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Superior mesenteric artery clinical classification and morphometrical analysis

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Background: *The superior mesenteric artery is one of the most important arteries in the abdominal cavity, which is of great clinical significance, especially in surgical procedures and fatal ischaemic complications. The aim of this study was to develop a clinical classification of the superior mesenteric artery.*

Material and methods: *Postmortem contrast-enhanced computed tomography of 104 (29.8% female, age 50.7 ± 18.7 years) human bodies were analysed. Based on anatomic predisposition to ischaemic and iatrogenic complications, a 3-tiered clinical classification of the superior mesenteric artery was developed. Type 0 was defined as standard risk for ischaemic and iatrogenic complications. Type 1 was defined as increased thromboembolic risk with decreased risk of iatrogenic bleeding, and type 2 was defined as decreased ischaemic risk with increased risk of iatrogenic bleeding. The supply area of the superior mesenteric artery was divided into 4 regions: pancreas, caecum, ascending colon, and transverse colon.*

Results: *Type 0 (standard risk) was found in 62.5% of cases. Type 1 was most frequently observed in the ascending colon region (15.4%). Type 2 was most frequently observed in the pancreatic region (17.3%). Regarding type, most abnormalities were found in the region of the ascending colon (18.3%), pancreas (17.3%), and transverse colon (16.3%).*

Conclusions: *The proposed clinical classification of SMA links anatomic variations in morphology with their clinical significance. A simple, 3-level classification can be easily applied in daily practice and serve as a great support for preoperative evaluation and recognition of patients at risk of iatrogenic or thromboembolic complications.* (Folia Morphol 2024; 83, 3: 597–603)

Keywords: superior mesenteric artery, intestinal vasculature, mesenteric ischaemia, iatrogenic abdominal bleeding, classification

INTRODUCTION

The superior mesenteric artery anatomy

The superior mesenteric artery (SMA) arises from the abdominal aorta, usually as the second major branch after the celiac trunk. The supply area of the SMA includes the head of the pancreas, the lower part of the duodenum, the jejunum, the ileum, the caecum, the appendix, the ascending colon, and the transverse colon [15]. In some cases, it may supply the liver [4]. Classic anatomical descriptions of the SMA branches include

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the inferior pancreaticoduodenal, middle colic, right colic, ileocolic, and jejunal arteries [15]. Rare anatomic variants have also been described previously [3, 5, 15]. A 5-level SMA classification has been described previously based on the prevalence of specific SMA branches [3].

The superior mesenteric artery thromboembolism

Thromboembolism of the superior mesenteric artery is a rare clinical situation (0.09–0.2% of all acute admissions to emergency departments) that results in mesenteric ischaemia and is associated with a very high risk of death (50–70%) [2, 11]. The method of treatment depends on the patient's condition and ranges from laparotomy in haemodynamically unstable patients to percutaneous revascularisation [2]. Mesenteric ischaemia is most commonly caused by SMA emboli (40–50% of cases) [11].

The superior mesenteric artery supply region surgical procedures

The most common surgical procedures performed in the SMA service area are related to oncologic treatment of colon cancer, particularly in the ascending and transverse colon. The number of colectomies performed is expected to increase by over 60% by 2030 [1]. Surgical treatment of appendicitis, carcinoma of the head or uncinate process of the pancreas, small bowel resection, and hernia surgery may also involve ligation of SMA branches [13]. Collateral circulation provides additional blood supply to the operated regions, which can lead to severe bleeding during surgery [16]. However, this factor plays a crucial role in preventing ischaemic complications [9].

The Arc of Riolan is a strategic vessel that provides collateral mesenteric circulation in 10% of people [17]. Preoperative examination of the bowel may play an important role in both preventing iatrogenic complications and diagnosing thromboembolic events.

The aim of the study

The aim of this study was to evaluate the anatomy and morphometry of SMA to establish a clinical classification of SMA types based on the anatomical favouring of ischaemic complications related to iatrogenic damage and thromboembolic events.

MATERIALS AND METHODS

Study population

Postmortem contrast-enhanced computed tomography angiography (CTA) scans of 104 (29.8% female, age 50.7 ± 18.7 years) human bodies acquired between 2012 and 2017 were retrospectively evaluated. Detailed imaging and contrast injection were described in a previous study [7]. Results were obtained using RadiAnt DICOM Viewer 3-dimensional reconstruction software [Medixant. RadiAnt DICOM Viewer (Software). Version 2022.1. 10 Feb 2022. URL: https://www.radiantviewer.com]. Arterial phase acquisition results were reconstructed and further analysed by 2 different investigators. If measurements differed > 5% between researchers, both measurements were repeated. If no consensus was found for quantitative assessment, the decision of the lead author was reported.

The superior mesenteric artery analysis

The diameter and angle of origin of the SMA, inferior pancreaticoduodenal, ileocolic, right, and middle colic arteries were measured. The distances between the origin of the SMA and each of the above branches were measured. The distance between the origin of the SMA and the origin of the abdominal aorta and aortic bifurcation was measured. The number of jejunal arteries, arterial anastomosis, and presence of additional arteries were determined. Three classes were formed:

- Type 0 — normal risk of thrombosis and additional iatrogenic bleeding, characterised by a common trunk for one large and one small vessel, a common trunk for 2 large vessels, or the absence of a large vessel in the presence of an additional artery supplying the area of interest.
- Type 1 — high risk of thrombosis and low risk of additional iatrogenic bleeding, characterised by the presence of common trunks for large branches of the SMA or the absence of a large vessel originating from the SMA in the presence of additional arteries supplying the same region.
- Type 2 — low risk of thrombosis and high risk of additional iatrogenic bleeding, characterised by the presence of all major vessels of the SMA, the presence of additional arteries and arterial anastomoses.

In addition, a letter code was used to label the vascular regions: p — pancreatic region, c — caecum, a — ascending colon, and t — transverse colon. See Figure 1 for a flowchart to determine the SMA type.

Statistical analysis

Data were analysed using IMB SPSS Statistics 28.0 (Predictive Solutions, Pittsburgh, PA, USA). Categorical

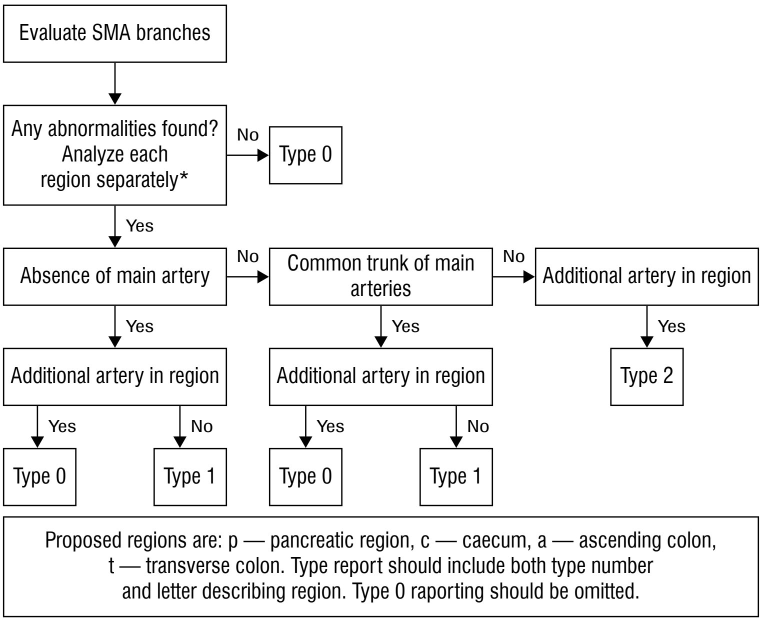

Figure 1. Flow diagram for determining type of superior mesenteric artery. SMA — superior mesenteric artery.

Table 1. The prevalence of superior mesenteric artery types categorised.

Category	Type	n [%]
general patients' prevalence	Type 0	65 (62.5%)
	Type 1	12 (11.5%)
	Type 2	21 (20.2%)
	Type 1 and 2	6 (5.8%)
Number of types per patient	0	65 (62.5%)
	1	22 (21.2%)
	2	15 (14.4%)
	3	2 (1.9%)
Types prevalence in pancreatic region	Type 0	86 (82.7%)
	Type 1	0 (0.0%)
	Type 2	18 (17.3%)
Types prevalence in caecum region	Type 0	100 (96.2%)
	Type 1	4 (3.8%)
	Type 2	0 (0.0%)
Types prevalence in ascending colon region	Type 0	85 (81.7%)
	Type 1	16 (15.4%)
	Type 2	3 (2.9%)
Types prevalence in transverse colon region	Type 0	87 (83.7%)
	Type 1	7 (6.7%)
	Type 2	10 (9.6%)

variables are presented as number (n) or percentages. Normal distribution was examined using the Shapiro-Wilk test. Quantitative variables are presented as means with standard deviation. Sex comparisons between quantitative variables were performed using the U-Mann-Whitney test. Categorical variables were compared using the chi-square test with Fisher's exact test when group number was lower than 5. Quantitative variable comparisons between SMA clinical types were performed with the Kruskal-Wallis test with post-hoc Dunn test and applied Bonferroni correction. Pearson and rho-Spearman correlations were performed. $R = 0.277$ ($p < 0.05$ for 104 patients) was considered significant. The p value < 0.05 was considered significant.

RESULTS

SMA classification

Type 0 (standard risk) was found in 62.5% of cases. Type 1 was most commonly observed in the ascending colon region (15.4%). Type 2 was most frequently observed in the pancreatic region (17.3%). Regarding type, most abnormalities were found in the region of the ascending colon (18.3%), pancreas region (17.3%), and transverse colon (16.3%). A summary of the prevalence of all types is provided in Table 1, and all anatomic abnormalities are provided in Table 1A in the Appendix. A statistically significant difference between the SMA types was found in the ileocolic artery diameter of origin ($p = 0.009$). The most common representatives for each SMA clinical type can be found in Figure 2. SMA and its branch origin diameter comparison between the presented types can be found in Table 2.

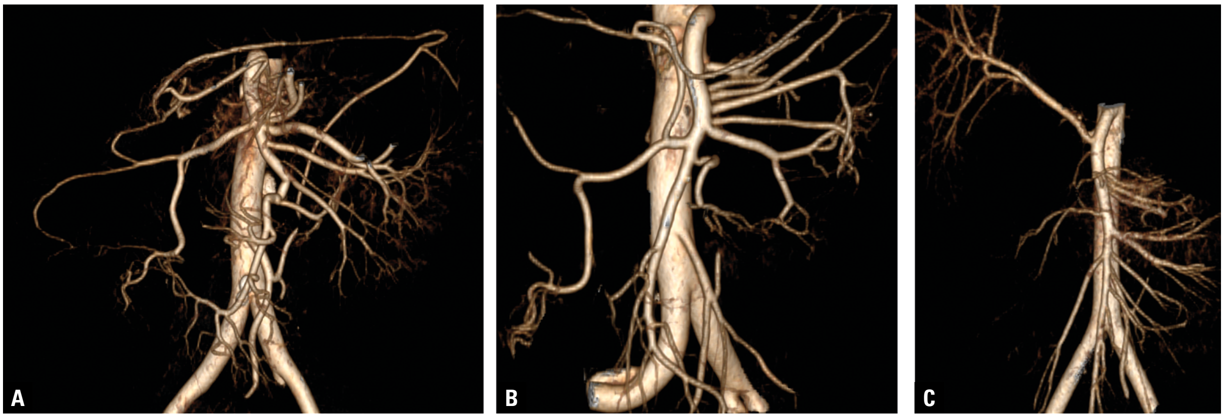

Figure 2. Representatives for each superior mesenteric artery type; **A.** Superior mesenteric artery type 0 with visualised Arc of Riolan; **B.** Superior mesenteric artery type 1, with single trunk for ileocolic, right colic, and middle colic artery; **C.** Superior mesenteric artery type 2, with common hepatic artery originating from superior mesenteric artery.

Table 2. Artery diameter comparison between superior mesenteric artery types.

Artery diameter	Type 0	Type 1a	Type 1c	Type 1t	Type 2a	Type 2p	Type 2t	p
	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	
IC diameter	3.7 ± 0.8	4.4 ± 0.9	4.5 ± 1.1	4.8 ± 0.8	4.3 ± 1.2	4.3 ± 0.9	4.3 ± 0.7	0.009
MC diameter	3.6 ± 0.9	3.7 ± 0.5	3.5 ± 1.1	3.7 ± 0.5	2.8 ± 0.4	3.7 ± 1.3	3.6 ± 1.6	0.389
IPD diameter	2.7 ± 0.7	3 ± 0.8	2.3 ± 1	3.3 ± 0.8	2.5 ± 0.2	2.9 ± 0.7	2.8 ± 0.6	0.230
RC diameter	3.8 ± 0.9	3.9 ± 0.7	3.7 ± 0.7	3.7 ± 1	4 ± 0.8	3.6 ± 1	3.8 ± 1	0.962
SMA diameter	8.7 ± 1.4	8.5 ± 1.3	8.5 ± 1.5	8.8 ± 1.5	7.2 ± 0.5	8.8 ± 1.4	9 ± 1.3	0.457

IC — ileocolic artery; IPD — inferior pancreaticoduodenal artery; MC — middle colic artery; RC — right colic artery; SMA — superior mesenteric artery.

DISCUSSION

The SMA runs along the superior mesenteric vein posterior to the pancreas. It courses in a convex line to the left side. The classic description of SMA shows the presence of 4 branches originating from the right margin, namely the inferior pancreaticoduodenal artery, which originates as the first branch of SMA and gives off an anterior and a posterior branch, which subsequently anastomose with the anterior and posterior branches, respectively, of the superior pancreaticoduodenal artery. Together, they supply the head of the pancreas and the lower part of the descending, transverse, and ascending portions of the duodenum. The middle colic artery, which gives off 2 branches, consists of a right branch supplying 2/3 of the right part of the transverse colon. It forms an anastomosis with the ascending branch of the right colic artery and nourishes the ascending part of the colon. The left branch of the middle colic artery supplies 1/3 of the left part of the transverse colon [8]. Together with the ascending branch of the left colic artery, it forms the Arc of Riolan (also known as the meandering mesenteric artery) [12]. It can serve as a vital conduit when one or more of these other arteries are occluded, the dilation of which is common in patients with isolated mesenteric artery dissection (ISMAD). The prevalence and diameter of the Arc of Riolan were significantly increased in the ISMAD group compared with the control group (83.16% vs. 35.79%, $p < 0.001$; 2.63 ± 0.56 mm vs. 2.12 ± 0.39 mm, $p < 0.001$) [14].

The peripheral arterial arch on the right side of the colon, which also forms the main collateral network between SMA and IMA, is called the artery of Drummond (also known as the marginal artery), which vascularises the transverse and descending colon and makes an important contribution to the collateral circulation of the left colic structures [12]. The right colic artery divides into an ascending branch that joins the ascending right branch of the middle colic artery, which together supply the ascending portion of the colon. It also gives off a descending branch of the right colic artery, which anastomoses with the colic branch of the ileocolic artery [6]. The ileocolic artery supplies the ascending colon, appendix, cecum, and ileum. It is traditionally described as the terminal branch. [15]. From the left margin, the jejunal and ileal arteries form anastomotic arcades. From these arcades, small straight arteries called vasa recta supply the intestinal wall [15].

The former classification of SMA distinguishes 5 morphological types based on the presence of certain branches:

Type I, classic (53.33% of cases): Type II, defined by the absence of the inferior pancreaticoduodenal artery (26.67% of cases). Type III characterised by the absence of the right collicular artery (3.33% of cases). Type IV characterised by the presence of a common truncus for the inferior pancreaticoduodenal artery and the middle collicular artery (3.33% of cases). Type V, characterised by an abnormal hepatic artery and the absence of the inferior pancreaticoduodenal artery (13.33% of cases) [3].

Based on our results, we found the following distribution of SMA morphological types in the previously presented classification: type 1 — 74.0%, type 2 — 13.5%, type 3 — 5.8%, and type 4 and type 5 — 2.9% each. In 1.0% of cases, the anatomy of SMA corresponded to more than one classification (absence of the right colic artery and absence of the inferior pancreaticoduodenal artery). The above classification allows characterisation of most anatomic variants of SMA in a simple and rapid manner. However, it omits the following variants that may be relevant and were detected in our study: an additional common hepatic artery independent of the presence of the inferior pancreaticoduodenal artery (18.3%), a common trunk of the pancreaticoduodenal artery and the jejunal artery (27.9%), a common trunk for the middle and right colic arteries (7.7%), colic branches from the common hepatic artery (1.0%), additional branches to the liver, with normal common hepatic morphology (1.0%), and inferior pancreaticoduodenal artery branches from the common hepatic artery originating from SMA (1.9%) [10].

In our study, we described 3 clinical types of SMA.

— Type 0 (Fig. 2A) — normal risk of thrombosis and additional iatrogenic bleeding, characterised by a common trunk for one large and one small vessel, a common trunk for 2 large vessels, or the absence of one large vessel in the presence of an additional artery supplying the affected area.
— Type 1 (Fig. 2B) — high risk of thrombosis and low risk of additional iatrogenic bleeding, characterised by the presence of common trunks for large branches of the SMA or the absence of a large vessel originating from the SMA in the presence of additional arteries supplying the same region.
— Type 2 (Fig. 2C) — low risk of thrombosis and high risk of additional iatrogenic bleeding, characterised by the presence of all major vessels of the SMA, and the presence of additional arteries and arterial anastomoses.

The use of a letter-based code facilitates communication between radiologists and surgeons and allows information to be communicated in a simplified and systematic manner. Emphasis on the functionality of the scale allows its direct application in daily clinical practice and ultimately leads to increased intraoperative patient safety. It is recommended that only the types associated with abnormalities (types 1 and 2) be indicated with a letter code assigned to the region and that type 0 not be indicated to allow clear communication.

Significant differences between postmortem and normal low-dose CT should be mentioned. In postmortem CT, higher doses of radiation and hydrophobic paraffin-based contrast agent is used, as opposed to the hydrophilic iodine contrast agent used in low-dose radiation CT patients. These features provide more detailed anatomical images compared to steady-state visualisation methods.

Limitations

There are several important limitations that should be noted with this study. First, this study was performed at a single centre and involved the analysis of retrospective computed tomography scans. The study involved only individuals belonging to a specific ethnic group (Caucasians). In addition, the male population was overrepresented in the study (70.2%). In addition, we did not analyse the population with confirmed mesenteric thromboembolism or iatrogenic intraoperative bleeding.

CONCLUSIONS

The proposed clinical classification of SMA links anatomic variations in morphology with their clinical significance. A simple, 3-step classification can be easily applied in daily practice and can serve as a great support for preoperative assessment and recognition of patients at risk of iatrogenic or thromboembolic complications. The proposed assessment can be easily performed by a radiologist or surgeon based on a simple 3-dimensional reconstruction with cheap, available tools.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement

Data can be obtained from the corresponding author upon reasonable request.

Ethics statement

This study was approved by the Bioethical Committee of the Jagiellonian University, Cracow, Poland (No. 1072.6120.241.2021 approved in 2021). The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki.

Author contributions

Radosław Chmiel — conceptualisation of the work, design of the work, the acquisition, analysis, interpretation of data for the work, drafting the work; Jakub Batko — conceptualisation of the work, analysis, interpretation of data for the work, drafting the work; Aleksiej Juszczak — analysis, revising the work critically for important intellectual content; Jerzy A. Walocha — interpretation of data for the work, revising the work critically for important intellectual content; Artur Moskała — design of the work, revising the work critically for important intellectual content; Andrzej Dubrowski — analysis, revising the work critically for important intellectual content; Krzysztof Woźniak — interpretation of data for the work, revising the work critically for important intellectual content; Artur Pasternak — the acquisition, revising the work critically for important intellectual content.

All authors approved the final version to be submitted and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Conflict of interest

None declared.

Supplementary material

Appendix Table 1A is available on the journal's website.

Appendix Table 1A. Prevalence of anatomical abnormalities within superior mesenteric artery.

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