Navigating the mesentery: part III. Unusual anatomy of ileocolic vessels

Short title: Unusual anatomy of ileocolic vessels

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The paper is based on the ongoing trial “Safe Radical D3 Right Hemicolectomy for Cancer through Preoperative Biphasic MDCT Angiography”, ethically approved by the independent committee REK Sør-Øst No. 2010/3354, Norway and registered at the clinicaltrials.gov (ClinicalTrials.gov Identifier: NCT01351714).

ABSTRACT

AIM: The ileocolic vessels are important landmarks in advanced surgery of the midgut. The aim of the present study is to present variations of ileocolic vessels relevant to complete mesocolic excision (CME) with D3 lymphadenectomy of the right colon, within their detailed and precise morphometric framework and deriving from a large and consistent series of operated patients. **METHODS.** An ongoing prospective trial “Safe Radical D3 Right Hemicolectomy for Cancer through Preoperative Biphasic MDCT Angiography” was reviewed. The imaging datasets underwent manual segmentation and 3D reconstruction, and the results were validated at surgery. A total of 356 patients were included in the study. **RESULTS.** A cross-section of the series revealed five (5) cases (1.4%) with variation of ileocolic vessels relevant to CME or D3 extended mesenterectomy. There were two cases with absence of a true classical ileocolic artery, two cases with absence of a true classical ileocolic vein, and one case of precocious bifurcation of the ileocolic artery, left to the superior mesenteric vein. The entire D3 area in all the cases was thoroughly documented and analysed from the morphometric point of view (calibers, lengths of vessels, crossing patterns). **CONCLUSION.** The preoperative visualization of patient’s individual 3D anatomy is a powerful tool in identifying the variations whose negligence could have dire consequences in complete mesocolic excision of the right colon.

Key words

MDCT angiography; segmentation; 3D reconstruction; ileocolic artery; ileocolic vein; variation; absence

What does this paper add to the literature?

We have introduced and developed a morphometric algorithm for preoperative identification of anatomical variability of ileocolic vessels and surrounding structures relevant to CME or D3 extended mesenterectomy for right sided colon cancer, which has an impact on the surgical procedure and patient’s outcome.

List of abbreviations used in the text:

3DVR – three-dimensional volume rendering

CME – complete mesocolic excision

GTH – gastrocolic trunk of Henle

ICA – ileocolic artery

ICV – ileocolic vein

IMV – inferior mesenteric vein

JIV – jejuno-ileal vein

JV – jejunal vein

MCA – middle colic artery

MCV – middle colic vein

MDCT – multidetector computer tomography

RCA – right colic artery

RCV – right colic vein

SMA – superior mesenteric vein

SMV – superior mesenteric artery

TIVT – terminal ileal venous trunk

INTRODUCTION

The superior mesenteric artery (SMA), axis of embryonic gut rotation, gives rise to numerous visceral branches. Its most distal right branch is the ileocolic artery (ICA), a vessel supplying the wide transition area between the large and the small bowel. It arises close to the posterior attachment line of the small bowel mesentery, descends right-ward within the mesentery towards the caecum, passing in front of the psoas major muscle, the ovarian/testicular artery and vein, and the ureter [1]. It usually divides into superior and inferior branches, the superior branch directed to the ascending colon, and the inferior branch to the ileocolic junction, but its divisional pattern is far more complex. It includes the upper and lower colic, ileal, appendicular, and anterior and posterior caecal arteries [2]. Therefore, the arterial irrigation of caecum derives mostly from the ICA; traction of this organ caudally, forward and to the right will tighten up the overlying mesentery, which facilitates identification of the vessel. The ileocolic fold is sometimes visible without traction, as presented in anatomical specimens (Figure 1). The ileocolic vein (ICV) accompanies the corresponding artery, and terminates as either a side tributary to the superior mesenteric vein (SMV), or its constituent in the form of a tripod with terminal ileal venous trunk (TIVT) and a jejunoileal vein (JIV)[3].

Figure 1. A formol-fixed dissection specimen. Arrows - ileocolic fold; TMC – transverse mesocolon; Mes – small bowel mesentery

Evidently, the anatomical features of the ileocolic vessels are of high significance in surgery for colorectal cancer, inflammatory bowel disease, mesenteric ischaemia, or reconstruction of the oesophagus with an ileocolic flap [4,5]. The scholar anatomy of

the visceral vasculature received additional wind in its sails with the advancement of complete mesocolic excision (CME) and the D3 lymphadenectomy of the right colon, introduced by Hohenberger et al., and developed by our study group [6,7]. This technically demanding and complex surgery entails minute excision of mesenteric (including lymphatic) tissue around the SMA and SMV, cranially from the level of the pancreatic notch down to 1 cm caudal to the ICA origin. Originally, the approach in this procedure was lateral to medial, but one possible first step is the identification of the superior mesenteric vessels [8,9] by following the ileocolic fold, as described above.

Most of the studies concerning the ICA and ICV describe them as the most constant collaterals of the SMA and SMV [2,3,10-13]. Therefore, the focus has been mostly on the ICV/ICA mutual topographic relations [12,14], on the type of ICA distal arborisation [2,15], on the crossing pattern between ICA and SMV [9-11], or on the level of ICV termination on the SMV [10,16].

The issue of the presence of ileocolic vessels is ambiguous in the literature. Their absence is noted in anecdotal reports [5], in reports from moderate-size series [12], or in prevalence reports from meta-analyses [11], all without imaging documentation or morphometric data. The aim of the present study is to present unusual anatomy of ileocolic vessels, validated at surgery and relevant to CME, i.e. extended D3 mesenterectomy for cancer, within their detailed and precise morphometric framework and deriving from a large and consistent series of operated patients.

MATERIAL AND METHODS

The study was based on the comprehensive data from the ongoing trial “Safe Radical D3 Right Hemicolectomy for Cancer through Preoperative Biphasic MDCT Angiography”, ethically approved by the independent committee REK Sør-Øst No. 2010/3354, Norway and registered at the clinicaltrials.gov [17]. The specificities of the surgical procedure have already been published [7]. A total of 356 patients were included in this study, making a cross-section of the trial. They all underwent preoperative computerized MDCT imaging and their datasets were analyzed by means of manual segmentation and 3D reconstruction of their vascular anatomy. For that purpose, three software packages were used: FDA approved Osirix MD v. 11.0 64-bit

image processing application (Pixmeo, Bernex, Switzerland), Mimics Medical image processing software, ver. 22.0, and 3-matic Medical software, ver. 14.0, last two Windows 7 ultimate edition x64 2019 (Materialise NV, Leuven, Belgium). A wide array of editing tools was applied for manual segmentation: open polygon, pencil, region of interest, repulsor, profile line thresholding, dynamic region growing, multiple slice editing with interpolation, split mask, etc. Further, the 3D virtual model of the SMA-SMV vascular tree underwent detailed morphological and morphometric analyses, and was afterwards exported as a three-dimension volume rendering (3DVR) model (with stills and video clips), as a STL file or a 3D PDF with annotations. The segmentation process and morphometry are already published [10,18] and have been proved to be superior to semiautomatic segmentation (19). In brief, the detailed report, apart from the description of the ICA/ICV variation, included the following parameters: ICV-GTH (gastrocolic trunk of Henle) length along the SMV right border; vertical aberrance between the origin of the middle colic artery (MCA) and the GTH base; distance between the origins of the colic arteries; MCA length until branching, calibre and course (including accessory MCA, if present); level of origin and calibers of jejunal arteries (JAs); inferior mesenteric vein (IMV) termination pattern; and calibers, crossing pattern and level of termination of jejunal veins (JVs).

RESULTS

A comprehensive analysis of the Akershus imaging series revealed five cases (1.40%) with variation or absence of true classical ileocolic vessels relevant to extended D3 right colectomy (Table 1).

Table 1. Variations of ileocolic vessels with detailed morphometry of the relevant adjacent structures

Case	Age, Sex	Brief description	ICV - GTH	MCA - GTH	Inter colic distance	MCA course	JA course	IMV and JV
1	71, F	Common colic trunk for ICA and MCA	0.89 cm	Common trunk levelled with GTH base	NA	NA	Two JAs (0.345 cm and 0.287 cm), arising by a large common trunk (0.609 cm) high above the IMV crossing	IMV opens into the SMV, crossing the JAs and the SMA anteriorly, 1.130 cm above the depart of the common MCA&ICA trunk A large (0.707 cm) JV trunk crosses the SMA posteriorly, just below the common MCA&ICA trunk origin
2	67, M	ICA has a short trunk, precociously dividing on the SMV left border	2.77 cm	MCA origin lies 0.73 cm below the GTH level	1.30 cm	MCA courses straight forward, in front of the SMV, and upward. It follows the left-hand side of the MCV. MCA caliber 0.30 cm, length 11.28 cm	1st vessel is the IPDA (0.250 cm), then the 1st JA (0.405 cm), both arising above the MCA origin; 2nd JA (0.376 cm) arises just above the ICA	IMV opens into the splenic vein, left and distant to the SMA A very large (1.173 cm) JV crosses the SMA posteriorly, its upper border at the ICA origin level. This JV receives PVs, and secondary level JVs Very close to the lower border of the JV trunk, SMV constituted from the tripod of TIVT, JIV, and ICV
3	72, F	Common colic trunk for ICA and MCA	5.58 cm	Common trunk lies 5.10 cm below the GTH level	NA	There is a slender (0.18 cm) acc. MCA for the left colic angle. It arises 3.26 cm above the common trunk	1st JA (0.222 cm) and 2nd JA (0.201 cm) arise above the accessory MCA origin level; 3rd JA (0.263 cm) arises just below the accessory MCA origin level	IMV opens into the SV, almost at the spleno-mesenteric junction, crossing the SMA anteriorly 1st JV (0.852 cm) courses horizontally, crossing the SMA anteriorly in front of the acc. MCA 2nd JV (0.535 cm) courses obliquely, crossing the SMA posteriorly 1.070 cm above the common trunk origin
4	59, M	ICA is highly positioned. ICV absent, replaced by affluents to GTH	NA	MCA origin lies 0.450 cm below the GTH level	1.13 cm	MCA courses upward and to the right. It bifurcates at the SMV left border, its two branches join the two MCVs. MCA caliber 0.28 cm, length 1.70 cm	Apart from the IPDA, the 1st JA (0.141 cm) arises above the regular MCA origin level; 2nd JA (0.496 cm) arises just below the MCA origin level; 3rd JA (0.377 cm) arises levelled with the ICA trunk	IMV opens into the splenic vein, left and distant to the SMA A very large (1.88 cm) JV crosses the SMA posteriorly, above and below the ICA origin
5	49, F	ICV absent, replaced by an ascending affluent to the GTH	NA	MCA origin lies 0.65 cm below the GTH level	2.32 cm	MCA courses upward, right, and slightly forward, crossing the SMV anteriorly, just below the MCV level. It bifurcates between the RCV and MCV bases, giving off branches for both. MCA caliber 0.33 cm, calibre 1.99 cm	1st JA (0.341 cm) arises above the MCA origin level; 2nd JA (0.360 cm) arises levelled with the MCA; 3rd JA (0.192 cm,) arises on the intercolic space; 4th JA (0.099 cm) arises just above the ICA origin level	IMV opens into the SMV, crossing the SMA anteriorly, 2.583 cm above the MCA origin level, just above the termination of the 1st JV 1st JV (0.886 cm) crosses the SMA anteriorly, above the MCA origin level 2nd JV (0.782 cm) crosses the SMA anteriorly, in the intercolic interval

NA – not applicable

Case presentations

Case 1 (Figure 2)

Figure 2. Case 1. a) 3DVR: A – common colic trunk, B – GTH; C – ICV, D – IMV, E – TIVT; b) operative image: isolation of common colic trunk; c) operative image: lymphadenectomy completed and the ICA branch of the common colic trunk ligated (arrow); d) STL file in 3-matic (common trunk highlighted with green spot)

There is a common colic arterial trunk (length 2.96 cm, calibre 0.39 cm), which descends, turning to the right and crossing anteriorly in turn the: JV, TIVT and ICV (tripod constituents of the SMV). This common trunk bifurcates into two branches: a descending, which follows the ICV anteriorly, and an ascending, which arborizes, following the GTH affluents. The SMA calibre below the common trunk departure is 0.39 cm. No regular or accessory MCA was observed.

Case 2 (Figure 3)

Figure 3. Case 2. a) 3DVR, abbreviations as in the text; b) operative image: SMA visible, with the ICA ligated at its base, elastic band looped around the MCA (top); the

measuring scale covering the SMV; c) STL file in 3-matic (ICA highlighted with green spot)

The ICA has a short and large trunk (length 0.73 cm, calibre 0.59 cm), passes to the right and upward and terminates by a precocious division in front and to the left of the SMV. Its lower branch (0.51 cm) turns 270 degrees, embracing the SMV and then follows the ICV from behind, while the upper branch (calibre 0.34 cm) follows the GTH affluent. The calibre of the SMA trunk below the ICA origin is 0.73 cm. The MCA was present, originating 3.26 cm cranial to the ICA origin.

Case 3 (Figure 4)

Figure 4. Case 3. a) 3DVR: A – common trunk; B – RCV; C – ICV; D – JV; E – accessory MCA (for left colic angle); b) STL file in 3-matic (common trunk highlighted with green spot)

There is a common colic arterial trunk (length 2.37 cm, calibre 0.41 cm), which takes a course upward and to the right, crossing the SMV posteriorly. After a “T”-shaped bifurcation, its upper branch joins the RCV (the latter bent upwards in front of the GTH), and its lower branch follows the ICV. The RCV terminates 3.56 cm above the ICV. The calibre of the SMA below the common trunk is 0.34 cm.

Case 4 (Figure 5)

Figure 5. Case 4. a) 3DVR: A – ICA; B – GTH; C – MCA; D – JV; b) operative image: ligated GTH (larger arrow), ligated ICA and MCA (smaller arrows); measuring scale lateral to the SMV; c) STL file in 3-matic (ICV replacement and ICA highlighted with green spots)

Apart from the MCA, there is a highly positioned ICA (length 2.71 cm, calibre 0.48 cm), which courses horizontally to the right, crossing the SMV just below the GTH level. After division, its branches follow the affluents of the GTH, i.e. there is no true classical ICV. There are two MCVs, terminating on the SMV 1.15 cm and 2.09 cm above and to the right of GTH, respectively. The calibre of the SMA below the ICA departure is 0.82 cm.

Case 5 (Figure 6)

Figure 6. Case 5. a) 3DVR: A – MCA; B – GTH; C – ICV replacement, affluent to the GTH; D – ICA (with a small lymph node); b) STL file in 3-matic: RGOV – right gastro-omental vein (ICV replacement and ICA highlighted with green spot)

A regular ICA (length 7.21 cm, calibre 0.21 cm) courses obliquely downward and to the right, crossing the SMV posteriorly. There is no true classical ICV, the ICA descending branch is followed by a venous affluent of the GTH. A RCV opens side-by-side with the GTH base; MCV opens 2.27 cm above and to the left of the GTH. The calibre of the SMA below the ICA departure is 0.37 cm.

DISCUSSION

The ICA and ICV can be the site of rare anatomical variation, such as fenestration [14], or pathology, e.g. inflammatory aneurysm [20] or low-grade liposarcoma [21], but by large their clinical significance lies in the right colectomy for cancer, either via open laparotomy, laparoscopy or robotic surgery [8,10,12,22].

In order to present the SMA and SMV arborisation, one can apply the fused 3D image of colon map, arteriography and venography [22], or the digital subtraction angiography [23]. We have chosen segmentation and 3D reconstruction based on one acquisition, as this image can easily be zoomed and observed from any angle, an option particularly appreciated by ones performing laparoscopic or robotic surgery.

Except for the exceptionally rare cases of ileocecal region agenesis [24], the ileocolic vessels seem to be almost invariably present [10,13,16,22]. Of course, the definition of a colic vessel comes into perspective here; for instance, a RCA can be defined either as an independent branch of the SMA, a side branch of the ICA or MCA, or both [11,13,22,25]. What adds to the confusion with nomenclature are the novel proposals in which the terminal SMA is classified as the ICA, and the “former” ICA becomes now the RCA [26]. However, we have decided to stick to the universally accepted ICA definition, given in the Introduction. In regard to the D3 extended mesenterectomy for cancer, only a vessel separately arising from the SMA can be considered a colic artery. The ICV is a rectilinear vessel of large caliber, considered as the best individualized

collateral affluent and the key to the operative identification of the SMV, i.e. the lower limit of the SMV surgical trunk [3].

There is no clear definition of ICA or ICV absence. In a case report by Orfaniotis [5] there were, in fact, two closely coursing parallel arteries replacing the ICA, one colic and the other ileal, with a regular ICV between them. In our series, albeit having a distal ileocolic axis in place, we stated the “apparent” ICA absence in cases where there was a single colic stem for the entire right colon, directed toward the hepatic angle of the colon. Within the same framework, the ICV absence was confirmed if the vein(s) from the ileocecal junction did not terminate directly in the SMV (either as a side tributary or a constituting vessel), but took an aberrant course towards the GTH and its affluents. We have also included a case in which an extremely short ICA divided on the SMV left hand side. When compared to the rare literature reports on this subject, we find that our prevalence of ICA absences was between the upper - 3.3% [12] and the lower limits - 0.2% [11], and our prevalence of ICV absence (0.6%) was higher than the ones in those two reports (0.0% and 0.3%, respectively). One can always attribute those differences to definition variation, but our present study includes a significant sample size, a detailed preoperative image analysis with segmentation and morphometry, and surgical confirmation, for all the cases.

The clinical significance of the superior mesenteric vascular tree is three-fold in D3 extended mesenterectomy for cancer. First and foremost, the pattern of the blood vessels indicates the position of the lymph vessels and accompanying lymph nodes [27]. Second, the preoperative insight in SMA and SMV anatomy helps finding the guiding landmarks in surgical dissection, and, last but not least, it aids in avoiding inadvertent intraoperative bleeding [22,28]. Therefore, a previous knowledge on patient’s individual vascular anatomy in the operative region is indispensable, which has been proven by the perioperative outcome in right colectomy patients with prior 3D simulated vessel arrangement pattern, when compared to the controls without preoperative imaging [16].

When the variants presented here are put into a true clinical setting, the morphometric data come into full scope. As mentioned before, the “SMV first” access is determined by the ICV [7,8,12] and the size of the SMV surgical trunk [3], i.e. the ICV-GTH

distance. In cases of ICA absence, this parameter is lost, and so might be the surgeon. In the other 3 of our cases this distance varied a lot (0.9-5.6 cm), but was within the ranges reported earlier [10,16]. As for the vertical level of the common ICA/MCA stem origin, it was either levelled or caudal to the GTH, which is in line with our earlier reports [10]. The dimensions of the two common colic trunks were within the size range of the ICAs and MCAs from the rest of the series, but the ICA with a precocious bifurcation was significantly larger and shorter. One of the common arterial colic trunks crossed the SMV anteriorly, and the other posteriorly. As for the ICA, the posterior crossing, which is more difficult to handle practically, is found in 28%-62% of the cases [10,11,12,16,22]. It is worth noting that the colic artery crossing pattern is independent of the ICA-GTH distance [16].

One of our cases with ICA absence had a slender accessory MCA arising above the common trunk and irrigating the splenic angle of colon. These types of arteries can be found in up to 25% of the cases [2].

Moreover, the surgical community today faces another paradigm change, namely, the significance of the “high tie”. While performing oncological surgery the attention of the surgeon is more focused on the surrounding lympho-vascular bundle (27) and its borders, and less on the blood vessel itself. The result of this approach is that more mesenteric tissue around the arterial origins is removed while preserving an intact lympho-vascular bundle, and the consequences can vary, (as we show in our cases) from de-vascularizing the transverse colon with a common trunk and no middle colic artery to arterial bleedings from an unsuspected vessel occurring in the area of the SMA and SMV, both anterior or posterior (Figures 2 and 5). There is little doubt that attempts to achieve hemostasis in these cases can lead to further injury of the SMA and SMV. On the other hand, previous surgery, e.g. a left colectomy would most probably lead to insufficient irrigation of the transverse colon, making a 3D roadmap a good aid in understanding the vascularization. On occasion, a careful analysis of the staging CT by the operating surgeon can in many cases provide enough data. Perhaps even more important are venous bleedings that can arise from the GTH or its branches that have been reported/underreported to cause fatal outcomes. It seems that such a vessel that replaces the ileocolic vein and drains into the GTH would be more than prone to cause a similar injury [29].

One of the plausible embryological explanations for the mentioned variations of the ileocolic vessels can be found in the remodelling, regression and obliteration of

vascular branches, through development of intraluminal pillars and folds, as a consequence of altered hemodynamic settings, i.e. flow shear stress [30], but this issue requires further studies.

Concerning the arterial network, the vast majority of bleeding in visceral surgery occurs in the area of the SMV surgical trunk, i.e. the space limited by the ICV and GTH [16,30]. This area also contains the fragile JVs or JIVs [3] which can be lacerated. Their topography is relevant, particularly if they are hidden by high-fat tissue. In our 5 cases, the JVs crossed the SMA posteriorly in 3 cases, anteriorly in 1 and in one there were JVs both anteriorly and posteriorly. This distribution agrees with the finding of Nakamura [31].

In conclusion, the preoperative visualization of the individual relevant 3D anatomy, accompanied with morphometry, will contribute to the safety of CME or D3 extended mesenterectomy for cancer, particularly in cases of anatomical variations.

REFERENCES

1. Lunniss, P.J. (2016) Large intestine, in: Gray's anatomy. The anatomical basis of clinical practice (editor-in-chief Standring S), Elsevier Limited, Philadelphia; pp.1136-1159. ISBN 978-0-7020-5230-9
2. Van Damme, J.P. and Bonte J. (1990) Vascular anatomy in abdominal surgery, Georg Thieme, Stuttgart, Germany. pp. 53-59. ISBN 13-743801-2
3. Gillot, C., Hureau, J., Aaron, C., Martini, R., Thaler, G., and Michels, N.A. (1964), The superior mesenteric vein, an anatomic and surgical study of eighty-one subjects. *J Int Coll Surg*, 41:339-369. PMID: 14147012
4. Keese, M., Schmitz-Rixen, T., and Schmandra, T. (2013), Chronic mesenteric ischemia: time to remember open revascularization. *World J Gastroenterol*, 19:1333-1337. doi: 10.3748/wjg.v19.i9.1333
5. Orfaniotis, G., Sacak, B., Nicoli, F., Ciudad, P., Gesakis, K., Lee, C.Y., and Chen, H.C. (2016), Absence of the ileocolic artery: Microsurgical implications in reconstruction of the esophagus with the free ileocolon flap. *Microsurgery*, 36:173-174. doi: 10.1002/micr.22392
6. Hohenberger, W., Weber, K., Matzel, K., Papadopoulos, T., Merkel, S. (2009), Standardized surgery for colonic cancer: complete mesocolic excision and central ligation—technical notes and outcome. *Colorectal Dis* 11:354–364. doi: 10.1111/j.1463-1318.2008.01735.x.
7. Nesgaard, J.M., Stimec, B.V., Bakka, A.O., Edwin, B., Bergamaschi, R., and Ignjatovic, D. (2019), Right Colectomy with Extended D3 Mesenterectomy: Anterior and Posterior to the Mesenteric Vessels. *Surg Technol Int*, 35:138-142. doi: PMID: 31237343
8. Yang, Y., Malakorn, S., Zafar, S.N., Nickerson, T.P., Sandhu, L., and Chang, G.J. (2019) Superior Mesenteric Vein—First Approach to Robotic Complete Mesocolic Excision for Right Colectomy: Technique and Preliminary Outcomes. *Dis Colon Rectum*, 62:894-897. doi: 10.1097/DCR.0000000000001412
9. Hameed, I., Aggarwal, P., and Weiser, M.R. (2019), Robotic Extended Right Hemicolectomy with Complete Mesocolic Excision and D3 Lymph Node Dissection. *Ann Surg Oncol*, 26:3990-3991. doi: 10.1245/s10434-019-07692-2

10. Nesgaard JM, Stimec BV, Bakka AO, Edwin B, and Ignjatovic, D. (2015), Navigating the mesentery: a comparative pre- and per-operative visualization of the vascular anatomy. *Colorectal Dis*, 17:810–818. doi: 10.1111/codi.13003
11. Negoï, I., Beuran, M., Hostiuc, S., Negoï, R.I., and Inoue, Y. (2018), Surgical Anatomy of the Superior Mesenteric Vessels Related to Colon and Pancreatic Surgery: A Systematic Review and Meta-Analysis. *Sci Rep*, 8:4184. doi: 10.1038/s41598-018-22641-x.
12. Wu, C., Ye, K., Wu, Y., Chen, Q., Xu, J., Lin, J., and Kang, W. (2019), Variations in right colic vascular anatomy observed during laparoscopic right colectomy. *World J Surg Oncol*, 17:16. doi: 10.1186/s12957-019-1561-4
13. Bruzzi, M., M'harzi, L., Poghosyan, T., Ben Abdallah, I., Papadimitriou, A., Ragot, E., El Batti, S., Balaya, V., Taieb, J., Chevallier, J.M., and Douard, R. (2020), Arterial vascularization of the right colon with implications for surgery. *Surg Radiol Anat*, 42:429-435. doi: 10.1007/s00276-019-02359-9
14. Lee, H., Yang, K., Choi, I.J., and Lee, J.H. (2015), The ileocolic vein passing through the ring-shaped part of ileocolic artery. *Surg Radiol Anat*, 37:1005-1007. doi: 10.1007/s00276-014-1408-1
15. Bergman, R.A., Thompson, S.A., Afifi, A.K., Saddeh, F.A. (1988) Compendium of human anatomic variation: text, atlas, and world literature. Urban & Schwarzenberg, Baltimore, USA. pp. 79-80 and p. 406. ISBN 0-8067-2502-8
16. Miyamoto, R., Tadano, S., Sano, N., Inagawa, S., Adachi, S., and Yamamoto M. (2017), The impact of three-dimensional reconstruction on laparoscopic-assisted surgery for right-sided colon cancer. *Wideochir Inne Tech Maloinwazyjne*, 12:251-256. doi: 10.5114/wiitm.2017.67996.
17. Safe D3 Right Hemicolectomy for Cancer Through Multidetector Computed Tomography (MDCT) Angio. Ignjatovic D. Available at: <https://clinicaltrials.gov/ct2/show/NCT01351714>; accessed 08.04.2020
18. Luzon, J.A., Andersen, B.T., Stimec, B.V., Fasel, J.H.D., Bakka, A.O., Kazaryan, A.M., and Ignjatovic, D. (2019) Implementation of 3D printed superior mesenteric vascular models for surgical planning and/or navigation in right colectomy with extended D3 mesenterectomy: comparison of virtual and physical models to the anatomy found at surgery. *Surg Endosc*, 33:567–575. doi: 10.1007/s00464-018-6332-8

19. Luzon, J.A., Kumar, R.P., Stimec, B.V., Elle, O.J., Bakka, A.O., Edwin, B., Ignjatovic, D (2019). Semi-automated vs. manual 3D reconstruction of central mesenteric vascular models: the surgeon's verdict. *Surg Endosc*, Nov 19. doi: 10.1007/s00464-019-07275-y
20. Sato, W., Watanabe, H., Nara, I., and Ito, H. (2017), Inflammatory aneurysm of ileocolic artery discovered on fluorine 18-fluorodeoxyglucose-positron emission tomography/computed tomography. *J Vasc Surg*, 66:1574-1575. doi: 10.1016/j.jvs.2016.07.132.
21. Zhang, D., Williams, W.D., and Lai, J. (2019), An Unusual Case of Cecal Mesenteric Dedifferentiated Liposarcoma Involving the Ileocolic Artery Resected by Right Hemicolectomy. *Anticancer Res*, 39:487-490. doi: 10.21873/anticancer.13138.
22. Hiroishi, A., Yamada, T., Morimoto, T., Horikoshi, K., and Nakajima, Y. (2018), Three-dimensional computed tomographic angiography with computed tomographic colonography for laparoscopic colorectal surgery. *Jpn J Radiol*, 36:698-705. doi: 10.1007/s11604-018-0775-7
23. Turmezei, T.D. and Cockburn, J.F. (2009) Digital subtraction angiography of the superior mesenteric artery: identifying arterial branches. *Clin Anat*, 22:777-779. doi: 10.1002/ca.20835
24. Cserni, T., Magyar, A., Németh, T., Paran, T.S., Csízy, I., and Józsa, T. (2006), Atresia of the ileocecal junction with agenesis of the ileocecal valve and vermiform appendix: report of a case. *Surg Today*, 36:1126-1128. doi: 10.1007/s00595-006-3302-x
25. Haywood, M., Molyneux, C., Mahadevan, V., Lloyd, J., and Srinivasaiah, N. (2016), The right colic artery: An anatomical demonstration and its relevance in the laparoscopic era. *Ann R Coll Surg Engl*, 98:560-563. doi: 10.1308/rcsann.2016.0257
26. Gamo, E., Jiménez, C., Pallares, E., Simón, C., Valderrama, F., Sañudo, J.R., and Arrazola, J. (2016), The superior mesenteric artery and the variations of the colic patterns. A new anatomical and radiological classification of the colic arteries. *Surg Radiol Anat*, 38:519-527. doi: 10.1007/s00276-015-1608-3
27. Nesgaard, J.M., Stimec, B.V., Soulie, P., Edwin, B., Bakka, A., and Ignjatovic, D. (2018), Defining minimal clearances for adequate lymphatic resection

- relevant to right colectomy for cancer: a post-mortem study. *Surg Endosc*, 32:3806-3812. doi: 10.1007/s00464-018-6106-3
28. Willard, C.D., Kjaestad, E., Stimec, B.V., Edwin, B., Ignjatovic, D., and RCC Study Group. (2018) Preoperative anatomical road mapping reduces variability of operating time, estimated blood loss, and lymph node yield in right colectomy with extended D3 mesenterectomy for cancer. *Int J Colorectal Dis*, 34:151-160. doi: 10.1007/s00384-018-3177-5.
 29. Garcia-Granero, A., Sánchez-Guillén, L., Frasson, M., Sancho Muriel, J., Alvarez Sarrado, E., Fletcher-Sanfeliu, D., Flor Lorente, B., Pamies, J., Corral Rubio, J., Valverde Navarro, A.A., Martinez Soriano, F., Garcia-Granero, E. (2018) How to reduce the superior mesenteric vein bleeding risk during laparoscopic right hemicolectomy. *Int J Colorectal Dis*, 33:235-239. doi: 10.1007/s00384-017-2940-3.
 30. Djonov, V.G., Kurz, H., and Burri, P.H. (2002), Optimality in the developing vascular system: branching remodeling by means of intussusception as an efficient adaptation mechanism. *Dev Dyn*, 224:391-402. doi: 10.1002/dvdy.10119
 31. Tan, K.Y., Moriya, Y., and Konishi, F. (2009), Small-bowel tumors with extensive mesenteric involvement can be resected with careful dissection of the mesenteric vessels with good outcomes. *Dis Colon Rectum*, 52:1184-1185. doi: 10.1007/DCR.0b013e3181a537fa
 32. Nakamura, M., Nakashima, H., Tsutsumi, K., Matsumoto, H., Muta, Y., Ueno, D., Yoshida, K., Hino, K., Urakami, A., and Tanaka, M. (2013), First jejunal vein oriented mesenteric excision for pancreatoduodenectomy. *J Gastroenterol*, 48:989-995. doi: 10.1007/s00535-012-0697-6

SUPPLEMENTARY MATERIAL

(The supplementary material are 3D PDF files, which should separately be downloaded and opened in Adobe Acrobat Reader, the 3D option enabled and then then please follow the instruction given below)

Supplementary material 1. Case 1. 3D PDF of the STL file derived from 3D segmentation in Mimics. On the “Views” drop-down menu, select “Detailed view” for captions.

Supplementary material 2. Case 2. 3D PDF of the STL file derived from 3D segmentation in Mimics. On the “Views” drop-down menu, select “Detailed view” for captions.

Supplementary material 3. Case 3. 3D PDF of the STL file derived from 3D segmentation in Mimics. On the “Views” drop-down menu, select “Detailed view” for captions.

Supplementary material 4. Case 4. 3D PDF of the STL file derived from 3D segmentation in Mimics. On the “Views” drop-down menu, select “Detailed view” for captions.

Supplementary material 5. Case 5. 3D PDF of the STL file derived from 3D segmentation in Mimics. On the “Views” drop-down menu, select “Detailed view” for captions.