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Arterial vascularization of the colon; a guide to surgical resection

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ABSTRACT

Background. Colorectal cancer is a commonly diagnosed neoplasia in men and women worldwide. This study aims to rigorously map the arterial distribution of the colon in order to assess the implications of vascular patterns in surgical resection. *Methods*. Cadaveric dissections were performed to explore the arterial distribution (including collateral blood flow) of the colon. The study used standard dissection tools and photographic documentation to detail the vascular architecture supporting the large intestine. *Results*. The dissection revealed important arterial branches and anastomoses in the area of the superior and inferior mesenteric arteries, which are able to ensure continuous local blood supply especially in cases of arterial ischemia. An important arterial anastomosis was identified between the right branch of the middle colic artery and the ascending branch of the right colic artery, as well as the specific distribution of the marginal artery of Drummond and Haller-Riolan anastomotic arch. *Conclusions*. The blood supply of the colon derived from both mesenteric arteries includes redundant arterial anastomoses, but which are critical in specific situations such as the approach and results of surgical resection. Understanding these vascular patterns and collateral pathways, as well as careful intraoperative surgical exploration, are essential for oncologic surgeons to ensure successful colic resections with minimal complications and morbidity.

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Introduction

Colorectal cancer is the fourth most commonly diagnosed cancer in men and the third most commonly diagnosed in women worldwide, with an increasing incidence every year [1]. Surgical resection is an important therapeutic procedure for treating solid tumors of the large intestine [2,3]. The extent of the resection is determined by the characteristics and local invasion of the tumor, as well as by the degree of blood vascularization of the colon and rectum [4]. Therefore, a comprehensive understanding of the distribution of the blood supply is essential to achieve a good oncological outcome by reducing postoperative complications and morbidity. As the COLOR study indicated, the prognosis also depends on the number of lymph nodes removed [5]. These lymph nodes are located along the major arterial vessels of the large intestine, which generally have a redundant arterial supply.

This redundancy arises from embryogenesis, as the superior mesenteric artery (SMA) is the central artery around which the digestive tract rotates during embryological development [6]. The blood flow to the digestive tract comes from three main arterial branches: the celiac trunk, the SMA, and the inferior mesenteric artery (IMA), originating from the abdominal aorta. The aorta forms during the third week of embryological development, so the abdominal structures initially receive nutrients from two dorsal aortas and a ventral and dorsal arterial supply [7]. As the embryo develops, this dual supply merges, with the two aortas combining after multiple arterial communications. Adult

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variations and collateral routes in the arterial supply of the colorectum exist due to the persistence of such dual structures [8]. The blood supply to the digestive tract arises from arteries of segments 10 (celiac trunk), 13 (SMA), and 21 (IMA), while other segmental arteries regress [9]. The celiac trunk supplies the foregut (stomach and duodenum), the SMA supplies the midgut (ileum, jejunum, and part of the colon), and the IMA supplies the hindgut (colon and rectum) [10]. Defining the exact limits, regions, and segments supplied by each artery is challenging due to numerous variations in their distribution [10]. Although inconsistent, these three arterial axes have many redundant collateral pathways between them, which are critically important for surgeons to achieve good oncological results (high lymph node yield, negative tumor margins) with low complications and morbidity.

This article aims to summarize the arterial distribution and, importantly, the collateral blood flow of the colon based on cadaveric dissections, from the perspective of surgical resections. The obtained results are presented and discussed, being at the same time compared with the data from the literature.

Materials and Methods

Study dissections were performed on five cadavers (three males and two females) at the department of anatomy, Carol Davila University of Medicine and Pharmacy, using a standard dissection kit consisting of forceps, scissors, and a scalpel. We captured photographs using a Nikon D700 camera (Nikon, Tokyo, Japan). The ethical committee approved the study (Approval number 237/14.10.2023). We positioned the cadavers in the supine position with their hands extended beside their bodies. The approach began with an abdominal incision starting from the xiphoid process, extending bilaterally and parallel to the costal edges towards both anterior-superior iliac spines. This process allowed us to reflect the abdominal wall flap inferiorly and gain direct access to the entire peritoneal cavity. The dissection started at the right parietocolic groove in the cecal region, entering the avascular plane of Toldt 1 retrocolic fascia. We continued the dissection cranially to the right colic angle, where we resected the right phrenic-colic ligament. The dissection then proceeded towards the mesentery on the right side, dissecting the pars tecta duodeni, which offered direct access to the root of the transverse mesocolon. After resecting the right gastrocolic ligament and identifying the root of the transverse mesocolon, we resected the sustentaculum lienis ligament and entered the left parietocolic groove. We incised the peritoneal reflection at Toldt 2 fascia and dissected the retrofascial space up to the root of the mesentery on the left side. We dissected and mobilized the root of the sigmoid mesentery, uniting the dissection planes and demonstrating the process. The dissection proceeded to the right mesenteric-colic region to identify the right ileocolic and colic vessels, highlighting the middle colic artery and its vein, the venous trunk of Henle, and the anastomotic arches in the transverse mesocolon. Finally, we continued the dissection towards the left mesenteric-colic region, identifying the origin of the inferior mesenteric artery and highlighting its branches along with the anastomotic vascular arches.

Results

The dissection began by revealing the blood supply to the cecum, ascending colon, and right colonic angle. We started by dissecting the root of the SMA from its emergence from the abdominal aorta, its main arterial axes within the transverse mesocolon, and the right mesocolon/ retroperitoneum (Figure 1).

Figure 1. Dissection of the mesentery to the right of the superior mesenteric artery. The green line denotes the arterial anastomosis between the right branch of the MCA and the ascending branch of the right colic artery. The red circle denotes the paucivascular area of Treves. Yellow lines indicate the straight colic vessels, originating from the paracolic arterial arches and providing direct blood supply to the colonic wall. Structures are numbered as follows: 1. Transverse colon, 2. Cecum, 3. Ileal and jejunal loops, 4. Ascending colon, 5. Superior mesenteric artery, 6. Middle colic artery, 7. Right branch of the middle colic artery, 8. Left branch of the middle colic artery, 9. Right colic artery, 10. Ileocolic artery.

The SMA, a primary branch of the abdominal aorta, emerges below the pancreas and crosses over the horizontal part of the duodenum. It branches off to the right to supply the colon (right colic artery, RCA; ileocolic artery, ICA; and middle colic artery, MCA) and to the left to supply the jejunal and ileal branches. The artery enters the mesentery's root, traveling between the anterior and posterior sheaths of the mesentery. We observed the trunks of the ICA and RCA (Figure 1) and the arterial anastomosis between the right branch of the MCA and the ascending branch of the RCA, marked by a green line in Figure 1. This collateral blood flow ensures a continuous blood supply if either of these two sources is obstructed or resected. The paucivascular area of Treves, devoid of large arterial arches or branches, is indicated by a red circle in the middle of Figure 1.

The straight colic vessels, marked by yellow lines, originate from the paracolic arterial arches and provide direct blood supply to the colonic wall. These vessels require the corresponding colonic wall to be resected if ligated or cut as they offer a terminal blood supply. We also noted the lateral and posterior positioning of the arteries relative to the veins (Figure 1), a distribution constant throughout the colon, significant in dissections.

Continuing logically to the left, we examined the arterial and venous distribution of the transverse colon, left colon, and left colonic angle. Figure 2 noted the unusually rich vascular supply to the left colonic angle in this cadaver. Here, the left and right branches of the MCA are visible.

Figure 2. Blood supply to the transverse colon. The green arch denotes the right left Branch of middle colic artery. The yellow arch marks the ascending branch of the left colic artery. Structures are numbered as follows: 1. Transverse Colon, 2. Superior Mesenteric Artery and Vein, 3. Right Colic Artery, 4. Middle Colic Artery.

The left branch of the MCA (red) forms an anastomosis with the ascending branch of the left colic artery (LCA, yellow) and a collateral intermesenteric anastomosis, ensuring adequate blood supply to the colonic wall if there is an obstruction in either the superior or inferior mesenteric artery territories. We observed multiple terminal branches of the paracolic anastomosis that directly feed the colonic wall (straight colic branches).

The dissection examined the blood supply of the descending colon (Figure 3), showing in detail the left paracolic blood vessels and the Haller-Riolan arterial anastomosis between the SMA through the MCA and the IMA through the LCA.

Figure 3. Blood supply to the left half of the transverse colon, left colic angle, and descending colon. Structures are numbered as follows: 1. Omentum, 2. Transverse Colon, 3. Left Colic Angle, 4. Descending Colon, 5. Sigmoid Colon, 6. Left Branch of the Middle Colic Artery, 7. Ascending Branch of the Left Colic Artery, 8. Inferior Mesenteric Vein.

This collateral pathway ensures blood supply to the left colon in cases of high ligation of the IMA. We also tracked the trajectory of the inferior mesenteric vein, which runs medially to the artery and ends cranially in the retroduodenal fossa. If mobilization of the left colon is required, then the vein can be resected to gain an additional length of 5 to 7 cm.

Moving distally toward the IMA, we showcased the blood supply characteristics to the sigmoid colon (Figure 4). We observed the IMA with the sigmoid trunk, where multiple sigmoid arteries branch off. Each artery splits into ascending and descending branches, forming multiple redundant arterial anastomoses in the mesosigmoid, akin to the arterial arches in the mesentery of the jejunum and ileum (Figures 4 and 5).

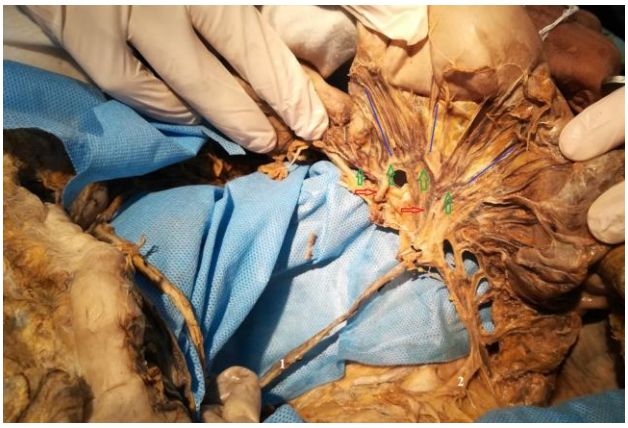

Figure 4. Dissection of the mesosigmoid. Structures are numbered as follows: 1. Inferior mesenteric vein, 2. Inferior mesenteric artery. The red arrows indicate the arterial sigmoid branches from the sigmoid arterial trunk. The green arrows denote the ascending and descending branches of the sigmoid branches forming arterial anastomoses in the mesosigmoid. The blue lines show the trajectory of the straight colic arteries emerging from paracolic arterial arches.

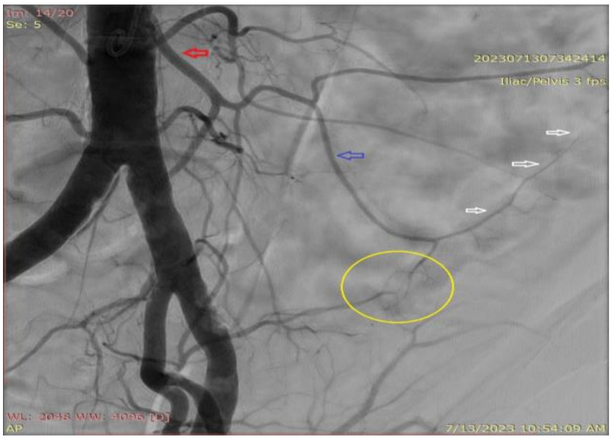

Figure 5. Angiographic view of the inferior mesenteric artery. The red arrow shows the trunk of the inferior mesenteric artery, the blue arrow denotes the sigmoid artery, the white arrow shows the paracolic artery (Drummond), and the yellow circle indicates the weak anastomosis between the rectal artery and an inferior branch of the sigmoid arteries.

Terminal straight colic arteries emerge from these arches to feed directly into the sigmoid colon's wall (Figures 4 and 5). The typical positioning of the veins anterior to the arteries (Figures 1 and 4) was noted. Both veins and arteries, situated superficially under the peritoneum, can easily rupture during dissection. Figure 6 provides a complete schematic representation of the colon's blood supply, originating from the superior and inferior mesenteric arteries.

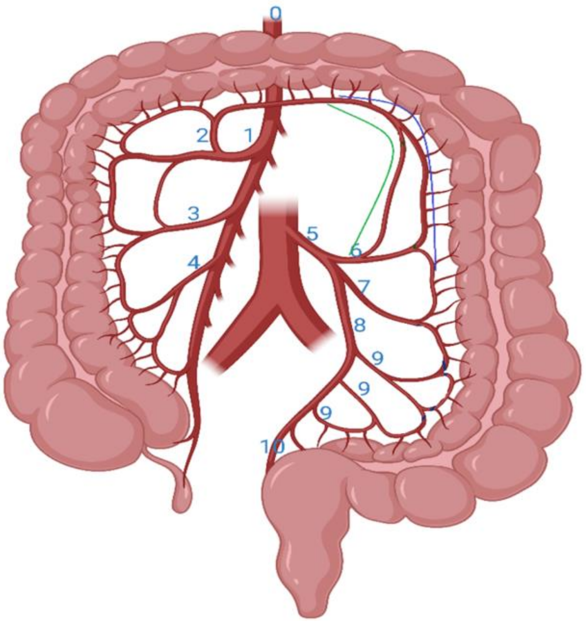

Figure 6. (received from biorender.com) Schematic overview of dissections demonstrating the rich blood supply of the colon via the superior and inferior mesenteric arteries. The green line marks the intermesenteric arterial arch (Haller-Riolan), and the blue line denotes the intermesenteric arch (Drummond or the marginal colonic artery). Structures are numbered as follows: 0. Superior mesenteric artery, 1. Right colic artery, 2. Middle colic artery, 3. Ileocolic artery, 4. Inferior mesenteric artery, 5. Left colic artery, 6. Sigmoidian arteries, 7. Superior rectal artery. It highlights the numerous redundant arterial anastomoses between these two primary aortic branches. Of particular significance are the Haller-Riolan anastomotic arch, situated distally to the colon wall in the mesentery, and the Drummond or marginal colonic artery, located close to the colonic wall also in the mesentery. Both structures are crucial for maintaining an adequate blood supply to the colon in cases where the main arterial branches are ischemic. These arterial pathways are invaluable assets for oncologic surgeons.

Discussions

The colon's blood supply primarily centers around the SMA, which descends through the mesentery after originating from the abdominal aorta. In rare instances (less than 1%), the SMA may form an anastomosis with the celiac artery, creating a common arterial trunk, a variation that may be accompanied by stenosis at its emergence from the aorta [11]. The MCA, the SMA's first branch serving the colon, emerges below the uncinate process of the pancreas and supplies the transverse colon. This artery forms significant arterial arches with neighboring arteries, including the IMA, as evidenced by our cadaveric dissections. Variations in its origin are noted in approximately 25% of individuals, and the artery may be absent in up to 9% of cases [12,13]. In such scenarios, the RCA, which becomes significantly enlarged, compensates for the absence of the MCA.

As Figure 2 illustrates, the MCA branches into two terminal branches (left and right), forming redundant anastomoses with both the RCA and the LCA. The splenic angle of the colon receives blood from the SMA through the MCA in only 11% of cases, with the majority receiving supply from the IMA through the LCA's ascending branch [14,15]. In cases of IMA obstruction, blood flow reverses, with the MCA ensuring adequate supply of the left colonic angle. This has significant implications for resections of the transverse colon that necessitate MCA ligation. We recommend (if possible), in cases of transversectomy, extending the resection to include the left colic angle to guarantee sufficient blood supply to the subsequent anastomosis.

The next branch from the SMA is the RCA, which may arise individually or in conjunction with the ICA. It supplies the ascending colon and exhibits wide variability in its distribution, emerging as a separate structure in only 13% of cases [16] and completely absent in 20% of patients [17]. The ICA, the SMA's last and most consistent branch, offers collateral supply to the terminal ileum, cecum, appendix, and right colon. The cecum receives blood from two arteries, the anterior and posterior cecal arteries, which stem from the ICA's ileal branch. The appendicular artery emerges from the posterior cecal branch, supplying the appendix. This branch forms an anastomosis with the

SMA's terminal branch, creating a marginal vascular arch with no other arterial anastomoses, as shown in Figure 1.

The IMA provides blood to the left colon, originating approximately 3 to 4 cm above the aorta's bifurcation and 7 cm below the SMA [18]. Its first branch, the LCA, ascends toward the splenic flexure, branching into ascending and descending arms. However, variability exists, and the LCA may be absent in 15% of individuals [19]. In such cases, the marginal colic artery assumes its role, supplying blood from both the sigmoid arteries and the MCA.

The sigmoid trunk, emerging from the IMA, branches out in the sigmoid mesentery, bifurcating into ascending and descending branches. These branches form multiple arterial anastomoses, creating a paracolic arterial arch extending to the cecum between the two mesenteric arteries. Extensive collateral circulation exists between the SMA, IMA, and the celiac trunk, ensuring an adequate blood supply in the event of an obstruction. We will discuss some critical collateral arterial pathways essential for colonic resection.

The Marginal Artery of Drummond, an arterial arch between the SMA and IMA located approximately 2-3 cm from the mesenteric wall of the colon [20], is the first collateral pathway. The vasa recti (straight terminal colonic vessels) emerge from this artery, feeding directly into the colonic wall. This artery, better developed in the left colon, spans from the cecum to the sigmoid, as demonstrated in Figure 5. However, it has a weak region at the splenic flexure known as Griffith's point [21], where the arterial anastomosis is small-caliber and up to 30% of individuals exhibit inadequate blood flow [22]. This region requires special attention in clinical practice due to its frequent association with ischemic colitis. In oncological cases that necessitate high IMA ligation for lymph node removal, assessing the patency of this arterial arch is crucial, potentially through arteriography or intraoperative indocyanine green imaging, which evaluates blood flow in this region after clamping but not resecting IMA [23]. Without these resources, surgeons should avoid anastomosis at the splenic flexure to prevent compromised healing and subsequent fistula formation. If patent, this artery can supply the entire left colon in cases of IMA blockage due to atherosclerosis or surgical resection.

The Arc of Riolan, an arterial anastomosis between the MCA and the LCA [24], is another critical collateral colon blood flow pathway. Located deep within the mesentery, it contrasts with the Marginal Riolan Artery, situated merely 3 cm from the colonic wall. Present in only 7% of individuals, the Arc of Riolan should not be presumed a consistent collateral pathway unless macroscopically confirmed [25].

Sudeck's point, identified as both a collateral pathway and a choke point [26], signifies an arterial anastomosis between the systemic and visceral arterial circulation through the upper rectal artery (a branch of the mesenteric artery) and the middle rectal artery (a branch of the internal iliac artery). Contrary to past beliefs that IMA ligation would lead to necrosis of the upper rectum, extensive intramural anastomosis from the middle or inferior rectal arteries ensures the blood supply and perfusion of the middle and upper rectum [10,27]. In cases of locally advanced cancers requiring extensive dissection and resection near the pelvic wall, alongside high IMA ligation removing two primary arterial sources of the rectum (superior and middle rectal arteries), it is preferable to leave a short rectal stump. This stump will receive blood supply from the inferior rectal artery, ensuring adequate anastomosis healing.

Lastly, the artery of Moskowitz [28], forming between the trunk of the MCA and the ascending branch of the LCA, represents the fourth collateral arterial supply of the colon. While its exact trajectory is debated, with some suggesting it may be another branch of the Riolan arch, it typically lies near the root of the colonic mesentery. This artery, encountered during the dissection of the Toldt 2 fascia of the descending colon, enlarges significantly when the SMA or IMA is obstructed, with its pulsation detectable upon palpation.

Such collateral pathways play a critical role in clinical practice, especially in patients with atherosclerotic disease, where they expand substantially. The slow accumulation of atheromatous plaques allows these pathways to develop, thereby preventing ischemia, a factor particularly pertinent in older individuals. Conversely, in younger patients facing acute arterial obstruction (e.g., thrombosis), these collateral pathways often lack the time to adjust and expand, leading to bowel ischemia [29]. Another crucial consideration in surgical oncology is the centripetal lymphatic drainage of the colon, which follows the main arterial axis. High ligation of the arteries, especially the IMA (emerging from the aorta below the third part of the duodenum), is imperative to secure an adequate count of lymph nodes [18]. In such instances, the blood supply to the superior rectum is maintained by the middle rectal artery, whereas the transverse colon receives blood from the SMA via the MCA. However, any anastomosis formed between these structures should not extend beyond 10 cm from the superior rectum.

This study's limitations stem from the relatively small number of cadavers dissected, although human anatomy tends to be remarkably consistent, particularly concerning the major arterial vessels. Administrative constraints and legislation within the European Union and our country limit access to a larger number of cadavers, yet our findings align closely with the existing literature.

Conclusions

In conclusion, the blood supply to the colon, primarily from the superior and inferior mesenteric arteries, includes several vital redundant arterial anastomoses between these two main branches of the aorta. Of particular importance are the Haller-Riolan anastomotic arch, found distal to the colon, and the Drummond or marginal colonic artery, located near the colonic wall. These structures play a critical role in ensuring an adequate blood supply to the colon under ischemic conditions, thereby significantly guiding oncological surgeons.

Compliance with ethical standards

Any aspect of the work covered in this manuscript has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

Conflict of interest disclosure

There are no known conflicts of interest in the publication of this article. The manuscript was read and approved by all authors.

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