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Arc of Riolan revisited — proposal of a new classification system

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Background: *The arterial supply of the large colon is provided by the superior mesenteric artery (SMA) and inferior mesenteric artery (IMA). A particularly important area, especially in the field of colorectal surgery, is the splenic flexure of the colon. There is a noticeable misunderstanding in the correct nomenclature of the major arterial anastomoses between SMA and IMA — Drummond's Marginal Artery (DMA), Arc of Riolan (AOR), and Moskovitz Artery (MA). The aim of this study is to organise the nomenclature and propose a new simplified one to facilitate communication between physicians of various specialties.*

Materials and methods: *Fourteen formalin-fixed cadavers (9 male, 5 female) accessible from the Chair of Anatomy of the Jagiellonian University Collegium Medicum were dissected to examine and describe the anatomical variations of anastomoses between SMA and IMA.*

Results: *The artery of Drummond was present in all 14 specimens maintaining the continuity of the vessel along its entire course. The Arc of Riolan was found in 7 out of 14 cadavers (50%). The artery of Moskovitz was not found. The average length measured between IMA and aortic bifurcation and between IMA and SMA was 51.00 mm and 84.68 mm, respectively.*

Conclusions: *SMA and IMA anastomoses form an arterial network that is characterised by high variability and trail in surgically strategic areas. For this reason, simplifying the terminology and using unambiguous names of these vessels based on their trail and anatomical relationship with IMV are crucial for the proper planning and execution of surgical procedures performed on the colon.* (Folia Morphol 2024; 83, 3: 707–715)

Keywords: intermesenteric anastomosis, IMA, SMA, Moskowitz artery, inferior mesenteric vein, cadaveric study

INTRODUCTION

The arterial supply of the large colon is provided by the superior mesenteric artery (SMA) and inferior mesenteric artery (IMA). These 2 arterial vessels arise from the abdominal aorta consecutively at the L1 and L3 vertebrae level. The IMA arises from the abdominal aorta slightly to the left of the median line of the human body, on average 4–5 cm above the aortic bifurcation. IMA normally divides into the superior rectal artery (SRA), sigmoid arteries (SA), and left colic artery (LCA) with descending (DBLCA) and ascending branches (ABLCA). However, in the

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subject literature, up to 43% of cases have an additional artery that emerges from the IMA or LCA and joins the Drummond marginal artery (DMA) medially to splenic flexure of colon, known as the arc of Riolan (AOR) [18]. The issue is that in a significant number of papers the arc of Riolan is confused with the Moskowitz artery (MA), also known as the meandric mesenteric artery, meso mesenteric artery, arch of Treves, central intermesenteric arch, or the artery of Gonzalez [11]. The Moskowitz artery is an anastomosis between the IMA and SMA, which can also be found as a direct connection of their trunks or branches, for example between the LCA and the middle colic artery (MCA), or the LCA and the accessory middle colic artery (AMCA) [3]. The Moskovitz artery is a vessel that runs medial to the arc of Riolan, and therefore closer to the inferior mesenteric vein (IMV) and the duodenum [8]. The specific trajectory of the AOR and MA can be substantial to preoperative imaging, avoiding injury to these vessels, which can easily provide ischaemia of the large colon. The purpose of this paper is to describe the different pathways of the AOR and to indicate why the differentiation between the MA, AOR, and the ascending branch of the LCA must be made, especially in surgical cases requiring mobilisation of the left colonic flexure and preparation of splenic flexure avascular space (SFAS) above the ventral edge of the pancreas (VEOP) [8]. Bearing in mind that the branches and anastomoses mentioned above are not the only vascular variations of this anatomical region, the authors recognise the AOR and MA as the most important ones considering their incidence, clinical implications, and reports, and especially considering the anatomical relationship with the IMV and IMA branching pattern itself [13].

MATERIALS AND METHODS

For this work, the authors dissected 14 formalin-fixed specimens (9 male, 5 female) accessible from the Chair of Anatomy of the Jagiellonian University Collegium Medicum. The access to the abdominal cavity was obtained by an bilateral longitudinal incision along anterior axillary line from the level of the first costa down to the anterior superior iliac spine and the transverse incision on the level of the first rib. The small bowel was mobilised and moved to the right to expose the parietal peritoneum on the posterior abdominal wall containing the aorta, the IMA, and its branches. Beforehand, every fold with probable vessels was established to protect them while stratifying the parietal peritoneum.

To receive clinically meaningful results, 3 measurements were conducted:

1. The distance between the aortic bifurcation and the origin of the IMA from the abdominal aorta.
2. The distance between the origin of the IMA and the SMA.
3. The vertebral level of aortic bifurcation and the origin of the IMA.

To obtain accurate measurements, the authors used an electronic calliper GEKO G01494 accurate to 0.01 mm. Long anatomical needles were used to mark the crucial points. Each time for the first and the second survey, 4 measurements were performed. Whereas the vertebral level was determined by palpating the promontory (S1/L5) with the wing of sacrum and by going upwards, finding a consecutive transverse process, and projecting them for proper anatomical tags. The statistical analysis and Student's test were conducted with Statistica version 13.3 (StatSoft) provided by Jagiellonian University Collegium Medicum. It should be mentioned that 2 of the 14 specimens were taken to the crematory during the measuring process; hence, the absence of 2 morphometric measures. All specimens that underwent a surgical procedure on the abdomen, with destroyed vascular net due to an accident or every other reason causing change of the vascularisation, were excluded from the study.

RESULTS

Anatomical variation

Fourteen formalin-fixed specimens were dissected and examined. The IMA, SMA, and Drummond's marginal artery (DMA) were found in 100% of cases. The arc of Riolan (AOR) was present in 50% of the specimens, creating an additional anastomosis between the IMA and SMA by connecting the left colic artery (LCA) or its ascending branch (ABLCA) and the left branch of the middle colic artery (LBMCA) or Drummond's marginal artery (DMA). The Moskowitz artery (MA) — the direct anastomosis between the trunks of the IMA and SMA – was not found. Respectively, each AOR crossed superficially the inferior mesenteric vein (IMV) (Fig. 1, 2).

Morphometric measures

The aortic bifurcation was most frequently projected at the level of the fourth lumbar vertebra

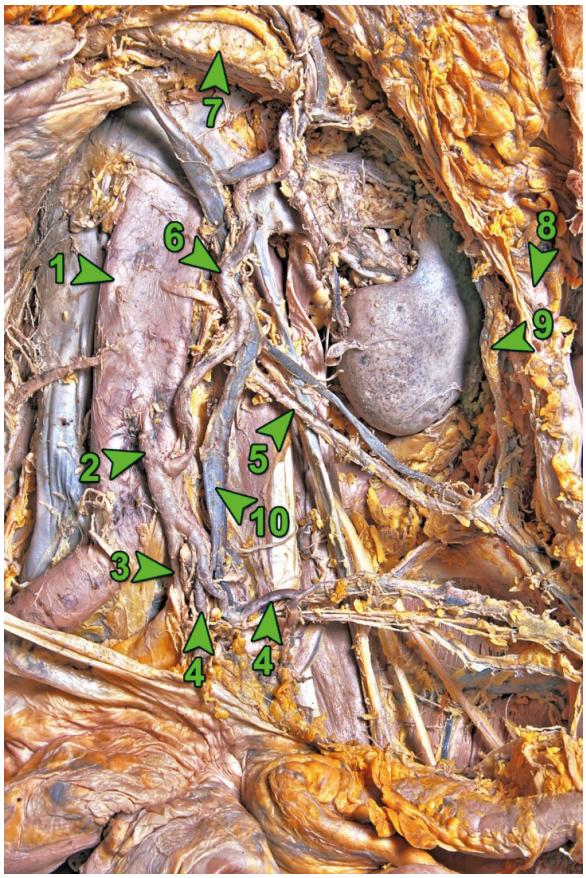

Figure 1. Specimen with dissected abdominal aorta and splenic flexure avascular space. Visible inferior mesenteric artery branches including the arc of Riolan crossing the inferior mesenteric vein; 1 — abdominal aorta; 2 — inferior mesenteric artery; 3 — superior rectal artery 4 — sigmoid arteries; 5 — left colic artery; 6 — arc of Riolan crossing the inferior mesenteric artery; 7 — ventral edge of the pancreas; 8 — descending colon; 9 — Drummond's marginal artery; 10 — inferior mesenteric vein.

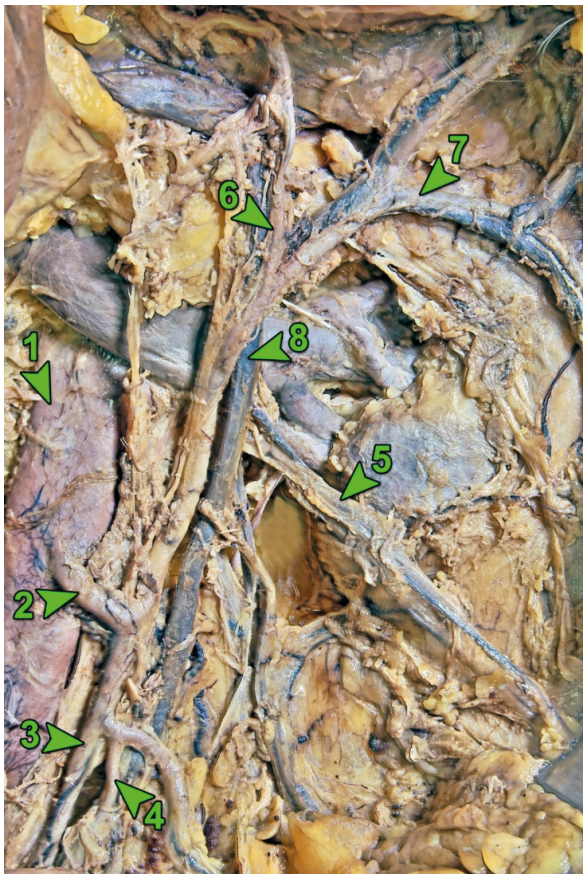

Figure 2. Specimen with dissected abdominal aorta and splenic flexure avascular space. Visible inferior mesenteric artery branches including the arc of Riolan crossing the inferior mesenteric vein; 1 — abdominal aorta; 2 — inferior mesenteric artery; 3 — superior rectal artery; 4 — sigmoid arteries; 5 — descending branch of left colic artery; 6 — arc of Riolan crossing the inferior mesenteric artery; 7 — ascending branch of left colic artery; 8 — inferior mesenteric vein.

Table 1. Projection of aortic bifurcation.

	L3/L4	L4	L4/L5	L5
Bifurcation aortae	2	7	1	2
Bifurcation aortae [%]	16.70%	58.30%	8.30%	16.70%

Table 2. Projection of inferior mesenteric artery (IMA).

	L2	L3	L3/L4	L4
IMA	3	7	1	1
IMA [%]	25.00%	58.30%	8.30%	8.30%

L4 (Tab. 1), whereas the origin of the IMA at third lumbar vertebra L3 (Tab. 2). The mean length between the origin of the IMA to aortic bifurcation was 51 mm +/– 1.37 mm. The Distance from the SMA to the IMA was measured as 84.68 mm +/– 1.94 mm. Student's test showed a p-value of 0.08176 for IMA-SMA distance as compared to the result obtained by Nakayama et al. in 2017 [12], whilst a p-value of 0.00939 for IMA-aortic bifurcation as referred to by Cai et al. in 2017 [4].

DISCUSSION

The main purpose of this article is to organise the anatomical nomenclature of the main anastomoses between the SMA and IMA and to propose one that is simpler and clinically relevant. Substantially, there is complete unison regarding the course and the name of Drummond's marginal artery. The authors have observed, however, a tendency in the subject literature to confuse the term AOR with MA [2, 6, 10, 11, 16, 18]. Despite the fact that many reports emphasise the

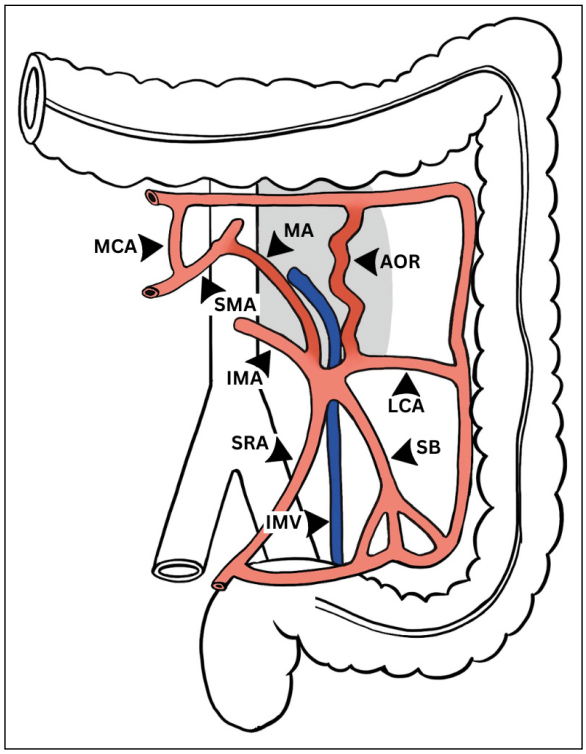

Figure 3. The anatomical relation between the arc of Riolan, Moskowitz's artery, and inferior mesenteric vein with marked splenic flexure avascular space (grey area); AOR — arc of Riolan; IMA — inferior mesenteric artery; IMV — inferior mesenteric vein; LCA — left colic artery; MA — Moskowitz's artery; MCA — middle colic artery; SB — sigmoid branches; SFAS — splenic flexure avascular space marked as the grey space; SMA — superior mesenteric artery; SRA — superior rectal artery.

necessity to systematise the anatomical nomenclature of the arterial connections of the left flexure of the colon, together with the clinical implications relating to colon ischaemia, anastomotic leakage, and damage to vessels running in the vicinity of the IMV during surgical procedures in this area, differences can still be observed at the level of understanding such terms as the arc of Riolan or Moskovitz's artery. Some authors claim that the anastomosis between the IMA and the SMA is named the intermesenteric artery whereas the names Moskowitz artery and arc of Riolan are just eponyms, which simply neglects the pathway of these 2 vessels [10, 19]. It is worth emphasising the existence of articles in which the distinction between the terms AOR and MA is described [8, 9].

Bruzzi et al. [3] published a paper with a certain approach to unifying the nomenclature in this matter. They claim that all the eponyms like arc of Riolan, Moskowitz's artery, meandric mesenteric artery, etc. should no longer be used. To identify them correctly, other phrasing was suggested, such as the following: arch of the first order, the most peripheral and the most frequent: the marginal artery, arch of the second order, the "V" termination of the ascending branch of the left colic artery, arch of the third order, more central: the inter-mesenteric trunk. The concept of the arch of the first, second, and third order certainly simplifies and unifies this classification, but the authors could not find any other sources using it.

Garcia-Granero et al. [8] accurately described the reduction in the splenic flexure avascular space (SFAS) associated with the presence of the arc of Riolan or Moskovitz's artery. The conclusion of the above-mentioned study confirms that the presence of a central anastomosis (Moskovitz's artery) significantly reduces the avascular space of the colon, thus increasing the risk of damage to important anastomosis running in the vicinity of the IMV with all its consequences. The presence of the arc of Riolan may cause technical problems, but the risk of damage to this vessel is much lower due to the greater distance from the ligated vein. Figure 3 shows all 3 main anastomoses between the SMA and IMA with marked SFAS. It is easy to observe the different course of the vessels, which was the basis of the authors' reflections and the classification itself. Clinical consideration is desirable and frequent in a great number of papers [1, 5, 14, 15]. High ligation of IMV is a stage of many surgical procedures performed on the colon that require splenic flexure mobilisation [1, 7, 8, 14, 17]. It is crucial to understand that Moskovitz's artery is an arterial vessel directly adjacent to the IMV (central intermesenteric anastomosis); thus, when the high ligation of IMV is performed there is a high probability of damaging the MA, causing arterial oozing with further consequences. Figure 3 shows the course of the MA with marked IMV course. Second, a more frequent anastomosis is the arc of Riolan, the course of which is presented in Figure 4. When the AOR is present there is also a probability of damaging this vessel during high IMV ligation/preparation of SFAS; however, the avascular space of the critical zone is present but reduced (contrary to the situation with the MA where there is no avascular space). Nonetheless, looking for and preserving the AOR during high IMV ligation is a crucial step in preventing colon ischaemia [17].

If anastomosis between the IMA and SMA exists, the additional portion of blood is flowing from the SMA to IMA's branches [5]. When an SMA obstruction occurs, reverse flow from the IMA to the SMA territory through the intermesenteric artery (IA), due to

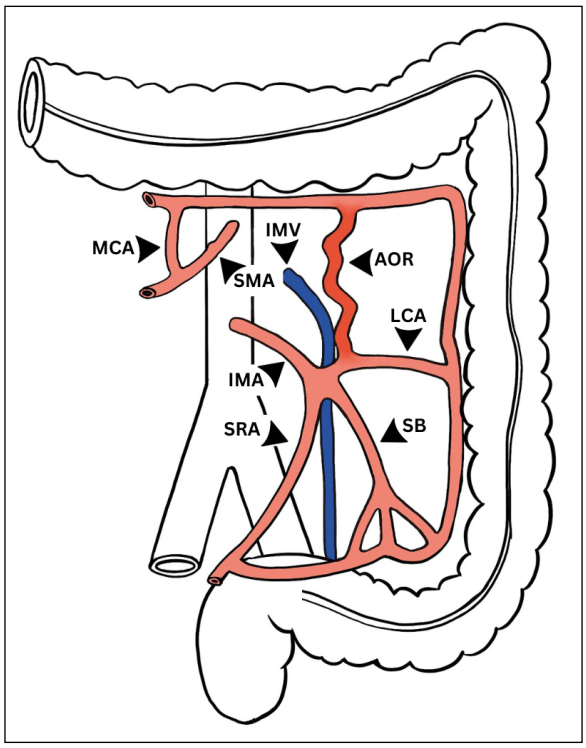

Figure 4. The anatomical relation between arc of Riolan and inferior mesenteric vein; AOR — arc of Riolan; IMA — inferior mesenteric artery; IMV — inferior mesenteric artery; LCA — left colic artery; MCA — middle colic artery; SB — sigmoid branches; SMA — superior mesenteric artery; SRA — superior rectal artery.

reduced blood pressure in the SMA and its branches, is able to supply the entire small bowel and the right half of the colon.[5] Additionally, anastomoses such as MA and AOR significantly avert local ischaemia in Griffith's Point (splenic flexure), where the vascularisation is often inconsistent [3, 18].

During their research the authors detected other misconceptions between AOR and ascending branch of left colic artery (ABLCA) (Fig. 5). The authors could not find any source that tried to distinguish when calling an artery AOR or ABLCA is legitimate. This problem should also be addressed in other scientific papers. Knowing that Drummond's marginal artery is created due to the connection between the branches of the sigmoid, left colic, and middle colic arteries, and the authors have seen the divisions of LCA very near the descending colon, they assumed a classification showed in Figure 6 and Figure 7. Due to this incoherence, they saw some authors for whom the AOR is ABLCA and Moskowitz's artery, so direct connection between the SMA and IMA was named the arc of Riolan [16].

In the authors' opinion, ordering the anatomical nomenclature of the main arterial anastomoses between the SMA and IMA requires referring the course of these arterial vessels to IMV. Otherwise, the multitude of anatomical variants of anastomoses between the IMA and SMA prevents proper diagnosis of the vessel and the use of this knowledge in practice. The probable reason for the lack of consensus on this issue may be an overly theoretical approach to the matter.

Hereby, the authors depict their proposition of classification for these arteries.

Drummond's marginal artery — DMA or arch of the first order

As already mentioned, there is unison on the pathway of DMA created by branches of the MCA, LCA, and Sigmoid branches.

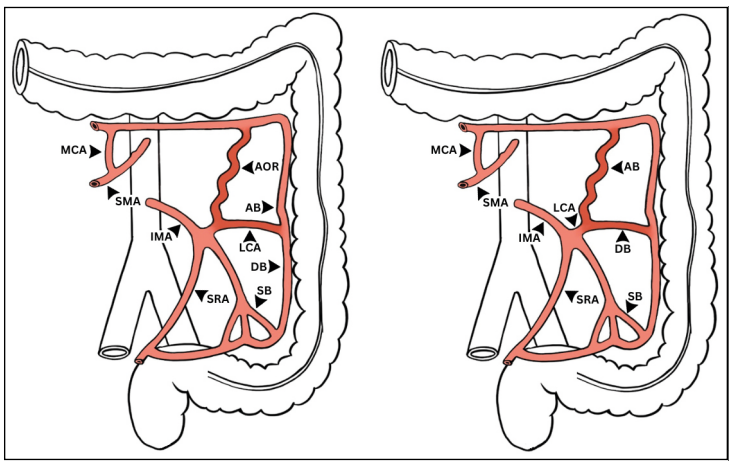

Figure 5. Two possible interpretations of the left colic artery division; AB — ascending branch; AOR — arc of Riolan; DB — descending branch; IMA — inferior mesenteric artery; LCA — left colic artery; MCA — middle colic artery; SB — sigmoid branches; SMA — superior mesenteric artery; SRA — superior rectal artery.

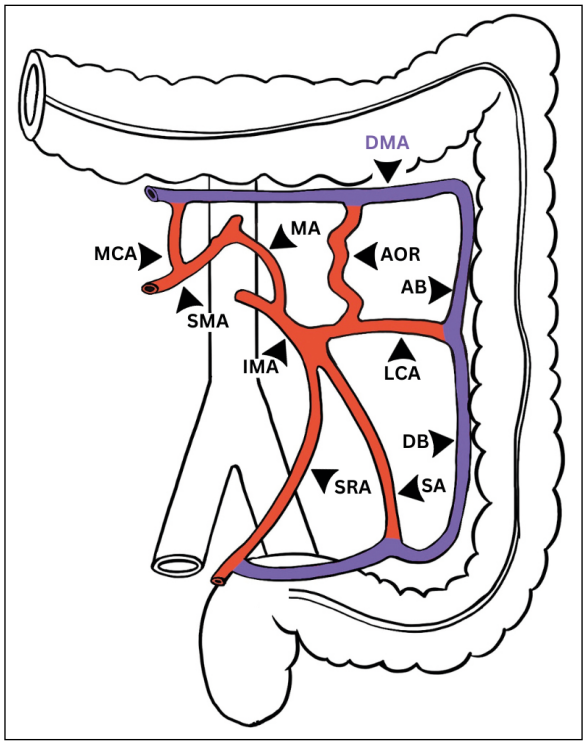

Figure 6. Variants of vascularisation of the large colon; AB — ascending branch; AOR — arc of Riolan; DB — descending branch; DMA — Drummond's marginal artery; IMA — inferior mesenteric artery; LCA — left colic artery; MA — Moskowitz's artery; MCA — middle colic artery; SA — sigmoid artery; SMA — superior mesenteric artery; SRA — superior rectal artery

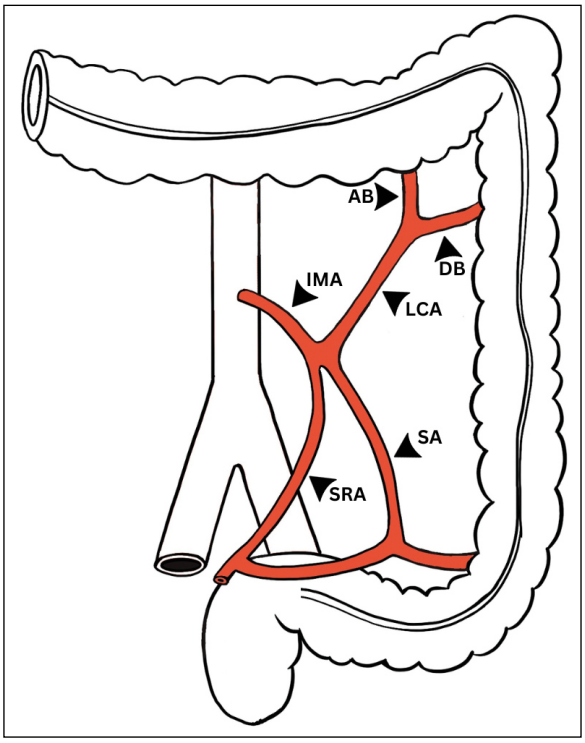

Figure 7. Variant with high division of LCA (Fig. 4) without AOR; AB — ascending branch; DB — descending branch; IMA — inferior mesenteric artery; LCA — left colic artery; SA — sigmoid arteries; SRA — superior rectal artery

The arc of Riolan — AOR or arch of the second order

In the authors' view, the AOR is the indirect anastomosis between the IMA and SMA. It does not matter whether the beginning of this branch is directly attached to the trunk of IMA or the left colic artery, but the trajectory of the AOR is initially always related to the pathway of the inferior mesenteric vein (IMV) in the parietal peritoneum [Figure 4]. On a certain level these 2 vessels go separate ways — the AOR more laterally and the IMV more medially. Because of this, the AOR relevantly minimises the splenic flexure avascular space (SFAS), which can be dangerous while operating in this area [8]. The AOR adjoins Drummond's marginal artery — DMA/left branch of middle colic artery — LBMCA medially to the splenic flexure of colon.

Moskowitz's artery — MA or arch of the third order

There are 3 possible pathways of Moskowitz's artery, which is a more direct anastomosis between the IMA and SMA. It is crucial to understand that the course of MA is strictly related with that of the IMV. MA completely abolishes the SFAS due to its more medial course than the AOR (Fig. 8–10). It is possible to find the origin of MA attached to the trunk of the IMA (Fig. 8), to the left colic artery or its branches (Fig. 9), or even to the AOR (Fig. 10). Finally, MA abuts to the trunk of the SMA or to the trunk of the MCA. In Figures 8–10 the MA is shown connecting to the trunk of the SMA, but it could also be connected to the trunk of the MCA.

CONCLUSIONS

SMA and IMA anastomoses form an arterial network that is characterised by high variability and trail in surgically strategic areas. For this reason, simplifying the terminology and using unambiguous names of these vessels based on their trail and anatomical relationship with IMV are necessary for the proper planning and execution of surgical procedures performed on the colon. In the authors' opinion, the anatomical classification of the main anastomoses between the SMA and IMA should be based on the course of the IMV in relation to arterial connections. This point of view facilitates a practical approach to

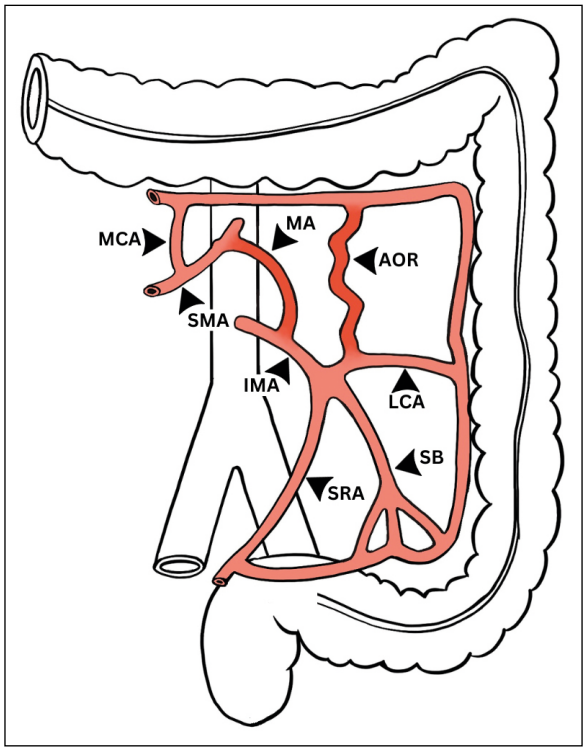

Figure 8. Scheme of possible anatomical relation between the arc of Riolan and Moskowitz's artery; AOR — arc of Riolan; IMA — inferior mesenteric artery; LCA — left colic artery; MA — Moskowitz's artery; MCA — middle colic artery; SB — sigmoid branches; SMA — superior mesenteric artery; SRA — superior rectal artery.

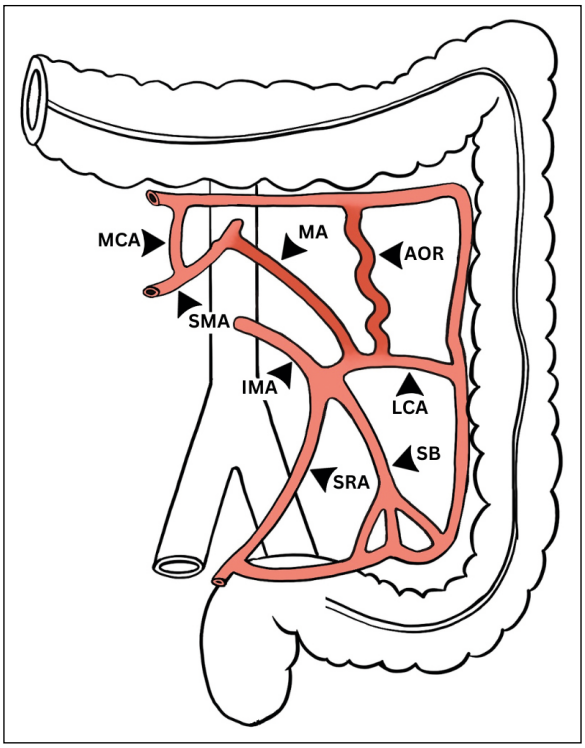

Figure 9. Scheme of possible anatomical relation between the arc of Riolan and Moskowitz's artery; AOR — arc of Riolan; IMA — inferior mesenteric artery; LCA — left colic artery; MA — Moskowitz's artery; MCA — middle colic artery; SB — sigmoid branches; SMA — superior mesenteric artery; SRA — superior rectal artery.

nomenclature and eliminates the impact of the enormity of anatomical variations in this region. Awareness of the not uncommon occurrence of arteries in the vicinity of the IMV should reduce the rate of arterial bleeding during high ligation of the IMV.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement

Data supporting reported results can be provided when requested from the corresponding author.

Ethics statement

All the cadavers used in this study were sourced by the legal procedure of donating the body to science. This practice is used widely in Poland to give students and researchers the possibility to thrive in the field of medicine.

Author contributions

First authors, Filip Keska and Julian Radon, oversaw the cadaveric study, statistical analysis, concept, and processing of this paper. Professor Jerzy Walocha, Professor Artur Pasternak, and Doctor Aleksiej Juszczak, second authors, supervised and had custody of this scientific work.

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Conflict of interest

Hereby, the authors declare that they do not have any conflict of interest.

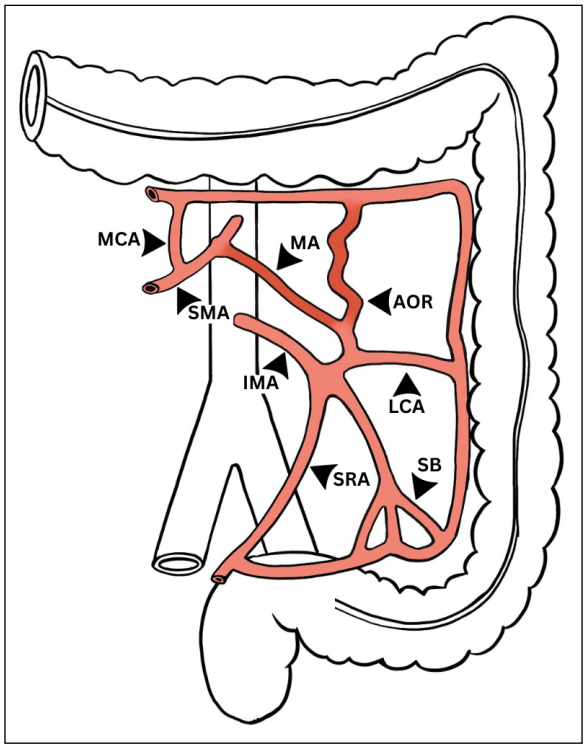

Figure 10. Scheme of possible anatomical relation between the arc of Riolan and Moskowitz's artery; AOR — arc of Riolan; IMA — inferior mesenteric artery; LCA — left colic artery; MA — Moskowitz's artery; MCA — middle colic artery; SB — sigmoid branches; SMA — superior mesenteric artery; SRA — superior rectal artery.

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