IMA.

**Statistical Analysis**

To evaluate the association between the clinical parameters and the length of the IMA, the Fisher exact probability test and Student t test were applied. Logistic regression analyses were applied for univariate and multivariate anal-
yses. All of the analyses were performed using the JMP10.0 software (SAS Institute Inc, Cary, NC), and differences at $p < 0.05$ were considered statistically significant.

**RESULTS**

**Frequencies of Bifurcating Patterns of the IMA**
The frequencies of the bifurcation patterns of the IMA are shown in Figure 1. The majority of patients were classified as either type 1 ($n = 193$ [41.2%]) or type 3 ($n = 209$ [44.7%]). Of all the patients, 42 (9.0%) had type 2 IMA bifurcation, and a small number of patients ($n = 24$ [5.1%]) lacked the LCA (type 4).

**Intersectional Patterns of the LCA and IMV**
Initially, we evaluated the anteroposterior positional relationship of the LCA and IMV (Fig. 3). The 24 patients who lacked the LCA were excluded from this analysis. The LCA ran across the IMV ventrally in 313 patients (70.5%), whereas it was located dorsal to the IMV in the other 131 patients (29.5%).

The intersectional patterns of the LCA and the IMV are shown in Figure 2. Among the 444 patients analyzed, type B was the most frequent pattern (44.4%), whereas types A and C had almost the same incidence rates. In types A and B (71.4%), the LCA ascended to the splenic flexure together with the IMV. In contrast, in types B and C (73.0%), the LCA was located lateral to the IMV. The anteroposterior positional relationship of the LCA and IMV was not associated with these 3 intersectional classifications (data not shown).

**Association Between the Length of the IMA and Clinical Features**
The length of the IMA widely varied, from 10.1 to 82.2 mm (Fig. 4). We divided the patients into 2 groups according to the length of the IMA, using the approximate median length of 40 mm as the cutoff value, and evaluated the associations between the IMA length and clinical features (Tables 1 and 2). In the univariate analysis, male sex, higher BMI, and IMA originating at the lower level of the lumbar vertebrae (L4) were associated with a shorter IMA. With regard to the LCA branching type, a shorter IMA significantly correlated with LCA solely bifurcating from the IMA (type 1) and running just to the medial side of the IMV (TYPE A; $p = 0.005$ and $p < 0.0001$), whereas the anteroposterior relationship between the IMA and IMV showed no association. In the multivariate analysis, male sex, IMA originating at the level of L4, LCA independently bifurcated from the IMA, and LCA located medial to the IMV were independently associated with a shorter IMA.

Moreover, the association between the IMA anatomy and patient characteristics was evaluated (Table 3). The incidence of a short IMA was significantly higher in men with high BMIs (75.0%), and the incidence of type C LCA was higher in women with low BMIs (36.9%).

**DISCUSSION**
Laparoscopic surgery for colorectal cancer is being increasingly used as a minimally invasive surgery. Patients who undergo laparoscopic colorectal cancer resection reportedly have significantly less blood loss and shorter hospital stays, and the reported oncologic outcomes are equivalent to those of open surgery. However, the vascular bifurcation tends to be misidentified when ligating mesenteric arteries during laparoscopic surgery because of a narrow view and the lack of depth perception. Therefore, it is important to preoperatively assess the arterial branching, potentially by using 3D images, to determine the mutual relationship of the IMA and IMV during surgery for the left-sided colon or rectal surgery. Recently, with rapid advances in its precision, 3D-CT angiography
has been proposed as an alternative, less invasive modality for evaluating vascular bifurcations. However, the clinical applicability of 3D-CT angiography for evaluating the anatomy of the IMA and IMV has not been reported.

Initially, we evaluated the variations in IMA branching. To achieve clear 3D-CT, the bolus tracking method was applied. We found that 5.1% of patients lacked the LCA (type 4) and that the majority of the cases with an LCA were classified as type 1 or type 3 (41.2% and 44.7%). In a study in which IMA branching was studied by dissecting cadavers, the reported frequencies of types 1, 3, and 4 were 41% to 56%, 38% to 50%, and 0% to 6%. In a study in which angiographic evaluation was used, the frequencies were 40% to 58%, 38% to 60%, and 0% to 3%4–6; these results are consistent with the results of the 3D-CT angiography in the present study. The variants of IMV were not evaluated in the present study because they are not as clinically important as IMA variations; moreover, it is difficult to distinguish a vein from an artery in 3D-CT angiography.

There are 2 methods to divide the IMA during surgery for left-sided colorectal cancers; first is ligating the IMA proximal to the origin of the LCA (high ligation) and second is performing ligation distal to the origin of the LCA (low ligation). High ligation allows dissection of the lymph nodes close to the aorta and makes the left colon more mobile, whereas the use of low ligation will avoid possible ischemia in the proximal bowel and consequent anastomatic leakage. However, some studies have reported that high ligation of the IMA does not increase the frequency of anastomatic leakage, and the anastomosis-protecting effects of low ligation remain controversial. During high ligation, the ascending branches of the LCA and IMV are divided at approximately the same level as the origin of the IMA. Therefore, evaluating the association between the LCA and IMV preoperatively is controversial.

Table 1. Association between univariate clinical features and the length of the IMA

<table>
<thead>
<tr>
<th>Univariate</th>
<th>IMA length &lt;40 mm</th>
<th>IMA length &gt;40 mm</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex, n (%)</td>
<td>251 (56.5)</td>
<td>193 (43.5)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>175 (69.7)</td>
<td>110 (57.0)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>76 (30.3)</td>
<td>83 (43.0)</td>
<td>0.006</td>
</tr>
<tr>
<td>Age, median (range), y</td>
<td>66 (31–90)</td>
<td>65 (21–91)</td>
<td>0.27</td>
</tr>
<tr>
<td>Body height, average ± SD</td>
<td>162.1 ± 9.3</td>
<td>161.9 ± 9.7</td>
<td>0.89</td>
</tr>
<tr>
<td>Body weight, average ± SD</td>
<td>61.5 ± 12.7</td>
<td>58.4 ± 12.3</td>
<td>0.02</td>
</tr>
<tr>
<td>BMI, average ± SD</td>
<td>23.3 ± 3.7</td>
<td>22.1 ± 3.6</td>
<td>0.003</td>
</tr>
<tr>
<td>Origin of IMA, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>9 (3.6)</td>
<td>16 (8.3)</td>
<td></td>
</tr>
<tr>
<td>L3</td>
<td>186 (74.1)</td>
<td>155 (80.3)</td>
<td></td>
</tr>
<tr>
<td>L4</td>
<td>56 (22.3)</td>
<td>22 (11.4)</td>
<td>0.002</td>
</tr>
<tr>
<td>Type of LCA bifurcation, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td>126 (50.2)</td>
<td>67 (34.7)</td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>21 (8.4)</td>
<td>21 (10.9)</td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td>104 (41.4)</td>
<td>105 (54.4)</td>
<td>0.005</td>
</tr>
<tr>
<td>LCA location, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventral to IMV</td>
<td>171 (68.1)</td>
<td>142 (73.6)</td>
<td>0.24</td>
</tr>
<tr>
<td>Dorsal to IMV</td>
<td>80 (31.9)</td>
<td>51 (26.4)</td>
<td></td>
</tr>
<tr>
<td>LCA location at the level of the origin of IMA, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type A</td>
<td>97 (38.7)</td>
<td>23 (11.9)</td>
<td></td>
</tr>
<tr>
<td>Type B</td>
<td>113 (45.0)</td>
<td>84 (43.5)</td>
<td></td>
</tr>
<tr>
<td>Type C</td>
<td>41 (16.3)</td>
<td>86 (44.6)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

IMA = inferior mesenteric artery; LCA = left colic artery; SA = sigmoid artery; IMV = inferior mesenteric vein; type 1 = LCA arose independently from SA; type 2 = LCA and SA arose from IMA at the same point; type 3 = LCA and SA had a common trunk; type A = LCA laid inside IMV; type B = LCA laid outside IMV; type C = LCA away from IMA.

Table 2. Association between multivariate clinical features and the length of the IMA

<table>
<thead>
<tr>
<th>Multivariate</th>
<th>OR</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex, female vs male</td>
<td>1.60</td>
<td>1.05–2.44</td>
<td>0.03</td>
</tr>
<tr>
<td>BMI, &lt;25 vs &gt;25</td>
<td>1.49</td>
<td>0.92–2.42</td>
<td>0.10</td>
</tr>
<tr>
<td>Origin of IMA, L2/3 vs L4</td>
<td>2.41</td>
<td>1.37–4.37</td>
<td>0.002</td>
</tr>
<tr>
<td>Type of LCA bifurcation, type 2/3 vs type 1</td>
<td>1.90</td>
<td>1.26–2.88</td>
<td>0.002</td>
</tr>
<tr>
<td>LCA location at the level of the origin of IMA, type C vs type A/B</td>
<td>3.82</td>
<td>2.44–6.06</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

IMA = inferior mesenteric artery; LCA = left colic artery; SA = sigmoid artery; IMV = inferior mesenteric vein; type 1 = LCA arose independently from SA; type 2 = LCA and SA arose from IMA at the same point; type 3 = LCA and SA had a common trunk; type A = LCA laid inside IMV; type B = LCA laid outside IMV; type C = LCA away from IMA.

Table 3. Association between patient characteristics and the anatomy of IMA

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>IMA length</td>
<td>64/130</td>
<td>12/29</td>
<td>112/201</td>
<td>63/84</td>
<td>0.0005</td>
</tr>
<tr>
<td>&lt;40 mm, n/N (%)</td>
<td>(49.2)</td>
<td>(41.4)</td>
<td>(55.7)</td>
<td>(75.0)</td>
<td></td>
</tr>
<tr>
<td>Origin of IMA</td>
<td>103/130</td>
<td>28/29</td>
<td>163/201</td>
<td>72/84</td>
<td>0.12</td>
</tr>
<tr>
<td>L2/3, n/N (%)</td>
<td>(79.2)</td>
<td>(96.5)</td>
<td>(82.1)</td>
<td>(85.7)</td>
<td></td>
</tr>
<tr>
<td>LCA location</td>
<td>48/130</td>
<td>6/29</td>
<td>59/201</td>
<td>14/84</td>
<td>0.03</td>
</tr>
<tr>
<td>type C, n/N (%)</td>
<td>(36.9)</td>
<td>(20.7)</td>
<td>(29.4)</td>
<td>(16.7)</td>
<td></td>
</tr>
</tbody>
</table>

IMA = inferior mesenteric artery; LCA = left colic artery; type C = left colic artery away from IMA.
important. It can be difficult to distinguish arteries from veins, especially the IMV from the LCA, using standard CT. Therefore, the association between the LCA and IMV was evaluated by arterial-phase CT in the present study.

The incidence of type C LCA was high in women with low BMIs. Proximal bowel ischemia has been reported as one of the serious complications after left-sided colectomy,16,20 and preservation of the marginal artery is essential to avoid this complication. In some cases, such as those with type C, the LCA runs very close to the marginal artery, and injury of the marginal artery may consequently occur. Park et al16 reported that, of 10 patients who developed postoperative colonic ischemia, 8 had undergone laparoscopic surgery. Although misidentification of the LCA and marginal artery could occur in both open and laparoscopic surgeries, preoperative evaluation of the association between the LCA and IMV is important, especially in laparoscopic surgery.

Although the lengths have been reported to range from 3 to 5 cm in a cadaveric study,1–4,16 the length ranged from 10.1 to 82.2 mm (median, 38.4 mm) in the present study. The incidences of lymph node metastases around the IMA root are reportedly 0.7% to 5.8%.18,22–24 However, no survival benefits of high ligation compared with low ligation have been observed in several reports.25,26 Although the presence of IMA lymph node metastasis was a considerable risk factor for systemic recurrence, the resection of the lymph node around the IMA may not contribute to survival.27 Conversely, there have been several reports from Asia indicating that D3 lymph node dissection is associated with a significant survival advantage.28 Therefore, the specific procedure for lymph node dissection around the IMA may not be identical between Western and Asian hospitals.

During the low ligation procedure in Asia, it is important to simultaneously perform lymph node dissection around the IMA to achieve D3 lymph node dissection.29,30 Additional lymph node dissection around the root of the IMA requires a longer operation duration as compared with the low ligation procedure without lymph node dissection.29,30 With longer IMAs, the required time for lymph node dissection along the IMA also increases. Moreover, if surgeons are aware of the presence of a shorter IMA preoperatively, they can avoid unnecessary intraoperative IMA exposure. Based on the results of the current study, surgeons can expect a shorter IMA in men with high BMIs.

The reported accuracies of 3D-CT angiography in the assessment of hepatic artery variance and stenoses of lower extremity arteries were 100% and 90.6%, using MI-3DVS software and Advantage Workstation Volume-Share 4 for evaluation.31,32 Therefore, we concluded that 3D-CT angiography could provide sufficient accuracy and reliability for IMA evaluation. In the present study, 3D reconstruction was performed using ZIO Station System software. Because angiographic examination was not performed, we could not demonstrate the accuracy of the 3D reconstruction with this software by comparing the actual length of the IMA and that measured by 3D-CT. Moreover, because this study was not a randomized controlled study, the advantages of performing 3D-CT angiography, such as shorter operation time and less blood loss, were not presented. These are the limitations of the present study.

CONCLUSION

We demonstrated the excellent clinical applicability of 3D-CT angiography. Using this modality, preoperative understanding of the anatomic vascular variations and the mutual 3D positional relationship between the IMA and IMV can be easily obtained, which would help surgeons to safely perform laparoscopic surgery on the left side of the colon and rectum.

REFERENCE


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