Splenic artery angiography: clinical classification of origin and branching variations of splenic artery by multi-detector computed tomography angiography method

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Background: The splenic artery (SA) variations are rarely reported in the literature. Knowledge of the range of the SA and other arterial anomalies and their specific frequencies is very important for every visceral surgeon as well as for treatment of gastrointestinal bleeding, organ transplantation, transarterial chemoembolisation of neoplasm, infusion therapy, therapeutic arterial ligation, iatrogenic injuries. At the literature, there are more studies on the coeliac trunk, superior mesenteric artery and hepatic artery variations, but studies on the SA variations are uncommon. The studies on the SA variations are mostly in the form of case reports, but there are not many studies with large population on this issue. The purpose of this study was to evaluate the SA alone and to determine the variations determined separately from the other arteries. Accurate awareness of all the possible anatomic variations is crucial in the upper abdomen surgery.

Materials and methods: Seven hundred fifty patients undergoing multi-detector computed tomography angiography between 2015 and 2017 were retrospectively evaluated for the SA variations. We created a new classification system to determine anatomic variations of the SA.

Results: Twenty-three different types were identified related to anatomic variations in the origin and branching pattern of the SA. While 596 (79.47%) patients had standard SA anatomy, 154 (20.53%) patients had variant SA anatomy.

Conclusions: The SA has quite different variation types and the practical context of the issue is of primary importance in surgery, gastroenterology, oncology and radiology. Liver and pancreas transplantation, splenectomy, embolisation of tumours of the abdominal organs, as well as other numerous diagnostic and therapeutic procedures, require detailed anatomical knowledge. (Folia Morphol 2020; 79, 2: 236–246)

Key words: anatomic variations, splenic artery, multi-detector computed tomography
INTRODUCTION

In standard anatomy texts, the splenic artery (SA) is the largest branch of the coeliac trunk (CT) which is common name of the left gastric artery (LGA), the common hepatic artery (CHA), and the SA. The CT originates from the abdominal aorta (AA) at the level of the twelfth thoracic vertebrae and supplies the liver, stomach, pancreas, superior of duodenum, and the spleen [3, 5, 7, 19, 43, 47, 48, 53, 54]. But, the main blood supply of the spleen is received via the SA. The SA turns inferiorly for a short distance after its origin, then turns left and runs horizontally behind the stomach, the upper border of the pancreas and it is divided into some branches leading to the stomach and the pancreas during this course. Finally, it enters in the lienorenal ligament as near the tail of the pancreas and the pancreas during this course. It is divided into some branches leading to the stomach, the upper border of the pancreas and it is divided into some branches leading to the stomach and the pancreas during this course. Finally, it enters the hilum of the spleen [20, 24, 42]. These branches are described as polar arteries that run to the upper or lower extremity of the spleen [8, 13, 14, 23].

According to literature studies, the SA may have origin variations that take direct origin from the AA, the CHA, the LGA or the superior mesenteric artery (SMA). Furthermore, abnormalities such as congenital absence, total duplication, intrahepatic course and variations of terminal branching pattern of the SA have all been reported in the literature [42]. Knowledge of anatomical variations in the SA system is crucial in the context of liver and pancreas transplantation, arterial chemoembolisation for visceral organ tumours (especially, the treatment of gastric cancer and pancreas cancer), for hepato-biliary-pancreatic surgical procedures, general upper abdominal surgery, and SA steal syndrome [4, 11, 16, 32, 55]. Additionally, the SA embolisation has become a safe and effective intervention for the treatment of hypersplenism, cirrhosis with portal hypertension, hereditary spherocytosis, idiopathic thrombocytopenic purpura, splenic trauma, SA steal syndrome, and thalassemia. However, major complications may follow the SA embolisation including: splenic abscess which have been documented to occur in 6.8% of patients undergoing SA embolisation, splenic infarction, contrast-induced renal insufficiency, splenic cyst development, and non-target embolisation [1, 2, 4, 9, 12]. Splenic artery aneurysms, that are often asymptomatic and incidentally identified, are the most common of the visceral artery aneurysms with an incidence in the literature between 0.1% and 10.4%. The SA steal syndrome is one of the vascular complications after liver transplantation, its incidence has been reported at 3.1–5.9% of liver transplantations, or occurs due to liver ischaemia, hepatic artery thrombosis and stenosis. The SA embolisation is an effective treatment of this syndrome [21, 30]. If branches of the SA are injured or ligated accidentally during upper abdomen surgeon such as gastrectomy, it may be fatal leading to splenic abscess, haemorrhage, or rupture [20, 23, 44]. For all these reasons, it is very important to determine variations of the SA. Most previous studies revealed that the SA has variations in the tortuosity, course, position and number of the branches. However, there is no a large population study about variation classification of the SA [24].

In recent years, variations in vascular structures have become more important with the developments in image technology such as multi-detector computed tomography (MDCT) and magnetic resonance. Especially, MDCT angiography is a reliable and non-invasive tool for the diagnosis of normal and pathological conditions of arteries. Unlike classical angiography, MDCT angiography clearly shows the course of the vessels and the degree of impairment of blood vessels as well as the relationship of blood vessels with surrounding structures and organs, and makes it possible to obtain high-quality three-dimensional images which are quite useful for demonstrating the details of visceral structures [22, 27, 33, 37, 40].

We created a new classification system to determine anatomic variations of the SA. Thus, we aimed to classify the anatomical variations of the SA clinically on the basis of abdominal angiographic images in a cohort of 750 patients and to contribute to the knowledge of the SA anatomy.

MATERIALS AND METHODS

Patients

This study followed the Declaration of Helsinki principles and was approved by the Medical School Non-Interventional Clinical Research Ethics Committee (December 21, 2017; decision no: 55). From December 2015 to October 2017, anatomic variations in the SA of 800 patients who underwent abdominal computed tomography angiography at the Department of Radiology of the Medical Faculty, University of Dicle, were retrospectively reviewed, but 50 cases in our study were excluded due to artefacts or history of major abdominal surgery. Finally, a total of 750 cases were included in the analysis, 344 (45.87%) female and 406 (54.13%) male; age range was 16–93
years, mean age ± standard deviation was 50.6 ± 16.2 years.

**MDCT technique**

Multi-detector computed tomography angiography was done using Philips Brilliance 64-slice computed tomography scanner by non-ionic contrast material that was injected into vein at 4 mL/s using an automated injector. Arterial phase images were obtained in 10–16 s, using the following parameters in all cases: collimation, 64 × 1 mm; step, 0.92; gantry rotation time, 0.75 s; section thickness 0.90 mm, and tube potential, 120 kV.

**Computed tomography examinations and images interpretation**

Multi-detector computed tomography angiography units were used in this study. The angiographic procedures were performed by two interventional radiologists. All angiography data were transferred to a workstation in order to evaluate vascular anatomy. The original scans were three-dimensionally reconstructed to confirm each assessment. We analysed the SA anatomy, including its origin site and proximal branching variants and classified these variants. Variants of the SA with unclear origin and branching were not classified. Arterial variations in the origin and branching pattern of the SA were defined in Table 1.

**Statistical analysis and classification**

All data were analysed using SPSS (v. 13.0 for Windows; Chicago, IL, USA). The overall results were expressed as mean ± standard deviation, frequencies, and percentages of the patients.

**RESULTS**

In our retrospective study, 22 different variation types associated with anatomy of the SA were identified. A total of 750 patients, 596 (79.47%; 276 females and 320 males) were included in normal anatomy of the SA and were classified as type I, different anatomical variations of the SA were detected in 154 patients (20.53%; 68 females and 86 males) and classified as other 22 types (Table 1). Percentages of SA types according to gender differences are presented in the Table 2.

The SA had classical origin in 596 (79.47%) patients in our study; it arose from the CT as four different types: The SA originated from the CT as a branch of the CT bifurcation (into the SA and CHA) in 510 (68.00%) cases, of the CT trifurcation (into the SA, LGA) in 82 (10.94%) cases, of the CT quadrifurcation (into the SA, LGA, gastroduodenal artery [GDA], and common root of the right hepatic artery [RHA] + middle colic artery [MCA]) in 3 (0.40%) cases.

| Table 1. Classification of origin and branching variations of the splenic artery |
|-------------------------------|---------------------------------------------|
| **Types of the splenic artery** | Rain (green colour) |
| **Anatomic variations of SA**  | Rain (green colour) |
| **Variations of origin of SA** | Rain (green colour) |
| Type 1 | SA originated from CT and divided into the classic branches |
| Type 2 | SA originated from HST |
| Type 3 | SA originated from HST and divided into LGA |
| Type 4 | SA originated from GST |
| Type 5 | SA originated from CMT |
| Type 6 | SA originated from HSMT |
| Type 7 | SA originated from AA |
| Type 8 | SA originated from SMA |
| Type 9 | SA absent |
| Type 10 | SA (double pattern) (the presence of an accessory SA) |
| Type 11 | SA and RRHA originated from a single common root from the aorta |
| Type 12 | SA and RLHA originated from a single common root from the CT |
| **Branching variations of SA**  | Rain (green colour) |
| Type 13 | SA runs to the spleen as two branches |
| Type 14 | SA originated from AA and divided into RLGA + RGDA |
| Type 15 | SA originated from AA and divided into RLGA + RCH |
| Type 16 | SA originated from AA and divided into RLGA + RLHA |
| Type 17 | SA originated from AA and divided into RLGA + a common root of RLHA and RGDA |
| Type 18 | SA originated from AA and divided into RLGA + RIRHA + a common root of the RLHA and RGDA |
| Type 19 | SA originated from AA and divided into RLGA + a common root of the RRHA and RGDA |
| Type 20 | SA originated from CT and divided into RLIPA + RLGA + RPHA |
| Type 21 | SA originated from AA and divided into RLGA + RLHA + RLIP + RRIPA |
| Type 22 | SA originated from CT and divided into RLCA |
| Type 23 | SA originated from CT and divided into RMCA |

AA — abdominal aorta; CHA — common hepatic artery; CMT — coeliacomesenteric trunk; CT — coeliac trunk; GDA — gastroduodenal artery; GST — gastrosplenic trunk; HSMT — hepatosplenicmesenteric trunk; HST — hepatosplenic trunk; LCA — left colic artery; LGA — left gastric artery; LIPA — left inferior phrenic artery; MCA — middle colic artery; PHA — proper hepatic artery; RCHA — replaced common hepatic artery; RGDA — replaced gastroduodenal artery; RIRHA — replaced right inferior phrenic artery; RLCA — replaced left colic artery; RLGA — replaced left gastric artery; RLIPA — replaced left inferior phrenic artery; RMCA — replaced middle colic artery; RPHA — replaced proper hepatic artery; RRHA — replaced right hepatic artery; RRIPA — replaced right inferior phrenic artery; RSA — replaced splenic artery; SA — splenic artery; SMA — superior mesenteric artery
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**DISCUSSION**

Variation of arterial anatomy is very common and occurs in nearly half of the population. Variations of abdominal vessels pose a higher risk of severe or even fatal complications, such as pancreatic leakage, ischaemia and necrosis [39]. The development of imaging technology regarding vessel variation has modified surgical and therapeutic approaches and arterial variations have become even more important. In variant patterns, vessels do not arise from their usual source and present as accessory or replaced vessels. Accessory vessel is a branch addition to the normal artery supply and replaced vessel is a branch that represents the primary blood supply to the organs, so replaced arteries must be strictly protected [10, 31, 34, 51].

There are many research and classification investigating variations in hepatic arteries, superior mesenteric artery, and CT [15, 17, 26, 36, 52]. Whereas, very few researches has been done on the SA. We classified 23 types of SA with our research on 750 patients. In our study, the SA took a classic origin from the CT in 596 (79.47%) patients (Fig. 1A–D). Standard CT anatomy, having the LGA, the SA and the CHA, cases, of the CT pentafurcation (into the SA, LGA, RHA, MCA, and common root of the left hepatic artery [LHA] + GDA) in 1 (0.13%) case.

**Table 2. Percentages of splenic artery types according to gender**

<table>
<thead>
<tr>
<th>Types of the splenic artery</th>
<th>Female</th>
<th>Male</th>
<th>Total: N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classical SA (SA originated from CT and divided into the classic branches) (Fig. 1A–D)</td>
<td>276</td>
<td>320</td>
<td>596 (79.47%)</td>
</tr>
<tr>
<td><strong>Anatomic variations of SA (variations of origin and branching)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Variations of origin of SA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>SA originated from HST (Fig. 2)</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Type 3</td>
<td>SA originated from HST and divided into RLGA (Fig. 3)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Type 4</td>
<td>SA originated from GST (Fig. 4)</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Type 5</td>
<td>SA originated from CMT (Fig. 5)</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Type 6</td>
<td>SA originated from HSMT (Fig. 6)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Type 7</td>
<td>SA (replaced) originated from AA (Fig. 7)</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Type 8</td>
<td>SA (replaced) originated from SMA (Fig. 8)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Type 9</td>
<td>SA absent (Fig. 9)</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Type 10</td>
<td>SA (double pattern) (the presence of an accessory SA) (one originated from the CT, the other originated from a common root of the CHA and SA) (Fig. 10)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Type 11</td>
<td>SA and RRHA originated from a single common root from the aorta (Fig. 11)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Type 12</td>
<td>SA and RLHA originated from a single common root from the CT (Fig. 12)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Branching variations of SA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 13</td>
<td>SA runs to the spleen as two branches (Fig. 13)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Type 14</td>
<td>SA divided into RLGA + RGDA (Fig. 14)</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Type 15</td>
<td>SA divided into RLGA + RCHA (Fig. 15)</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Type 16</td>
<td>SA divided into RLGA + RLHA (Fig. 16)</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Type 17</td>
<td>SA divided into RLGA + a common root of the RLHA and RGDA (Fig. 17)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Type 18</td>
<td>SA divided into RLGA + RRHA + a common root of the RLHA and RGDA (Fig. 18)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Type 19</td>
<td>SA divided into RLGA + a common root of the RRHA + RGDA (Fig. 19)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Type 20</td>
<td>SA divided into RLPA + RLGA + RPFA (Fig. 20)</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Type 21</td>
<td>SA divided into RLGA + RLHA + RLPA + RRIPA (Fig. 21)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Type 22</td>
<td>SA divided into RLCA (Fig. 22)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Type 23</td>
<td>SA divided into RMCA (Fig. 23)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>344</td>
<td>406</td>
<td>750 (100%)</td>
</tr>
</tbody>
</table>

AA — abdominal aorta; CHA — common hepatic artery; CMT — coeliacomesenteric trunk; CT — coeliac trunk; GDA — gastroduodenal artery; GST — gastrosplenic trunk; HSMT — hepatosplenomesenteric trunk; HST — hepatosplenic trunk; LCA — left colic artery; LGA — left gastric artery; LIPA — left inferior phrenic artery; MCA — middle colic artery; PHA — proper hepatic artery; RCHA — replaced common hepatic artery; RGDA — replaced gastroduodenal artery; RIPA — right inferior phrenic artery; RLGA — replaced left gastric artery; RLHA — replaced left hepatic artery; RLIPA — replaced left inferior phrenic artery; RMCA — replaced middle colic artery; RSA — replaced splenic artery; SA — splenic artery; SMA — superior mesenteric artery
has been reported in 79.10% of the 604 patients in the studies of Koops et al. [26], 63.90% of the 607 patients in the studies of Farghadani et al. [10], and 75.70% of the 1000 patients in the studies of Hiatt et al. [15]. The SA originated from the hepatosplenic trunk (HST) and divided into the classical branches in 30 (4.00%) cases in our study (Fig. 2). In 5 (0.67%) cases of our study, the SA originated from the HST, but it also divided into LGA in addition to the classical branches (Fig. 3). Thangarajah et al. [49] found the HST in 8 (4%) patients of the 200 patients. Ugurel et al. [50] reported the HST in 3 (3%) of the 100 patients. Huang et al. [18] reported an abnormal LGA deriving from SA in 1 (0.42%) of 238 cases. The gastrosplenic trunk, the LGA and SA originated from the aortic abdominal artery in a common root, was found in 12 (2.00%) of 600 patients by Covey et al. [6], in 3 (1.10%) of the 275 cases by Nakamura et al. [38], in 143 (2.86%) of 5002 patients by Song et al. [46]. This variation pattern was found 26 (3.47%) in
our study (Fig. 4). In 8 (1.07%) cases of our study, the SA arose from the coeliacomesenteric trunk (CMT), in which both the SMA and CT originated as a common root from the aortic abdominal artery (Fig. 5). Similar to this variation, the SA arising from the hepatosplenomesenteric trunk (HSMT), which appeared as a HSMT and LGA originating separately from the aorta, was found in 2 (0.27%) cases of our study (Fig. 6). In the literatures, the reported incidences of the CMT are 2.38%, 1.00%, and 2.70% [51]. Kobayashi et al. [25] found that 14 (1.2%) cases had the CMT in 1200 cases. Song et al. [46] found that it originated from the CMT in 53 (1.06%), while the SA originated from the HSMT in 34 (0.68%) patients of the 5002 patients. The SA originated direct from AA in 9 (1.20%) cases in our study (Fig. 7). Iacob et al. [19], Matusz et al. [35], one each reported a case of the SA arising independently from the AA. The SA originated from the SMA in 1 (0.13%) cases in our study (Fig. 8). Ugurel et al. [50] found the splenomesenteric trunk in 1% of 100 patients. Absent of the SA was visualised in 4 (0.53%) cases of our study (Fig. 9); this was a rare variation in literature.

The presence of an accessory SA is quite rare and symptomatic. This variation of the SA is said to be due to intra-parenchymatous anastomosis between the inferior polar artery of SA and the splenic branches of left gastroepiploic artery [28, 42]. In presence of the accessory SA (double pattern) in our study: while one originated from CT, the accessory SA originated from a common root of the CHA and SA in 1 (0.13%) case of our study (Fig. 10). Padmalatha et al. [41] and Patel and Lowe [42], each one has reported an accessory SA, already a branch of main SA, in a cadaver in their cases. The SA (replaced) and RHA (replaced) originated directly from the aorta with
a single common root in 2 (0.27%) cases in our study, there is no report about this variation in literature (Fig. 11). Caruso et al. [4] found a RHA originating from the SA associated with both a CHA originating from the CT and a LHA originating from the LGA on a cadaveric organ donor. The SA and LHA (replaced) originated from a single common root from the CT 1 (0.13%) cases in our study (Fig. 12). The SA runs to the spleen as two branches 1 (0.13%) cases in our study (Fig. 13).
Our study showed that the SA had quite different branching patterns. In the most common branching pattern of the SA in our study, the SA originated from AA and divided into LGA, GDA, and the classical branches in 25 (3.33%) cases (Fig. 14). Slaba and Assaf [45] reported that the gastroduodenal artery originated from the SA in a case study. Li and Ren [29] found that the GDA and SA originated as a common trunk from the anterior surface of the AA as gastroduodenal-splenic trunk a cadaver. The replaced left gastric artery (RLGA) and the replaced common hepatic artery (RCHA) arose from the SA originating directly from the AA in 15 (2.00%) cases of our study (Fig. 15). The RLGA and replaced left hepatic artery (RLHA) arose from the SA originating directly from the AA in 5 (0.67%) cases in our study (Fig. 16). The RLGA and a common root of the RLHA and replaced gastroduodenal artery (RGDA) arose from the SA originating directly from the AA in 1 (0.13%) in our study (Fig. 17). The SA originating directly from the AA divided into the RLGA, replaced right hepatic artery (RRHA), and a common root of RLHA and RGDA in 4 (0.53%) in our study (Fig. 18). The SA originating directly from the AA divided into the RLGA and a common root of the RRHA and RGDA in 6 (0.80%) in our study (Fig. 19). The SA originating directly from the AA divided into the RLIPA, RLGA, and replaced proper hepatic artery (RPHA) in 3 (0.40%) in our study (Fig. 20). The SA originating directly from the AA divided into the RLIPA, RLGA, and replaced inferior phrenic artery (RIPA), and replaced right inferior phrenic artery (RRIPA) in 1 (0.13%) in our study (Fig. 21). Kervancioglu et al. [24] found an accessory SA originating from the LGA, after its origin, it divided into the left and right inferior phrenic and the left hepatic arteries. The SA originating from the CT divided into the replaced left colic artery (RLCA) and the classical branches in 2 (0.27%) in our study.
The SA originating from the CT divided into the replaced middle colic artery (RMCA) and the classical branches in 2 (0.27%) in our study (Fig. 23). In particular, the double pattern of the SA, the absence of the SA, and the SA originating from the SMA is rarely reported variations in the literature.
The limitation of our study is that the images were evaluated retrospectively and only in the arterial phase. For this reason, we excluded some images that have poor quality owing to the fact that scanning was obtained in improper seconds.

CONCLUSIONS

In conclusion, in our study performed in 750 patients, anatomic variations of the SA were classified using a 23-type classification system. The presented study is one of the rare studies in the literature. The awareness of variation patterns in vessel anatomy of the abdomen is very important in surgery, gastroenterology, oncology and radiology procedures such as transcatheter arterial chemoeMBOLisation of neoplasm, gastrectomy, cholecystectomy, surgical procedures of the pancreaticoduodenal areas, laparoscopic surgery, liver and pancreas transplantation, splenectomy that are applied for diagnosis and treatment of abdominal problems. Additionally, the familiarity of vascular varieties is extremely important that it enables an efficient surgery and reduces the risk of complications such as upper gastrointestinal bleeding, ischaemia that can lead to major morbidity and mortality.

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