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Arterial variations in the upper abdominal region and their surgical relevance - with special focus on the blood supply of the pancreas

PhD thesis

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LIST OF ABBREVIATIONS

CT: computed tomography

PV: portal vein

SMV: superior mesenteric vein

SMA: superior mesenteric artery

LGA: left gastric artery

CHA: common hepatic artery

SA: splenic artery

GDA: gastroduodenal artery

PDA: pancreaticoduodenal artery

LHA: left hepatic artery

RHA: right hepatic artery

PHA: hepatic artery proper

a.: artery

PDJ: pancreaticoduodenal-jejunal

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1. INTRODUCTION

Knowledge of widespread variations of the upper abdominal arterial system is important in preoperative planning. Abdominal surgeons, interventional radiologists frequently face anomalies in the arborization pattern of the celiac trunk and the superior mesenteric artery in their everyday practice. The presence of so many variations can be explained by multiple remodeling of fetal vessels. Multiple remodeling process of fetal vessels explain the high incidence of vascular variations (36,1%) [1].

From the 3rd to 8th fetal week the organ systems develop, and later they grow and differentiate. During the growth of the organs, the supplying arterial system also changes. From the paired dorsal aorta, several metameric vitelline arteries run to the wall of the yolk sac. The distal ends of the vitelline arteries will open to ventral anastomosis of Tandler, which is formed between the 4th and 7th fetal week [2] (Figure 1.1.). In the further development, the double arterial supply is gradually eliminated: the right and left dorsal aortae are translocated medially, they fuse, and most of the vitelline arteries and the ventral anastomosis disappear. As a result of the remodeling, the 10th, 13th and 21st segmental vitelline arteries persist as the later celiac trunk, superior and inferior mesenteric arteries. Anomalies in the remodeling will lead to arterial variations. For example, the arch of Bühler [3] is a remnant of the ventral anastomosis of Tandler (Figure 1.2.), or the celiacomesenteric trunk is formed by the persistence of the ventral anastomosis and the absence of the 10th vitelline artery (the celiac trunk and the superior mesenteric artery share the same origin).

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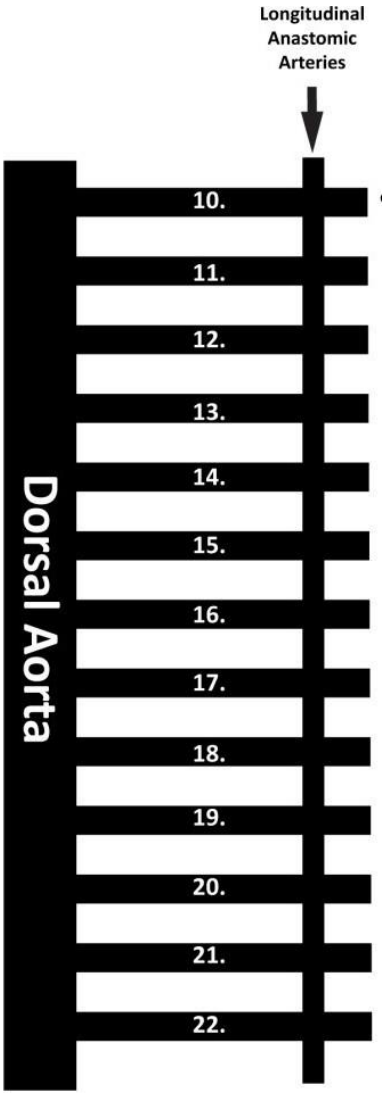

Figure 1.1. Formation of the ventral anastomosis of Tandler [4]

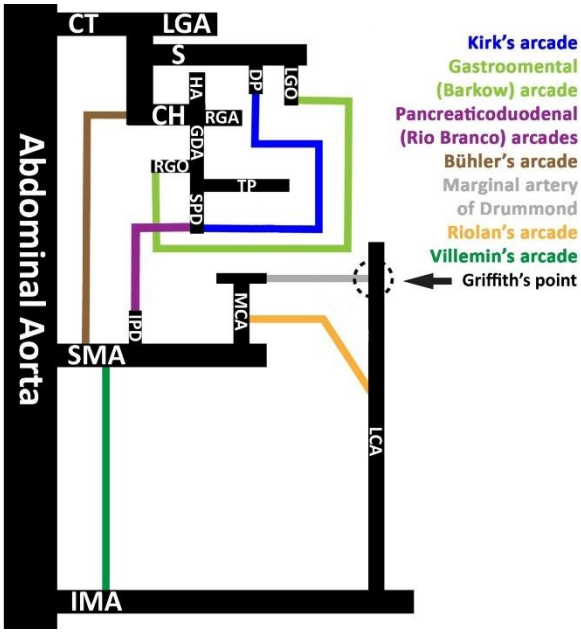

Figure 1.2. Possible remaining anastomoses after remodeling [4] CT: celiac trunk; LGA: left gastric a.; S: splenic a.; DP: dorsal pancreatic a.; LGO: left gastroomental a.; CH: common hepatic a.; HA: proper hepatic a.; RGA: right rastic a.; GDA: gastroduodenal a.; RGO: right gastoomental a.; TP: transverse pancreatic a.; SPD: superior pancreaticoduodenal a.; SMA: superior mesenteric a.; IPD: inferior pancraticoduodenal a.; MCA: middle colic a.; IMA: inferior mesenteric a.; LCA: left colic a.

The formation of the arteries supplying the pancreas is related to the development of the pancreas itself. The pancreatic buds are evaginations of the distal foregut endoderm and the hepatic diverticulum, from the future bile duct. The dorsal bud from the distal foregut is larger and becomes the superior anterior part of pancreatic head, body and tail. The posterior inferior part of pancreatic head and posterior part of uncinate process originate from the smaller ventral bud, which is related to the developing bile duct, therefore the head of the pancreas is supplied by the gastroduodenal artery. The development of this region also explains variant connections between aberrant hepatic arteries and pancreaticoduodenal arteries. (Figure 4.27.)

Anatomy books describe the ordinary pattern, when no alteration can be found. The aorta gives of three unpaired visceral branches: the celiac trunk, the superior and inferior mesenteric arteries. The celiac trunk trifurcates into the LGA, SA and CHA. The CHA splits into PHA and GDA, the latter gives of the superior PDA. The first branch of the SMA is the inferior DPA. Superior and inferior PDA split into an anterior and a posterior branch, which both anastomose, therefore two (anterior and posterior) pancreaticoduodenal arterial arches are formed [5-7].

Most of the vascular variants of the upper abdominal region are noticed when a patient has to undergo upper abdominal surgery, where the variants can be source of bleeding. Also, during transarterial chemoembolization, the variant vessels should be mapped to reach the target lesion. It is also important to mention that in case of stenosis of the celiac trunk – which may occur in 12,5-24% [8] – a patient can be even asymptomatic if the blood flow is compensated through the anastomoses of Rio Branco [9]. Aneurysm of the visceral arteries is a rare disease, but has a high mortality rate, as their symptoms are non-specific, and by the diagnosis, 25% of them are already ruptured. Most visceral artery aneurysms occur on the lienal artery (60-70%), the least frequent locations are the branches of the inferior mesenteric artery (<1%). Aneurysm on the pancreaticoduodenal arches is seen only in 2% frequency, but they have a very high mortality rate [10, 11], and in the international literature, an unfortunate series of 16 cases has been published, where all of them were ruptured at the time of diagnosis [12]. Interventional radiologists also have to take the pancreaticoduodenal arches into account when embolization is

necessary. In case of upper gastrointestinal bleedings, the source of the bleeding cannot be detected with angiography in 46%, therefore, “blind embolization” is performed [13]. However, hepatic ischemia does not develop in patients because of the alternative blood supply through the pancreaticoduodenal arcades. In hepatic hemorrhage embolization, if the celiac trunk has stenosis – the hepatic arteries can be reached through the SMA and inferior PDA [14]. In duodenal hemorrhage, the GDA is the aim of embolization, but in this case, the arches may provide “back door” bleeding, therefore the inferior PDA should also be embolized through the SMA [13].

In case of celiac trunk stenosis (median arcuate ligament syndrome), the whole length of the pancreaticoduodenal arches can be dilated. Nakayama [15] stated, that from the dilation of the arches, the stage of celiac stenosis can be calculated. In such cases, additional work may be necessary during pancreaticoduodenectomy: in moderate stenosis, the median arcuate ligament should be transected, while in severe stenosis, an arterial anastomosis should be reconstructed (for example between the middle colic a. and GDA). The current surgical practice has been published by Berney [16], who proposed to check the pulsation of PHA while the compression of the GDA before the transection of the GDA and the pancreatic head – therefore the blood flow from the celiac trunk to the liver can be assessed. According to Nakayama [15], the preoperative detection of a dilated arch can replace the method described by Berney [16], as additional surgery could be planned before the operation.

Benign pancreatic lesions need less radical surgery, and with the developing quality of the imaging methods, these lesions – as they are usually asymptotic – are diagnosed more frequently [17]. Instead of pancreaticoduodenectomy, less invasive enucleation, central pancreatectomy or duodenum preserving pancreas head resection can be curative. When performing duodenum preserving pancreatic head resection, the posterior pancreaticoduodenal arch is preserved, which provides enough blood flow for the duodenum and the bile ducts [18].

Pancreatic cancer gives priority of the region. Although the field of oncology made a great improvement in the 21st century, this has not influenced the treatment of pancreatic

cancer. The consequence is a growing incidence (18%) and mortality, (15%) based on the data of the National Cancer Register and the Hungarian Central Statistical Office. In the USA, the third most frequent reason of death in tumor diseases is the pancreatic ductal adenocarcinoma, and with the growing incidence, it may be the second most frequent by 2030. In Hungary, the growth of incidence is also expected upon the national data [19]. By the time of the diagnosis, the pancreatic cancer is usually advanced, so only 15-20% of the patients can undergo curative surgery. The only chance for complete healing is the R0 surgical resection. (After surgery, the resection margin is evaluated by histology, R0: intact margin; R1: microscopic residual tumor is present; R2: macroscopic residual tumor is present.) In the past decades, the ratio of operable patients increased, and the surgical mortality decreased. These days in Hungary, surgical mortality is under 5% compared to fifty years earlier, when is ranged 15-20%. The frequency of postoperative complications also decreased which is 35-40%. Seventy-five percent of the ductal adenocarcinomas are in the head of the pancreas, which can be removed by pancreaticoduodenectomy, first described by Allen Oldfather Whipple [20]. The resection involves the removement of the duodenum, the head of the pancreas, the gall bladder, common bile duct, regional lymph nodes and – if necessary – the antrum of the stomach. At the reconstruction step, the bile duct, the remaining pancreas, and the stomach are connected to the jejunum. In the 21st century, the surgical technique improved regarding to the tumors infiltrating the vessels. Earlier, if the PV or the SMV was affected, the tumor was considered to be irresectable, but in the past few years a new surgical approach evolved, by which the tumor is removed with the great veins (PV, SMV). If arteries are also affected, their concomitant resection can be achieved technically, but this procedure hasn't become routine because of its high complication rate and mortality [21]. The higher risk underlines the importance of preoperative mapping of the upper abdominal arterial network, since when the surgeon reaches the arteries, this may mean an irreversible phase of intervention ("point of no return"). When performing the resection, the pancreatic head is separated from the body, and according to the current surgical protocol, the resection plane is at the level of the SMV. Earlier studies showed that in case of portal annular pancreas, the resection is suggested to be extended to the left [22], to reduce the rate of postoperative bleeding. Therefore, the investigation of the fine pancreatic vasculature is essential.

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2. OBJECTIVES

Variations of the arteries supplying the pancreas might be critical, and the intrapancreatic vascularization of the pancreatic tissue also plays an important role in surgical interventions. The **first aim** of our research is to investigate the upper abdominal arterial system focusing on the blood supply of the pancreas.

Apart from the portal annular pancreas, we presume that the optimal line of pancreatic resection could be different from the level of the SMV. Therefore, our **second aim** is to simulate pancreatic resections within the plane of the SMV, and parallel planes in 1 and 2 cm distance right and left from the SMV. An additional goal is to gauge the transected vessel diameters in the selected planes of pancreatic parenchyma (Figure 2.1.). The total diameter of transected vessels should be kept to a possible (potential) minimum, because it may be correlated with the risk of intraoperative blood loss and postoperative bleeding. A transection plane is defined optimal, when the total cut vessel surface is at its lowest, and as a result, the incidence of intraoperative and postoperative bleeding would occur less frequently.

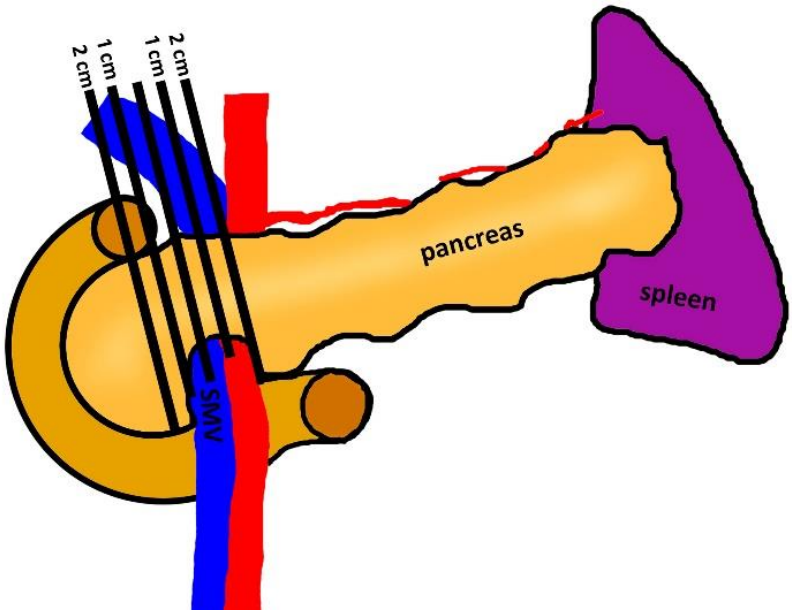

Figure 2.1. Simulated resection planes in 1 and 2 cm distance right and left from the SMV [23]

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3. METHODS

Our research is based on 50 abdominal vascular corrosion casts, which were prepared using an improved corrosion method. Regarding the use of human tissues for research, the project complies with the Declaration of Helsinki guidelines. Prior authorization was acquired from the Ethical Committee of Semmelweis University (TUKEB No.: 185/2004). Abdominal organ complexes (Figure 3.1.) were obtained from deceased people, who offered their bodies for educational and research purposes by living donation at the Department of Human Morphology and Developmental Biology, Semmelweis University. Organ complexes were chosen from cases without any known pancreatic disease, abdominal trauma, nor any gross macroscopic alteration. We were unable to get comprehensive premortal information on the cadavers. The corrosion casts were given unique identification numbers.

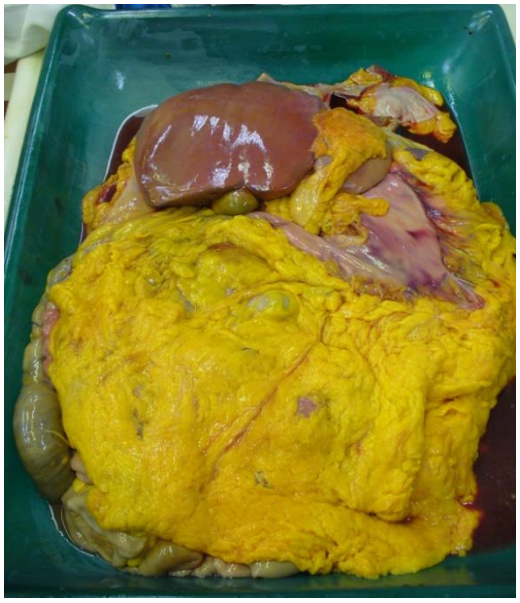

Figure 3.1. Abdominal organ complex before preparation

Preparation was done by the following order: the periaortic connective tissue has been removed from its proximal end (Figure 3.2.). The dorsal lumbar arteries were ligated (Figure 3.3.). On the ventral side, the celiac trunk, superior mesenteric artery and renal arteries were identified, and the aorta was clamped just distal from the level of the renal arteries. To get more flow towards the pancreas, the renal arteries were also ligated. The

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proximal end of the abdominal aorta was cannulated (Figure 3.4.), in 25 cases, another cannula was also placed into the PV (Figure 3.5.).

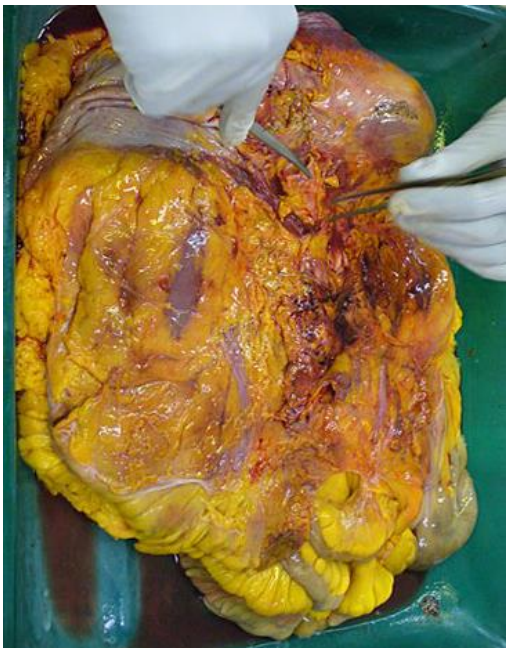

Figure 3.2. Preparation of the abdominal aorta

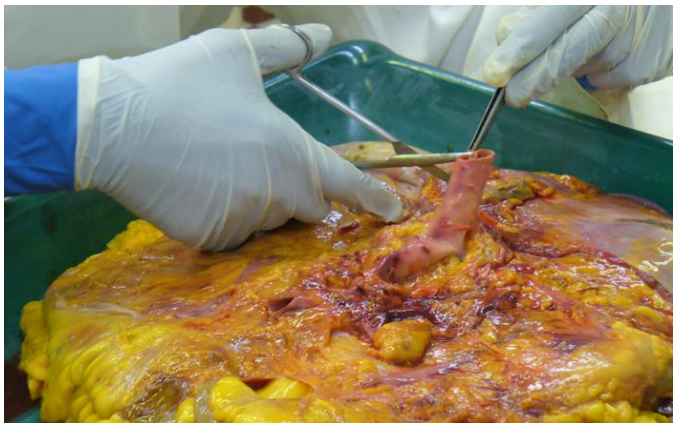

Figure 3.3. Dorsal side of the abdominal aorta before the ligation of lumbar arteries

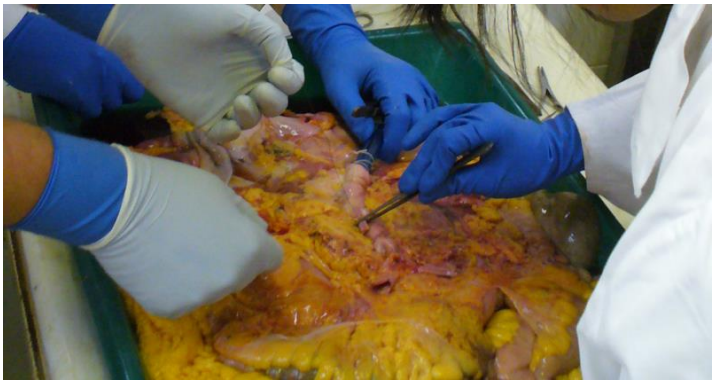

Figure 3.4. Cannulation of the abdominal aorta

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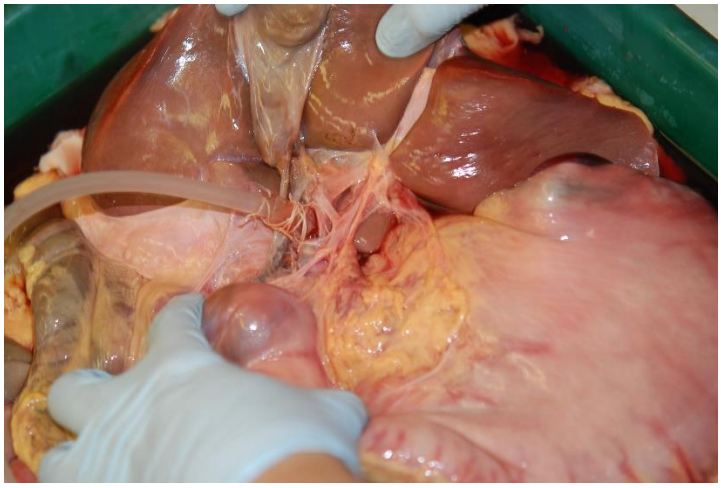

Figure 3.5. Cannulation of the portal vein

The organ complex was irrigated through the cannula with water to check for any leakage. Next, the specimen was put into tap water, therefore the floating in water position provided anatomical orientation of the organs. For injection, the resin developed by M. Kiss [23] was used, with the color code red for the arteries and yellow for the PV. The resin viscosity was set to fill vessels even with a diameter of 0,5 mm^2 in cross section. The injected resin hardened in a few minutes, and after hardening it maintained the vascular shape. The injected amount of resin ranged between 120-180 ml for the abdominal aorta, and 35-60 ml for the PV. Earlier, the specimens were corroded with concentrated HCl at room temperature [24]. In order to speed up this process, a better corrosion method was needed. Other chemical methods (Na_3PO_4, KOH) and biological methods (Septifos) were checked for corrosion ability at room temperature and with heating as well. KOH was found to be the most effective in a temperature range of 60-70°C. The corrosion was done in a specifically designed and built water bath with thermostat. The method was tried out on rat models for another research [25], where the cast showed intact fine vasculature (Figure 3.6.), therefore it was ready to be used on human tissue.

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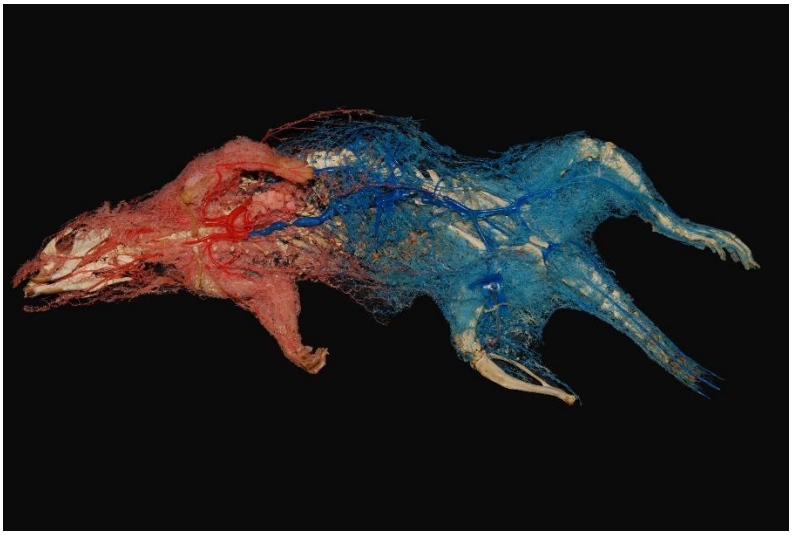

Figure 3.6. Rat vascular cast corroded with the KOH method. Red: resin injected from the common carotid artery, blue: resin injected from the left femoral artery [25]

With the use of heated KOH solution, the corrosion process for an organ complex needed only 5-7 days, the ideal amount of KOH was 500 g for each specimen.

After the corrosion process, the casts were washed to remove any residual tissue, and they were ready for analysis. Written documentation was done after the identification of the vascular variations. When making photo documentation, we came over another problem. Some variations were in the deep part of the specimens covered with other superficial branches, furthermore, the branches were oriented in several planes. To ensure proper documentation and further analysis, CT scans were taken of the casts, using a Philips Brilliance 16-unit CT (parameters: 140 kV, 300mAs, collimation: 16x0.75mm, overlap 50%) at the Department of Radiology and Oncotherapy, Semmelweis University. When necessary, 3D reconstructions were also created to demonstrate the variations. The CT scans provided the opportunity to make measurement of the chosen vessels, simulating clinical practice. The CT analysis was performed by a qualified radiologist with more than five years of clinical experience.

On all CT scans, the diameter of the pancreaticoduodenal arches was measured. On those casts, which had the PV system filled up, other measurements were done: Specific planes were reconstructed along the axis of the SMV, and parallel planes were also reconstructed to simulate pancreatic resection surfaces using eRAD PACS software. Since the pixel size was available from the eRAD program, ImageJ was used to count the pixels on the

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pancreatic territory and determine the vessel cross section. This technique offers precise information on the pancreatic vasculature at the “planned” resection plane (Figure 3.7.).

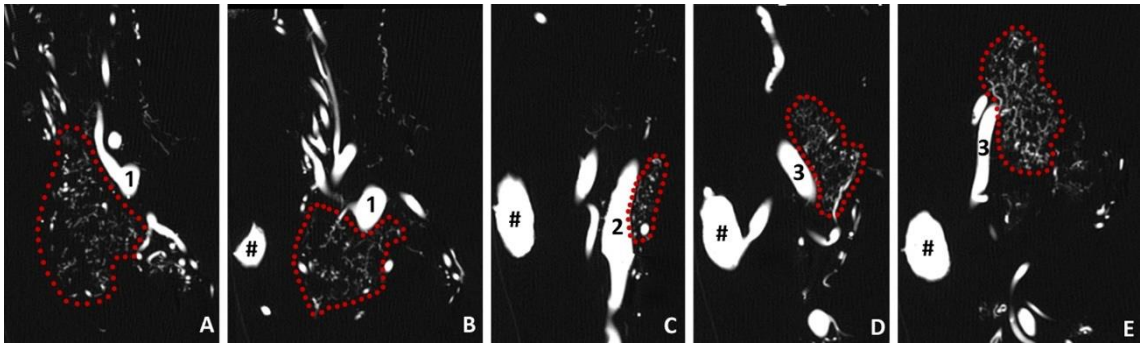

Figure 3.7. Reconstructed planes. A: 2 cm right; B: 1 cm right; C: level of SMV; D: 1 cm left; E: 2 cm left. The outline of the pancreas is marked with red dots [23]

1: PV; 2: SMV; 3: splenic vein; #: abdominal aorta

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4. RESULTS

We have analyzed all the 50 corrosion casts checking for every variation from the level of the aorta until the pancreaticoduodenal arcades to get the arterial patterns of the region. From the abdominal aorta, the celiac trunk and the superior mesenteric artery are taking part in the blood supply of the pancreatic head.

4.1. Abdominal aorta

In our series of 50 corrosion casts, every specimen contained one SMA arising from the abdominal aorta, but the celiac trunk showed some interesting variations. Celiacomeseneteric [26] and celiacobimesenteric trunk (common origin of the celiac trunk, superior and inferior mesenteric a.) [27] are known in the literature, but none of our cases displayed such variations. Celiac trunk with the typical three tributaries (LGA, CHA and SA) was found in 42 cases (84%). The most frequent aberrant variation was the hepatosplenic trunk, where the LGA branched off directly from the abdominal aorta, therefore the CHA and SA formed a common trunk (Figure 4.1.) – this variation occurred in 6 cases (12%). In two casts (4%) the variation of gastrosplenic trunk was observed, in which is the LGA and SA showed common origin; the CHA was given off by the abdominal aorta in one case (Figure 4.2.), and in the other case it was the branch of the SMA (Figure 4.3.).

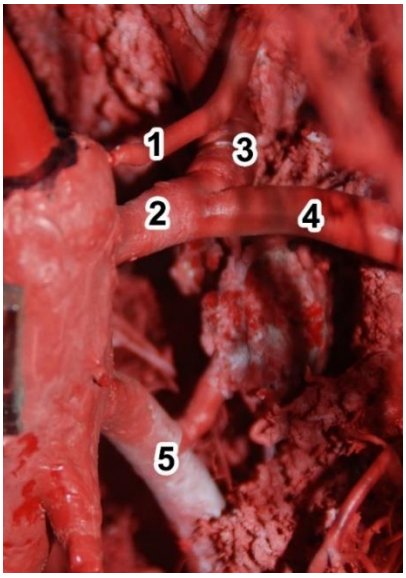

Figure 4.1. Hepatosplenic trunk, the LGA is a direct branch of the abdominal aorta.
1: LGA; 2: hepatosplenic trunk; 3: SA; 4: CHA; 5: SMA

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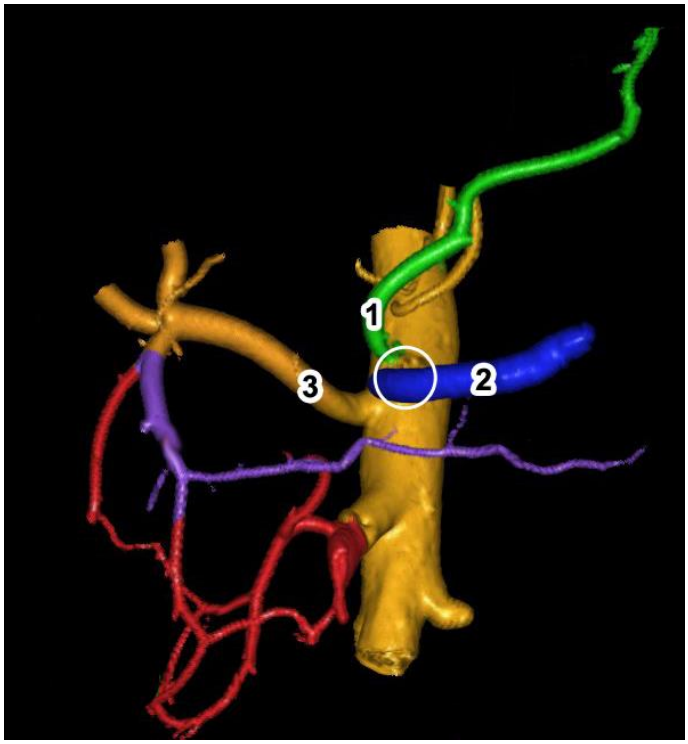

Figure 4.2. Gastrosplenic trunk, the CHA is a direct branch of the abdominal aorta
3D CT reconstruction.
1: LGA (green); 2: SA (blue); 3: CHA; the gastrosplenic trunk is marked with a circle

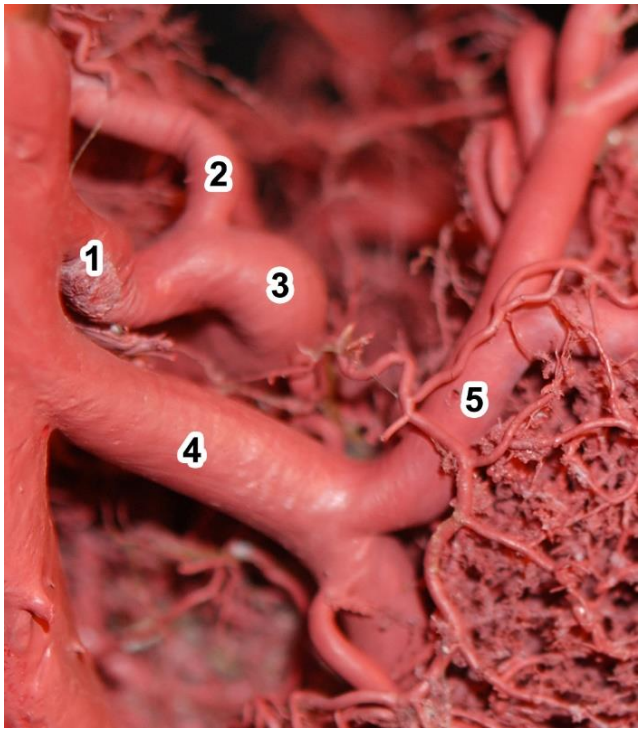

Figure 4.3. Gastrosplenic trunk, the CHA is a branch of the SMA. [28]
1: gastrosplenic trunk; 2: LGA; 3: SA; 4: SMA; 5: CHA

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4.2. Celiac trunk

While analyzing the primary branching pattern of the celiac trunk, the classic anatomical description of trifurcation was found only in 13 cases (26%). The most frequent pattern was found in 28 cases (56%), where the LGA was given off by the celiac trunk as the first branch, and a bit more distal, the celiac trunk splits into CHA and SA (Figure 4.4.). In one case, we observed the CHA as the first branch of the celiac trunk, then more distally, it splits to LGA and SA (Figure 4.5.). Double LGA was found in two specimens (4%) (Figure 4.6.).

The celiac trunk had extra, non-visceral branches in several cases. One of the inferior phrenic arteries was arising from the celiac on 11 casts (22%) (Figure 4.7.), and both inferior phrenic arteries were arising from the celiac trunk in one case (Figure 4.8.). Extra visceral branches were also documented: GDA (Figure 4.8.), left superior suprarenal artery (Figure 4.9.), inferior PDA (Figure 4.10.) and inferior posterior PDA (Figure 4.11.) were found in one case each.

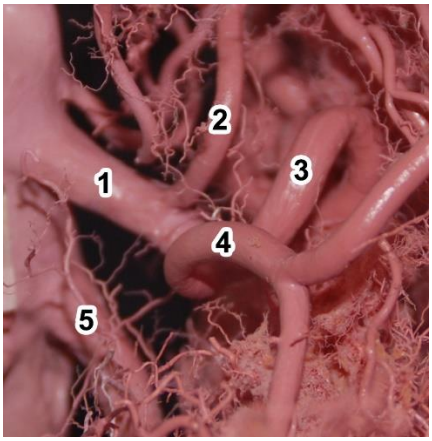

Figure 4.4. LGA is the first branch of the celiac trunk.
1: celiac trunk; 2: LGA; 3: SA; 4: CHA; 5: SMA

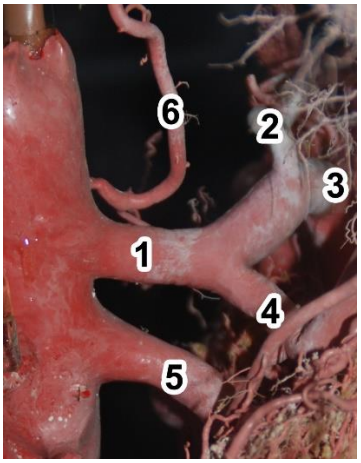

Figure 4.5. CHA is the first branch of the celiac trunk.
1: celiac trunk; 2: LGA; 3: SA; 4: CHA; 5: SMA; 6: inferior phrenic artery

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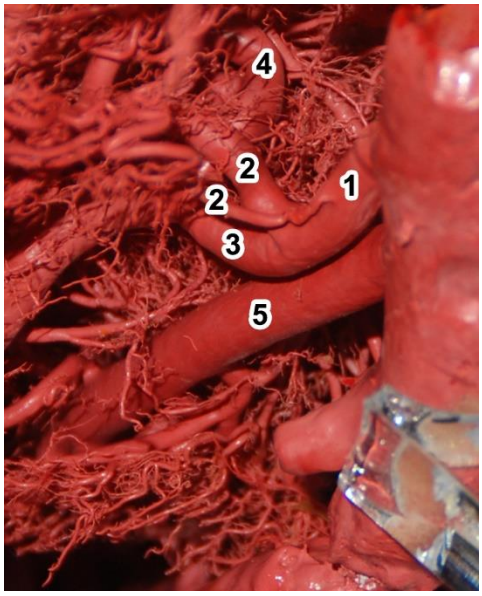

Figure 4.6. Two LGA arising from the celiac trunk.

1: celiac trunk; 2: LGA; 3: SA; 4: CHA; 5: SMA

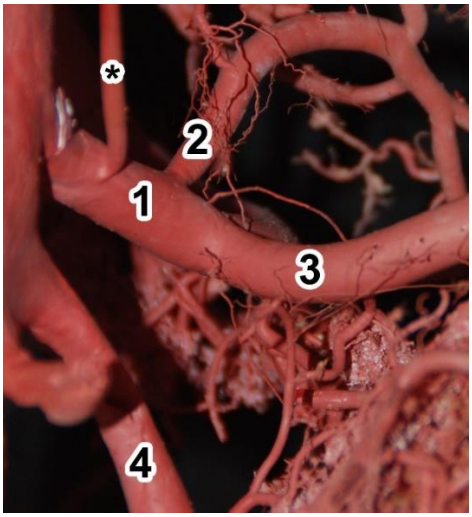

Figure 4.7. Inferior phrenic arising from the celiac trunk.

1: celiac trunk; 2: LGA; 3: CHA; 4: SMA; *: right inferior phrenic artery

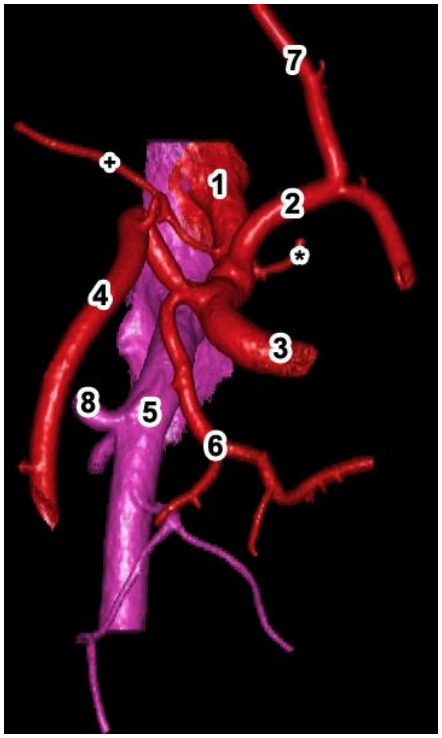

Figure 4.8. Both inferior phrenic arteries arise from the celiac trunk, the GDA is also a direct branch of the celiac trunk. 3D CT reconstruction.

1: celiac trunk; 2: LGA; 3: SA; 4: GDA; 5: SMA; 6: superior posterior PDA; 7: replaced LHA; 8: replaced RHA; *: left inferior phrenic artery; +: right inferior phrenic artery

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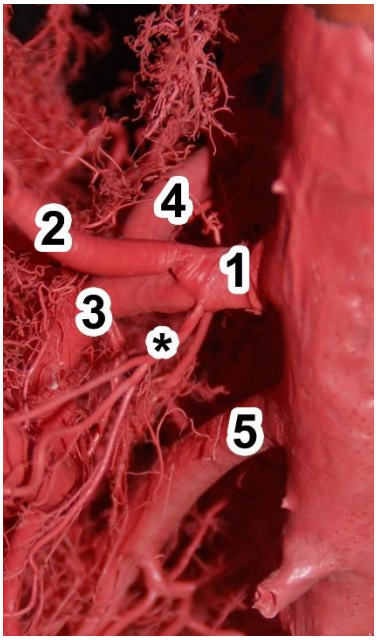

Figure 4.9. Superior suprarenal artery arising from the celiac trunk.
1: celiac trunk; 2: LGA; 3: SA; 4: CHA; 5: SMA; *: left superior suprarenal artery

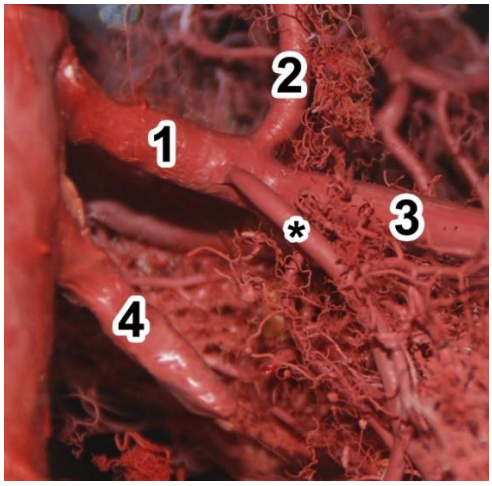

Figure 4.10. Inferior PDA arising from the celiac trunk.
1: celiac trunk; 2: LGA; 3: SA; 4: SMA; *: inferior PDA

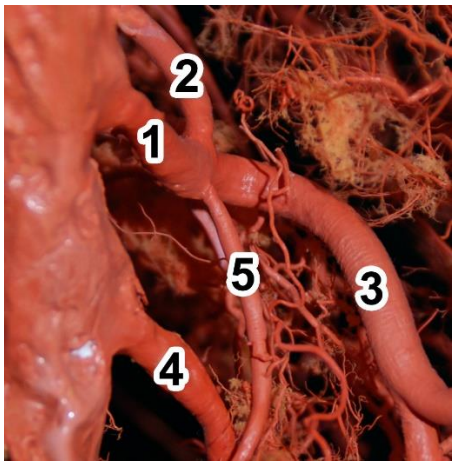

Figure 4.11. Inferior posterior PDA arising from the celiac trunk.
1: celiac trunk; 2: LGA; 3: CHA; 4: SMA; 5: inferior posterior PDA

4.3. Left gastric artery

Among the primary branches of the celiac trunk, the LGA may give rise to a variant left hepatic artery, which emphasizes the surgical importance of this vessel (liver surgery and liver transplantation). Twelve (24%) of our specimens showed a variant accessory or replaced LHA arising from the LGA.

4.4. Splenic artery

The splenic artery runs tortuously to the left, behind the stomach, along the superior border of the pancreas, giving off branches supplying the pancreatic tissue. The anatomical terminology uses the terms dorsal pancreatic artery, greater pancreatic artery and artery to tail of pancreas for these vessels. The use of these terms is still confused and unclear even in international journals due to the lack of their definition – however, specifying these branches goes beyond this thesis. It is still clear that not all of these arteries are always present, and moreover, they can be multiple in number. In our series, the SA gave one branch towards the pancreas in 6 cases (12%), two branches in 14 cases (28%), which gives evidence that not all branches are necessary present. In 10 cases (20%), four branches, in 4 cases (8%), five branches were found, which are examples for the various presence of the mentioned arteries. The SA gave rise to three arteries towards the pancreas in 16 cases (32%).

4.5. Common hepatic artery

The CHA was present on almost every specimen, except two cases. In one of these exceptions, the LHA and RHA were direct branches from the celiac trunk (Figure 4.12.), in the other case, the liver was supplied by a double replaced system (Figure 4.8.), therefore the LHA arose from the LGA and the RHA stemmed from the SMA. The variant origin of the CHA was already mentioned in the cases of gastrosplenic trunks: in one case, the CHA was branching from the abdominal aorta (Figure 4.2.), in also one occasion, the CHA was given by the SMA (Figure 4.3.). In the remaining 46 cases, the CHA was a direct branch of the celiac trunk.

The liver is frequently supplied by variant arteries, in many cases, the variant vessels branch off the SMA or LGA – these variant arteries are called extrahepatic arteries, as they do not branch from the PHA, they are classified by the Michels classification (Table 5.7.).

Anatomy books describe two branches of the CHA: the PHA and the GDA, which variation occurred in 58% of our cases. In 22%, the CHA got an extra side branch, and in 22%, the CHA had more than two branches at its terminal end. In cases of an extra side branch, the extra artery was a minor artery supplying the pancreatic head in 7 specimens. Inferior posterior PDA was arising from the CHA in 2 cases (Figure 4.13.), in the further

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cases, the extra branch was an aberrant right gastric artery (Figure 4.14.) and a superior posterior PDA in one-one case (Figure 4.15.).

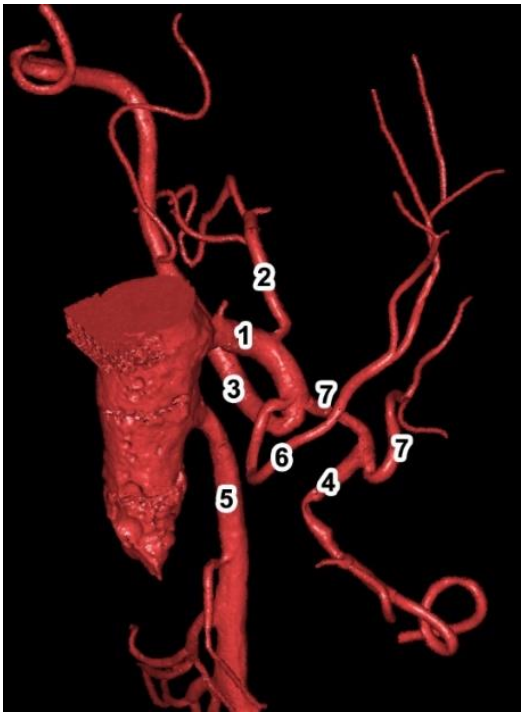

Figure 4.12. Right and left hepatic arteries are direct branches of the celiac trunk, the GDA is given off by the LHA. 3D CT reconstruction.
1: celiac trunk; 2: LGA; 3: SA; 4: GDA; 5: SMA; 6: RHA; 7: LHA

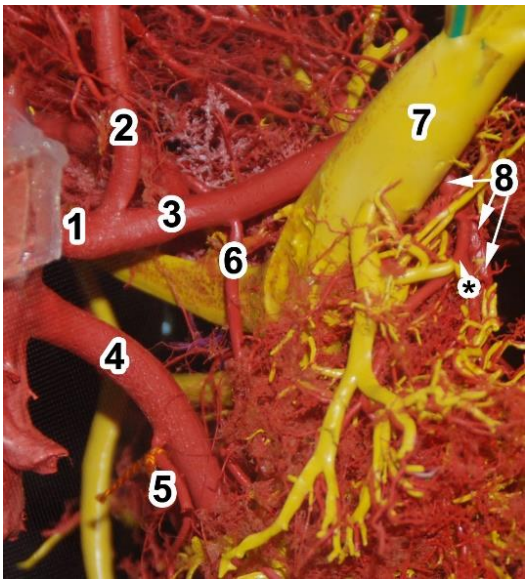

Figure 4.13. Inferior posterior PDA is branching off from the CHA.
1: celiac trunk; 2: LGA; 3: CHA; 4: SMA; 5: inferior anterior PDA, 6: inferior posterior PDA; 7: PV; 8: GDA; *: superior posterior PDA

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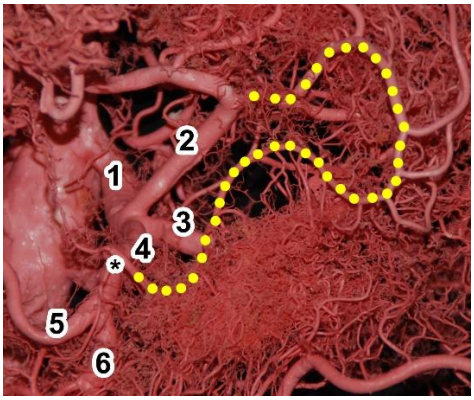

Figure 4.14. Right gastric artery is branching off from the CHA.
1: celiac trunk; 2: LGA; 3: SA; 4: CHA; 5: PHA; 6: GDA; *: right gastric artery; yellow dots mark the anastomosis between right and left gastric arteries

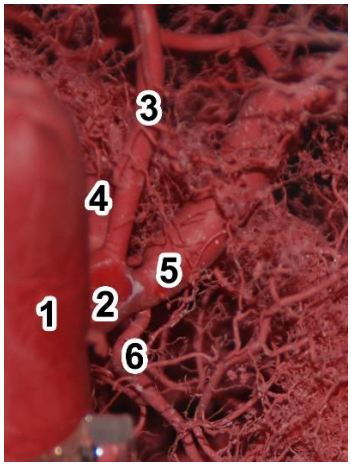

Figure 4.15. Superior posterior PDA is branching off from the CHA.
1: abdominal aorta; 2: celiac trunk; 3: LGA; 4: SA; 5: CHA; 6: superior posterior PDA

In cases of more than two terminal branches, the most common variation was the trifurcation (14%). In 3 cases, the trifurcation was formed by the LHA, RHA and GDA, therefore PHA didn't exist on these specimens (Figure 4.16.). The trifurcation was formed by the PHA, GDA and the right gastric in three cases as well (Figure 4.17.). We encountered a variation, where the PHA, GDA and a superior posterior PDA formed the trifurcation (Figure 4.18.). Quadrifurcation was found on three casts (6%), and all three cases showed the same arteries forming the quadrifurcation, which were the GDA, LHA, RHA and the right gastric artery (Figure 4.19.). Pentafurcation was found in only one case, where the terminal branches of the CHA were the GDA, LHA, RHA, right gastric artery and an artery supplying segment 4 of the liver (Figure 4.20.).

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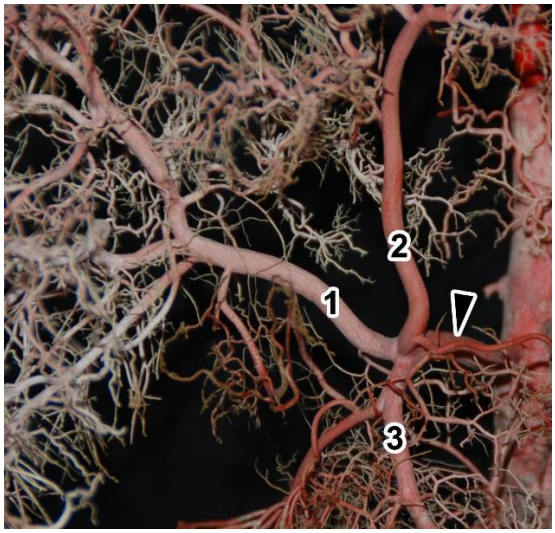

Figure 4.16. Trifurcation of the CHA.
1: RHA; 2: LHA; 3: GDA;
arrowhead: CHA

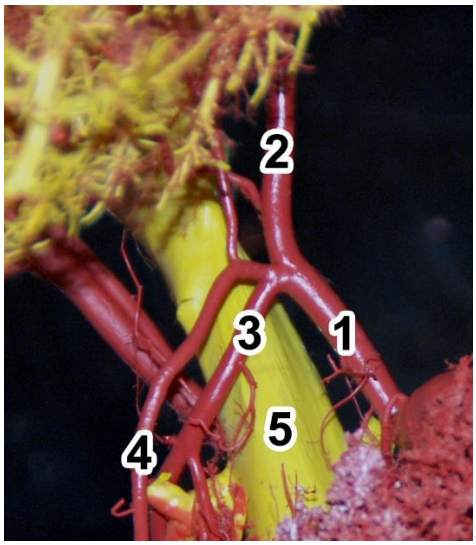

Figure 4.17. Trifurcation of the CHA.
1: CHA; 2: PHA; 3: GDA;
4: right gastric artery

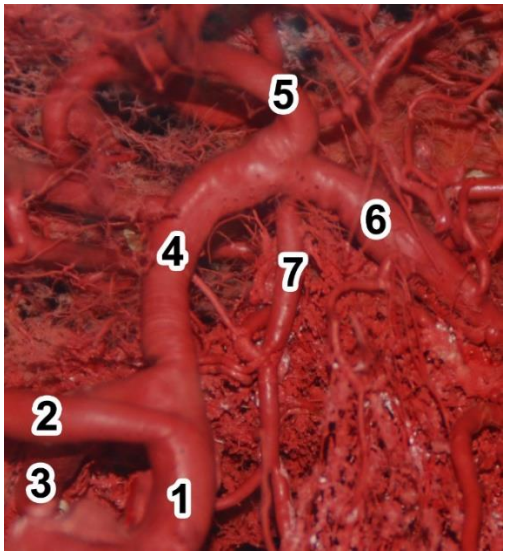

Figure 4.18. Trifurcation of the CHA.
1: celiac trunk; 2: LGA; 3: SA; 4: CHA;
5: PHA; 6: GDA;
7: superior posterior PDA

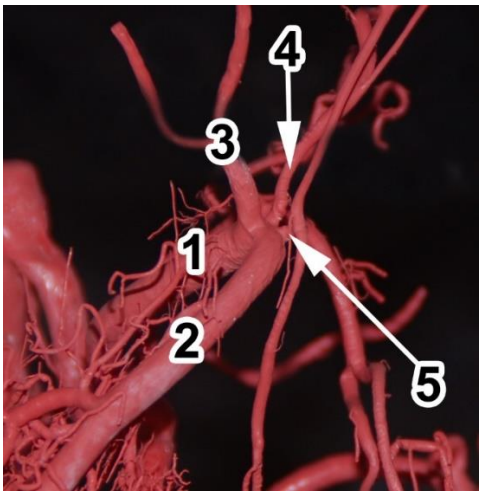

Figure 4.19. Quadrifurcation of the CHA
1: CHA; 2: GDA; 3: RHA; 4: LHA;
5: right gastric artery

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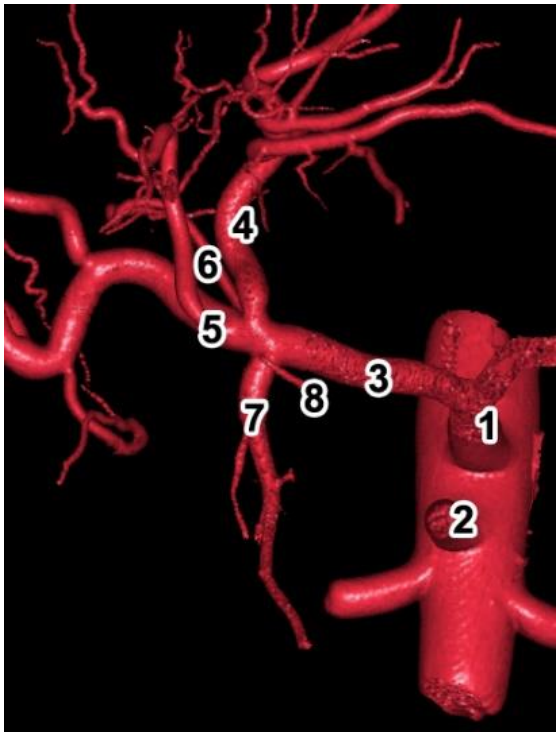

Figure 4.20. Pentafurcation of the CHA. 3D CT reconstruction. [29]
1: celiac trunk; 2: SMA; 3: CHA; 4: LHA; 5: RHA; 6: artery of segment 4; 7: GDA;
8: right gastric artery

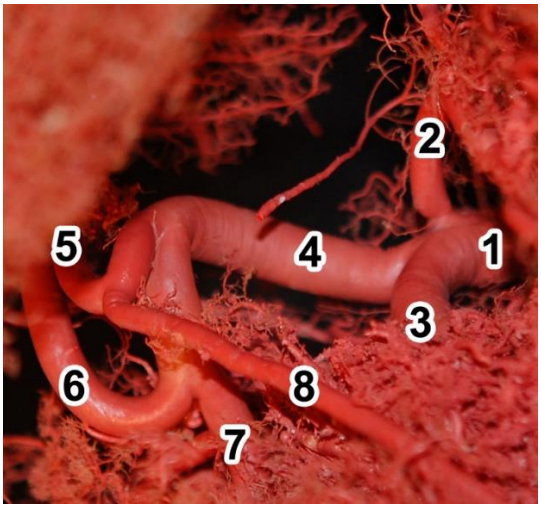

Figure 4.21. The GDA is branching off from the RHA. [29]
1: celiac trunk; 2: LGA; 3: SA; 4: CHA; 5: LHA; 6: RHA; 7: GDA; 8: right gastric artery

4.6. Gastroduodenal artery

The GDA arose from the CHA in 86% of our cases. Variant origin of the GDA is related to the variations of the hepatic arteries. In two specimens, the GDA derived from the RHA (Figure 4.21.), the PHA was missing in both cases, as the CHA was splitting to LHA and RHA, the GDA got its origin from the latter. On four casts, we found GDA arising from the LHA, these cases also had an early splitting to LHA and RHA. Three out of these four specimens didn't contain PHA, since the CHA split to LHA and RHA (Figure 4.22.), on the remaining one cast, even the CHA was absent, as the LHA and RHA branched off from the celiac trunk (Figure 4.12.). We encountered one case, where the GDA was a direct branch of the celiac trunk, as this specimen didn't contain CHA - the liver was supplied by a double replaced system (Figure 4.8.), thus the LHA stemmed from the LGA, while the RHA from the SMA.

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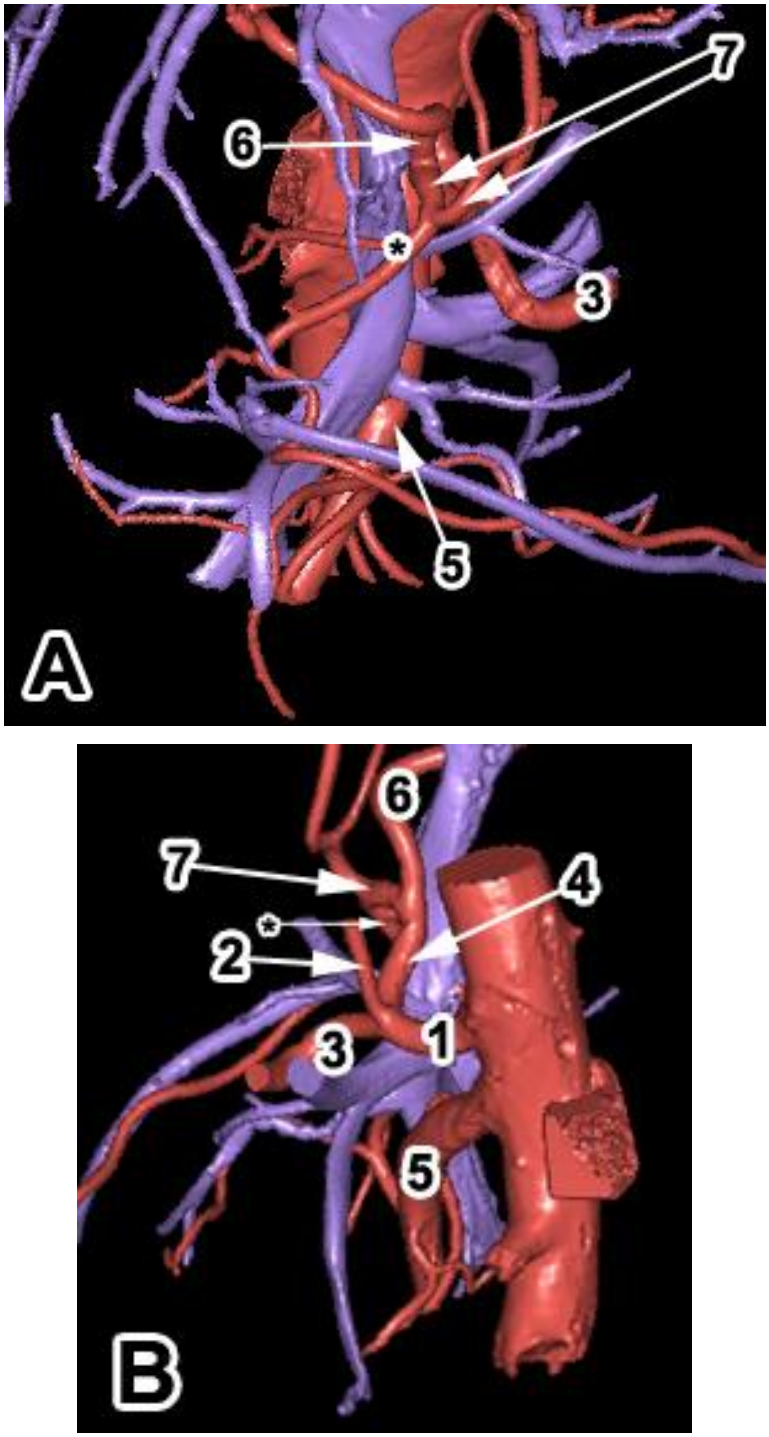

Figure 4.22. The GDA is branching off from the LHA.

A: anterior aspect; B: left lateral aspect. 3D CT reconstruction. [29]

Red: arterial system; Purple: portal vein system

1: celiac trunk; 2: LGA; 3: SA; 4: CHA; 5: SMA; 6: RHA; 7: LHA; *: GDA

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4.7. Pancreaticoduodenal arteries

Arches formed by the pancreaticoduodenal arteries show wide range of variations. On one hand, the main inferior and superior PDA trunks are not always present – as described by many anatomy textbooks, and on the other hand, the arteries forming the arches also alter from the normal variant. The number and diameter of the arches are also not constant.

Superior PDA was found only in 10% of our cases (Figure 4.23.), in the remaining 90%, the superior anterior and superior posterior PDA had separate origin. Inferior PDA could be observed on 80% of our specimens. The 1st jejunal artery shared a common origin with the inferior PDA in 70% frequency. On specimens, where the inferior anterior and inferior posterior PDA have a separate origin (20%), the 1st jejunal artery branched off from one of these arteries in 80%.

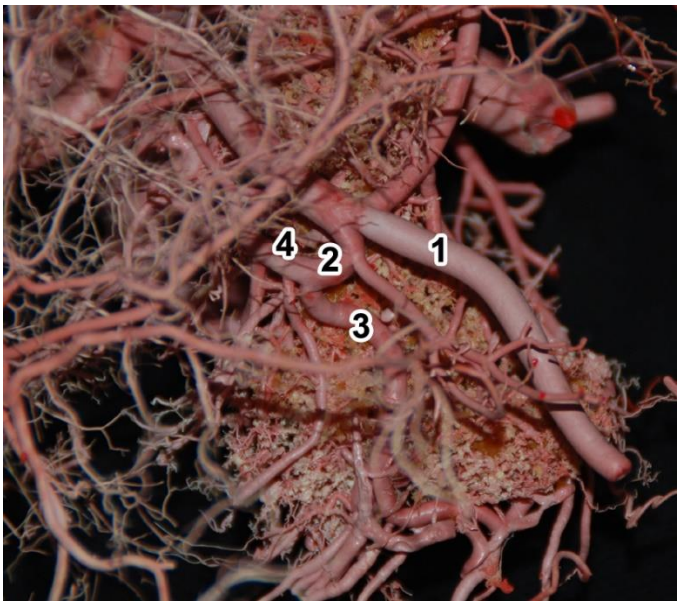

Figure 4.23. The superior PDA is present.

1: GDA; 2: superior PDA; 3: superior anterior PDA; 4: superior posterior PDA

4.7.1. Superior pancreaticoduodenal artery

On every specimen, which contained the superior PDA, it was a branch of the GDA. On one occasion, the superior PDA was arising from the GDA, which had a variant origin from the LHA, the other casts showed the normal variation.

In 68% of our cases, superior anterior and superior posterior PDA were separately arising from a regular GDA (Figure 4.24.). In 12%, we observed superior anterior and superior

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posterior PDA arising from a variant GDA. The variant GDA was given off by the LHA in three cases, by the RHA in two cases and in one case, the GDA got its origin from a replaced CHA arising from the SMA (Michels IX).

The origin of the superior posterior PDA from the GDA was observed in 10% in our series. In two cases, it was given off by the CHA (Figures 4.15. and 4.18.), in two further cases, it branched from a replaced RHA (Michels III) (Figure 4.25.) and in one case, the superior posterior PDA originated from the PHA (Figure 4.26.).

The origin of the superior anterior PDA didn't show variations, it branched off from the superior PDA – if it was present – otherwise it was given off by the GDA.

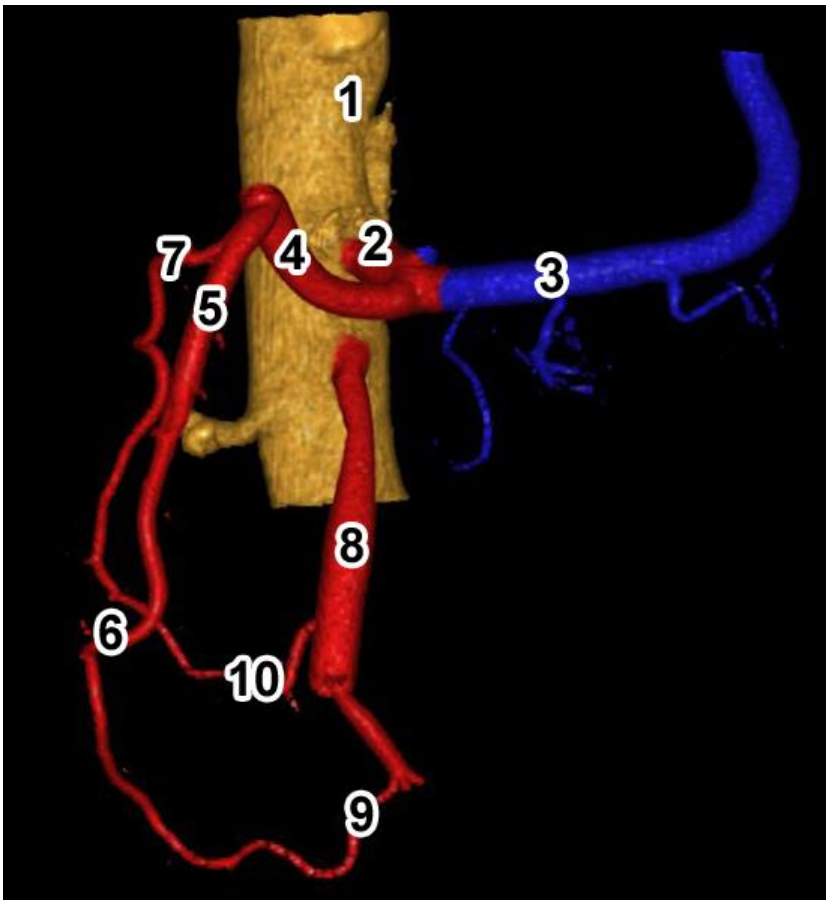

Figure 4.24. Superior anterior and superior posterior PDA origin separately from the GDA, inferior anterior and inferior posterior PDA origin separately from the SMA.
3D CT reconstruction.
1: abdominal aorta; 2: celiac trunk; 3: SA; 4: CHA; 5: GDA; 6: superior anterior PDA; 7: superior posterior PDA; 8: SMA; 9: inferior anterior PDA; 10: inferior posterior PDA

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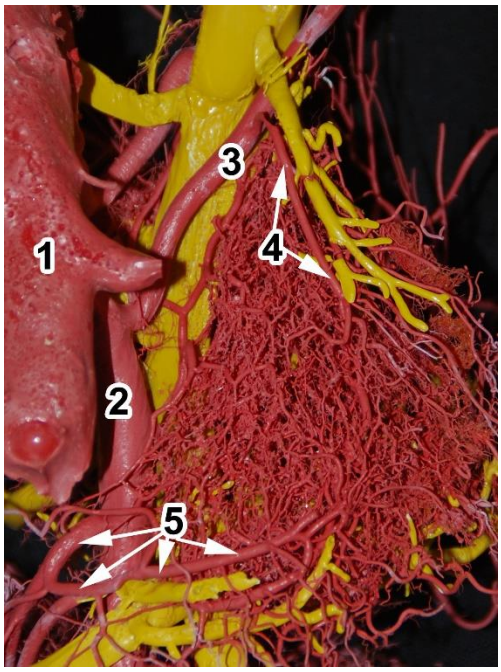

Figure 4.25. Superior posterior PDA is given off by a replaced RHA. The PV system is filled with yellow resin.
1: abdominal aorta; 2: SMA; 3: replaced RHA; 4: superior posterior PDA;
5: inferior PDA

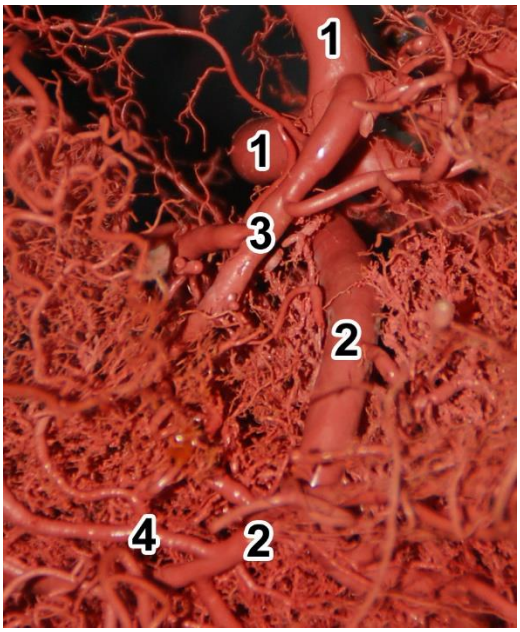

Figure 4.26. Superior posterior PDA is given off by the PHA.
1: PHA; 2: GDA
3: superior posterior PDA;
4: superior anterior PDA

4.7.2. Inferior pancreaticoduodenal artery

In cases, where the inferior PDA was present (80%), we observed variant origin of this artery in two cases. In one case, the celiac trunk (Figure 4.10.), on the other occasion, a replaced RHA (Michels III) gave origin of the inferior PDA.

The inferior anterior PDA showed no aberrant origin.

The source of inferior posterior PDA showed variations on three casts. It was a branch of the celiac trunk (Figure 4.11.), or the CHA (Figure 4.13.) or a replaced RHA (Michels III) (Figure 4.27).

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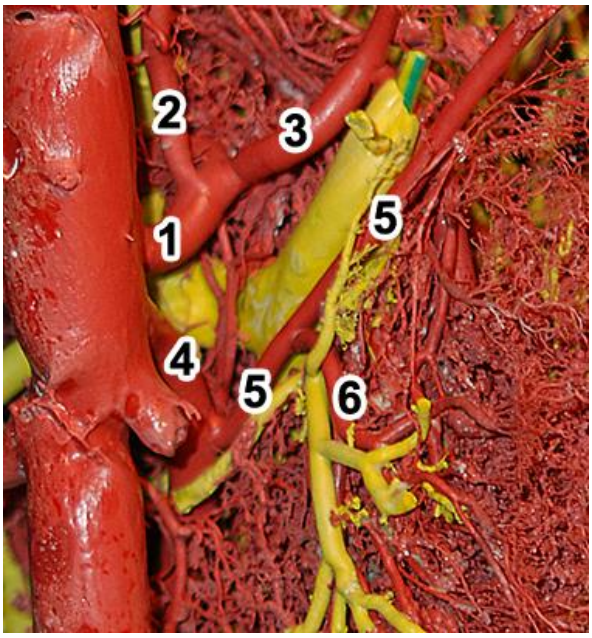

Figure 4.27. Inferior posterior PDA is given off by a replaced RHA. The PV system is filled with yellow resin.
1: celiac trunk; 2: LGA, 3: CHA; 4: SMA; 5: replaced RHA; 6: inferior posterior PDA

4.7.3. Arterial arches in the pancreaticoduodenal system

On the series of our 50 corrosion casts, we encountered different number of anastomoses formed by the pancreaticoduodenal arteries in the region of the pancreatic head. Two arterial arches were present in 29 cases (58%), three arches in 15 cases (30%), one arch in 3 cases (6%), five arches in 2 cases (4%) and four arches in 1 case (2%). All specimens had at least one arterial arch.

Diameters of every arch were measured on the CT scans of the casts, but we had sufficient number of cases for statistical analysis only in the group of two arches (Table 4.1.). In the literature, definite method to determine the dominant arch is not available, therefore we used our own criteria on determining the dominance (Table 4.2.).

1.) The first criterion was to have a greater diameter regardless of the difference. The measurement accuracy was 0,1 mm. By this criterion of any diameter differences the anterior arch was wider in 52%, the posterior in 38% and in 10% they had the same size.
2.) Considering our data on the average diameter of the arches, which were 1, 472 ± 0,432 mm, and 1,383 ± 0,343 mm for anterior and posterior arches respectively, the 0,1 mm difference seem to be too low threshold to determine dominance. The

second criterion was therefore a minimum difference of 0,3 mm in diameter. By this criterion, the anterior arch was dominant in 41%, the posterior in 24% and in 35% the difference between the arches didn't reach 0,3 mm.

3.) In the first two criteria, we investigated the diameter, but as the blood flow through the arches correlates with the cross section of the vessels, the next criterion was a higher cross-sectional area with at least 25% rate. By this criterion, the anterior arch was dominant in 52%, the posterior in 35% and in 13% the difference between the arches haven't reach the threshold.
4.) We checked the cross-section difference with a higher, 50% difference criterion as well. By this criterion, the anterior arch was dominant in 31%, the posterior in 31% and in 38% the difference hasn't met the minimum criterion.

Three pancreaticoduodenal arcades were presented in 30% of our cases, but besides the two ordinary arcades, the third arcade is frequently formed by an anastomosis between the anterior and posterior arches (67%). In 26% of the three-arcade specimens, the posterior arch was duplicated (Figure 4.28.) and in one case, the anterior arch was doubled (Figure 4.29.). Dominance of three arches was also assessed, but our statistical analysis turned up no pertinent information.

One pancreaticoduodenal arch was found in three cases, the diameters were 3.9, 2.4 and 1 mm. The cast with 3.9 mm diameter had an arcade functioning instead of the two (Figure 4.30.), while the further two cases contained the usual pancreaticoduodenal arteries supplying the head of the pancreas, but only one arch was formed.

Cases with four or five arches are considered rare in the literature, therefore they need detailed description. On the cast with four pancreaticoduodenal arcades (Figure 4.31.), superior posterior and superior anterior PDA arose separately from the GDA, but the superior anterior PDA divided to three branches, each of them forming a separate arch.

Five arcades were presented by two casts, both had a variant RHA arising from the SMA. One of these casts (Figure 4.32.) showed three separate superior PDA arising from the GDA. The inferior anterior and inferior posterior PDA had separate origins, they formed two arches with each other and met the three superior PDA from the GDA. The other cast (Figure 4.33.) is similar, but this specimen had only two superior PDA branching off from the GDA, the fifth arcade was a separate one.

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Measurement of the pancreaticoduodenal arches		Calculated data from the measured diameters	
Diameter of anterior arch (mm)	Diameter of posterior arch (mm)	Difference between anterior and posterior arches (mm)	Cross-sectional area difference between anterior and posterior arches. Cross sectional area = (diameter/2)2*∏, the difference is shown in %
1,3	1,3	0	0
1,3	1,1	0,2	18,2
0,9	1,6	0,7	77,8
1,1	1,6	0,5	45,5
1,3	1	0,3	30
1	1,3	0,3	30
1,5	1,3	0,2	15,4
2,4	2	0,4	20
1,5	0,9	0,6	66,7
1,8	1,5	0,3	20
1,4	1,2	0,2	16,7
1,6	1,2	0,4	33,3
1,9	2,5	0,6	31,6
2	1,7	0,2	17,6
0,8	1	0,2	25
1,2	1,4	0,2	16,7
1,6	1,3	0,3	23,1
1,3	1,7	0,4	30,1
1,6	1,6	0	0
0,8	1,2	0,4	50
2,1	1,2	0,9	75
1,4	1,4	0	0
1,8	1,3	0,5	38,5
1,7	1,3	0,4	30,8
2,3	1,3	1	70,9
0,8	1	0,2	25
1,4	1,9	0,5	35,7
1,8	1,1	0,7	63,6
1,1	1,2	0,1	9,1

Table 4.1. Diameter of the pancreaticoduodenal arches, difference between anterior and posterior arches, and cross-sectional area difference on specimens with two arches (29 casts). [28]

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Criteria:	Any difference between the arches	Difference in diameter ≥ 0,3 mm	Difference in cross-sectional area ≥ 25%	Difference in cross-sectional area ≥ 50%
Dominance				
Anterior arch	52% (15 case)	41% (12 case)	52% (15 case)	31% (9 case)
Posterior arch	38% (11 case)	24% (7 case)	35% (10 case)	31% (9 case)
Co-dominance	10% (3 case)	35% (10 case)	13% (4 case)	38% (11 case)

Table 4.2. Dominance of the pancreaticoduodenal arches determined by differently calculated values on specimens with two arches (29 casts). [28]

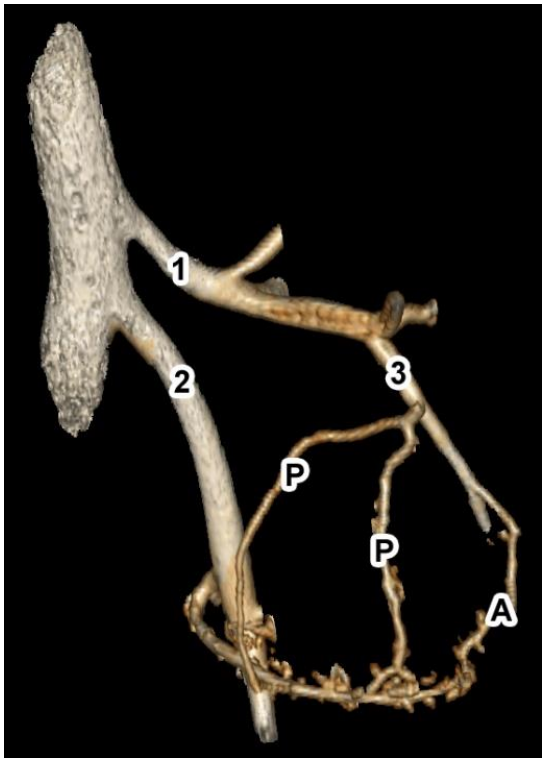

Figure 4.28. Double posterior arch.
3D CT reconstruction. [28]
1: celiac trunk; 2: SMA; 3: GDA; A: anterior arch; P: posterior arches

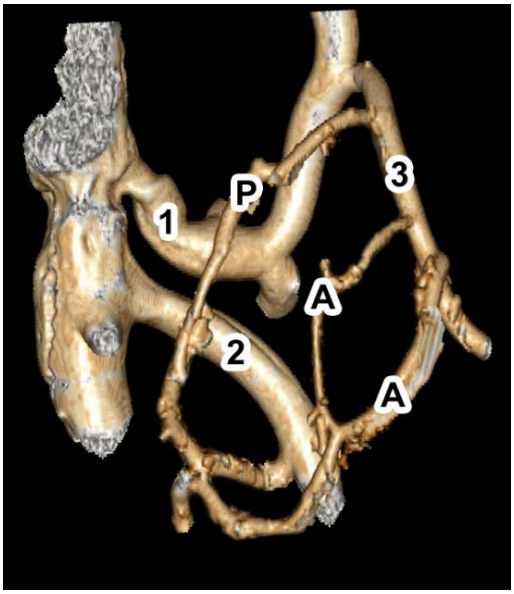

Figure 4.29. Double anterior arch.
3D CT reconstruction. [28]
1: celiac trunk; 2: SMA; 3: GDA; A: anterior arch; P: posterior arches

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Figure 4.30. One pancreaticoduodenal arch. 3D CT reconstruction. [28]
1: celiac trunk; 2: SMA; 3: GDA;
#: pancreaticoduodenal arch

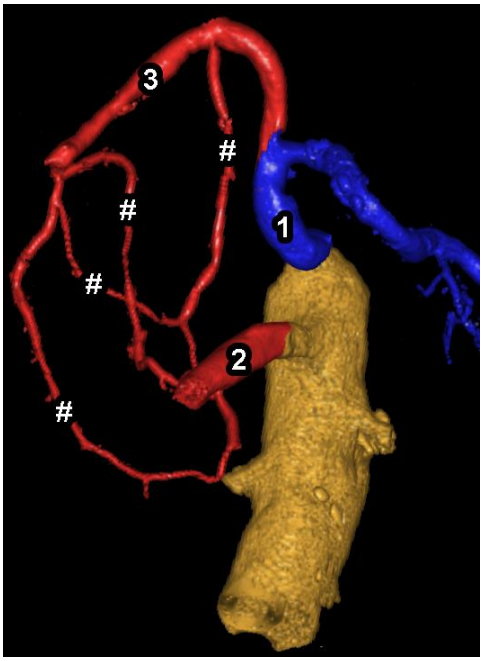

Figure 4.31. Four pancreaticoduodenal arches. 3D CT reconstruction. [28]
1: celiac trunk; 2: SMA; 3: GDA;
#: pancreaticoduodenal arches

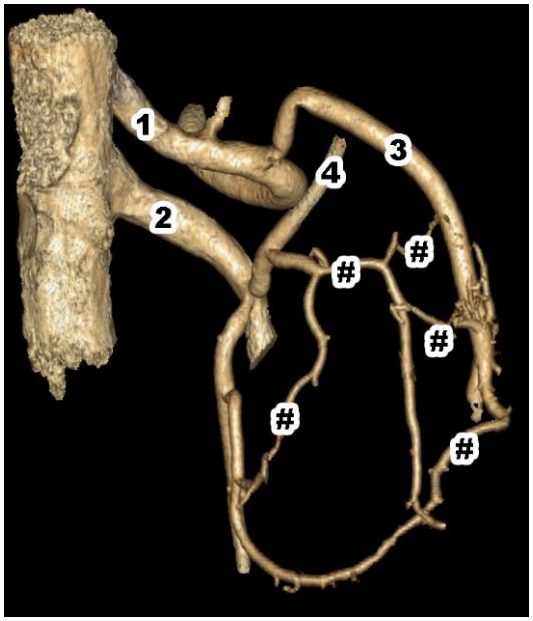

Figure 4.32. Five pancreaticoduodenal arches. 3D CT reconstruction. [28]
1: celiac trunk; 2: SMA; 3: GDA;
4: variant RHA; #: pancreaticoduodenal arches

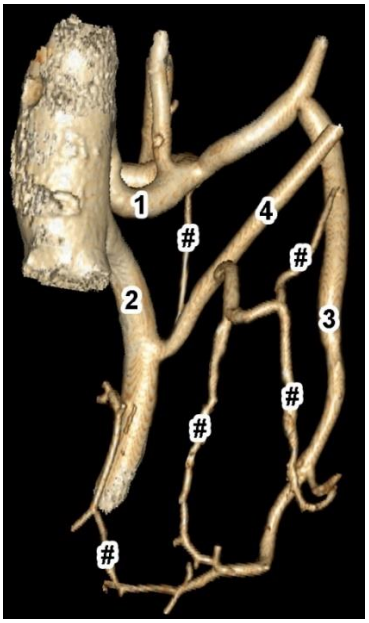

Figure 4.33. Five pancreaticoduodenal arches. 3D CT reconstruction. [28]
1: celiac trunk; 2: SMA; 3: GDA;
4: variant RHA; #: pancreaticoduodenal arches

The inferior mesenteric artery may provide a branch forming an anastomosis with the pancreatic branches in extreme rare cases. As our series contains 50 specimens, an appearance of such a variation would distort our statistical data, therefore it was not in the focus of our research. In our department - apart from the research – during the gradual anatomy education, approximately 50 cadavers are dissected a year, and in one case, we came across a variation, where the inferior mesenteric artery had an anastomosis with the pancreatic branches: the anastomosis formed a direct connection between the left colic a. and transverse pancreatic a. [4]. The fact, that this was the only case in the known past ~30 years, proves the extreme rare occasion of such variations.

4.7.4. Intrapancreatic vasculature – measurements in theoretical resection planes

As described earlier (Figure 2.1.), we also investigated the optimal plane of pancreatic head resection by measuring total vascular cross-sectional surface in selected planes. For this research, we checked 25 of our specimens, whose PV system had also filled up with resin.

The measurements resulted in data that varied greatly based on the pancreatic size, therefore the data were standardized to the SMV plane. In Table 4.3, the total vascular resection surface found in particular selected planes were correlated with the percentages of the total sectional profiles in the SMV plane. The vascular resection surface displaying the lowest value may be considered as the optimal line of resection.

The surgical resection is advised in the plane with the possible lowest number of vascular injuries. In our series of 25 casts, the advisable plane is that of the SMV in 11 cases, 2 cm to the left of SMV in 10 casts, 1 cm to the left of SMV in 4 cases, 1 cm to the right of SMV in 1 specimen and 2 cm to the right of SMV in none of our series (Figure 4.34.). Sample No. 20. displayed the same value of vascular resection surface at the plane of the SMV and at the plane 1 cm to the left from the SMV.

The SMV plane group contains the greatest number of cases with the lowest values (11 of 25), however, the left sided extension groups (1 or 2 cm to the left of SMV) contains the majority of our cases (14 of 25). The surface of transected vessels following left-sided resections may be as low as 29% in relation to the SMV plane (Table 4.3.).

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Location of the selected plane:	2 cm right from the SMV	1 cm right from the SMV	SMV (standard)	1 cm left from the SMV	2 cm left from the SMV
Sample No.	Total vascular surface of each plane compared with the total vascular surface in the standard SMV plane in %				
No. 1.	199%	169%	100%	37%	61%
No. 2.	182%	275%	100%	127%	96%
No. 3.	91%	189%	100%	72%	68%
No. 4.	216%	262%	100%	148%	130%
No. 5.	87%	61%	100%	198%	119%
No. 6.	71%	197%	100%	53%	49%
No. 7.	168%	124%	100%	52%	49%
No. 8.	293%	230%	100%	48%	58%
No. 9.	96%	137%	100%	34%	29%
No. 10.	379%	122%	100%	107%	200%
No. 11.	126%	126%	100%	94%	112%
No. 12.	180%	202%	100%	141%	111%
No. 13.	283%	493%	100%	253%	130%
No. 14.	279%	337%	100%	135%	165%
No. 15.	159%	322%	100%	240%	243%
No. 16.	177%	154%	100%	123%	40%
No. 17.	265%	360%	100%	124%	87%
No. 18.	335%	621%	100%	165%	192%
No. 19.	41%	95%	100%	44%	29%
No. 20.	144%	175%	100%	100%	115%
No. 21.	214%	248%	100%	102%	74%
No. 22.	815%	995%	100%	305%	300%
No. 23.	207%	179%	100%	120%	123%
No. 24.	463%	248%	100%	278%	893%
No. 25.	238%	299%	100%	82%	74%

Table 4.3. Total vascular diameters in different transection planes related to the standard SMV plane in percentages. [23] Lowest values are underlined, presenting the optimal resection surface in each sample.

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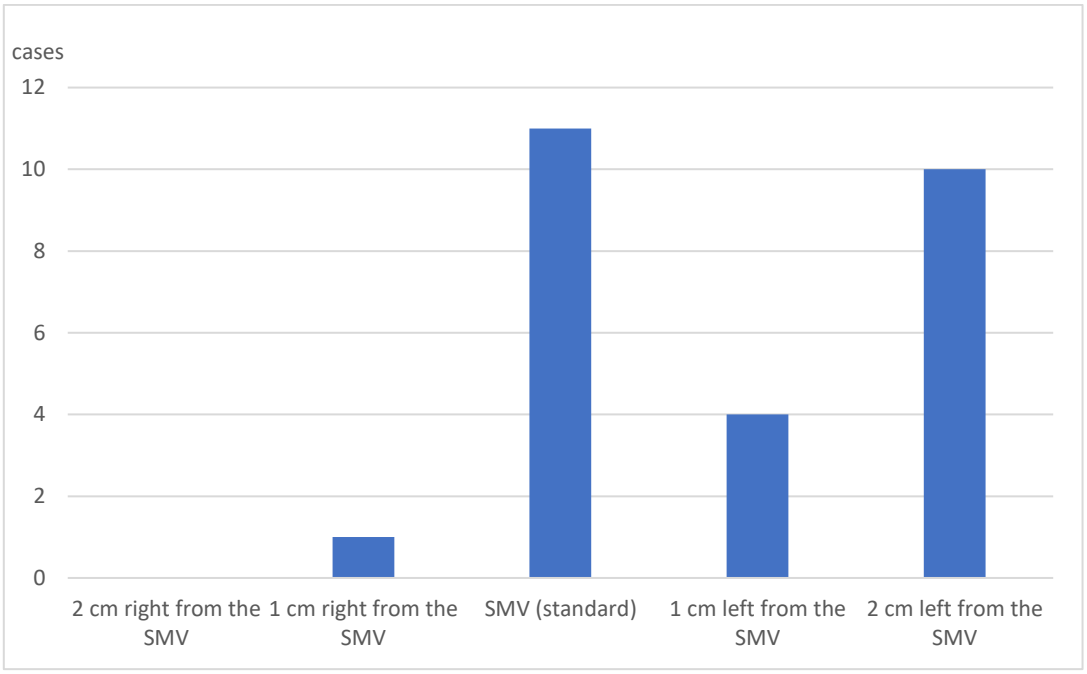

Figure 4.34. The location of the optimal resection plane in our series of 25 specimens [23]

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5. DISCUSSION

During revision of the literature, several papers describe the vascular variations in the upper abdominal region, but these publications focus on the origin or branching patterns of one specific vessel. We compared our findings with the literature according to each vessel.

5.1. Abdominal aorta

The unpaired visceral branches of the abdominal aorta are the celiac trunk, the SMA and the inferior mesenteric artery. Common origin of these vessels may occur, but these variations are too rare to occur on our series of 50 specimens:

Celiacomesenteric trunk is formed by the fusion of the celiac trunk and the SMA, and it is published usually as a case report, in which this variation was observed during routine dissection or as an accidental finding in radiology. Only few review papers are known, the latest one [30] describes the occurrence of this vascular anomaly in 0,76%, but some earlier researches showed higher frequency, 1,5% [26].

Celiacobimesenteric trunk is formed by the fusion of the three unpaired visceral branches, and until today, there is only one known case published [27].

The fused superior and inferior mesenteric arteries are called common mesenteric a., but some authors describe it as SMA, that gives off the inferior mesenteric a. [31]. This variation is also rare, therefore it is published in case studies. Frequency of such variant is estimated to be under 0,1%, as published only in one book [32].

5.2. Celiac trunk

The first known description of the celiac trunk was in 1756 by Haller [33], as a short artery arising from the aorta, ending in trifurcation, giving rise to the SA, CHA and LGA. Even before Haller, Galenus (II. century) and Vesalius (1538) also knew about the celiac trunk, but their description was not precise; Vesalius assumed the celiac is dividing to left and right branches supplying the liver and the spleen. Since the classic definition of the celiac trunk, several articles have been written about the variations of the celiac trunk, using different nomenclatures, thus it was necessary to form a classification to avoid misunderstandings. The first classifications were published in 1917. Lipshutz [34] formed

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four groups, where type I. was celiac trunk with all three branches, in each further group, one of the branches had a separate origin from the aorta (Table 5.1.).

type	
I.	Celiac trunk with trifurcation
II.	LGA from aorta –hepatosplenic trunk
III.	SA from aorta –hepatogastric trunk
IV.	CHA from aorta –gastrosplenic trunk

Table 5.1. Classification of the celiac trunk by Lipshutz (1917)

Eaton [35] also published his own classification in 1917, but he formed types and subtypes of the variations, organizing them in a table (Figure 5.1.). This classification is more detailed than the one provided by Lipshutz. He describes additional variant branches given off by the celiac trunk, and also separates the group of celiac trifurcations from the group of celiac trunks which have all three branches, but they don't form trifurcation. Eaton also focused on variant extrahepatic arteries. In his classification system, the normal variant is found in the middle of the first row (Class a, Type II/2). In the table, as the variations got further to the right, the origin of the LGA gets more distance from the celiac trunk, and to the left, the origin of the CHA is showing more variants. In the further rows, extra side branches are added to the previous patterns, and by this way, a total amount of 15 subtypes are described and organized. Even this system is logical, it became too complex, some variations are still missing, and in specific cases, it is controversial.

The first classification used widespread was published in 1928 by Adachi [36]. It is more detailed than Lipshutz's grouping, as it considers variations related also to the SMA, but easier to use than Eaton's classification (Table 5.2.).

Morita was the first in 1935, who added a type to the classification [37], where the LGA, SA and CHA all have separate origin, therefore no celiac trunk is present, otherwise, the classification is like Lipshutz's.

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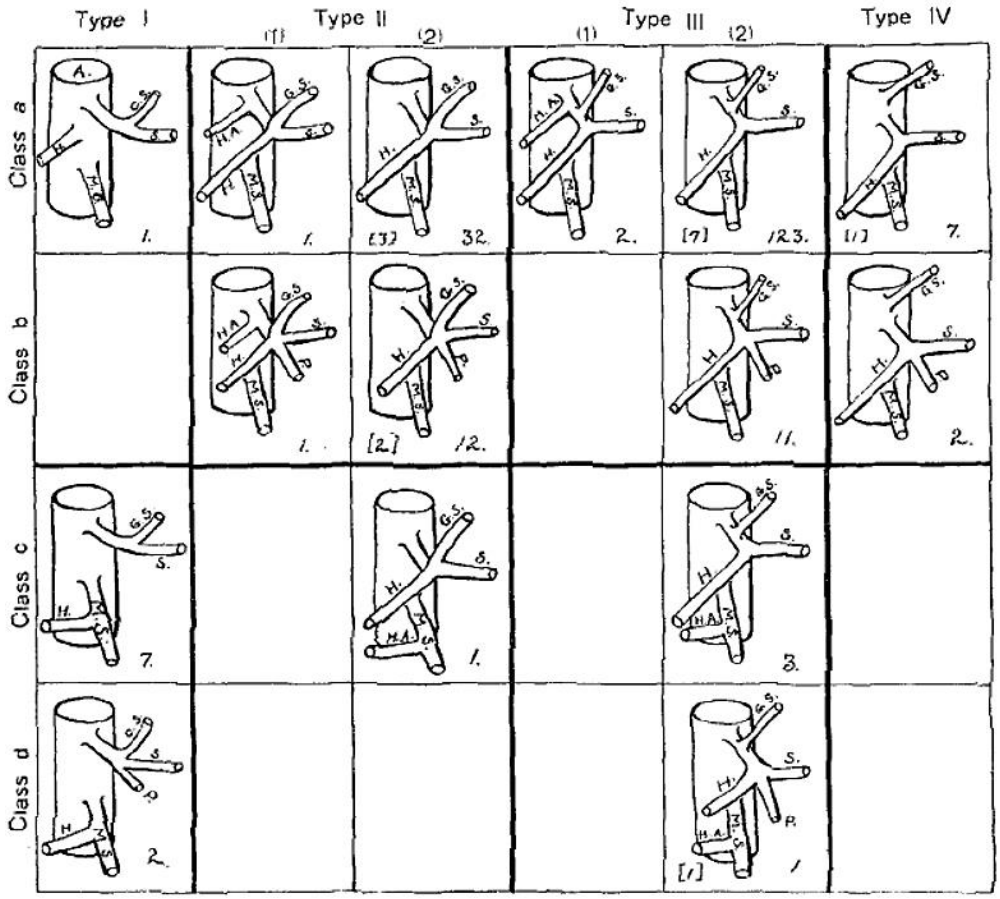

Figure 5.1. Detailed classification of the celiac trunk by Eaton (1917) [35]

A: abdominal aorta; G.S.: LGA; H.: CHA; H.A.: accessory hepatic a.; S.: SA;

P.: a. supplying the pancreas

type	
I.	Celiac trunk with trifurcation
II.	LGA from aorta –hepatosplenic trunk
III.	LGA from aorta + hepatosplenomesenteric trunk
IV.	Celiacomesenteric trunk
V.	Hepatomesenteric trunk + gastrosplenic trunk
VI.	CHA from SMA

Table 5.2. Classification of the celiac trunk by Adachi (1928)

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In the second half of the 20th century, the categorization system described by Michels in 1955 became the standard classification [38]. A new variation, the celiacocolic trunk was added, which case represents the middle colic a. as a branch of the celiac trunk (Table 5.3.).

A few decades later, in 1997, Uflacker expanded the Michels' classification based on angiographic studies [39] (Table 5.4.).

type	
I.	Celiac trunk with trifurcation
II.	LGA from aorta or LGA from SA or LGA from CHA
III.	LGA from aorta+ hepatosplenomesenteric trunk
IV.	SA from SMA
V.	Gastrosplenic trunk
VI.	Celiacomesenteric trunk
VII.	Celiacocolic trunk

Table 5.3. Classification of the celiac trunk by Michels (1955)

type	
I.	Celiac trunk with trifurcation
II.	LGA from aorta
III.	SA from aorta
IV.	LGA from aorta + hepatosplenomesenteric trunk
V.	Gastrosplenic trunk
VI.	Celiacomesenteric trunk
VII.	Celiacocolic trunk
VIII.	Absence of celiac trunk

Table 5.4. Classification of the celiac trunk by Uflacker (1997)

In 2009, Higashi focused on the pattern of celiac trunks with all three branches present [40], questioning the trifurcation as a normal variant. The LGA as a first branch of the celiac trunk was found to be the most frequent variant.

One of the latest classifications was published in 2015 by Marco-Clement (Table 5.5.), which system considers additional side branches, but doesn't deal with the course of these extra vessels to avoid a too complicated classification [41]. To keep the system clear, rare variants are excluded, and four types with eight subtypes are included.

type	
I.a	LGA is the first branch of the celiac trunk
I.b	Celiac trunk with trifurcation
I.c	Celiac trunk with extra side branch
II.a	Hepatosplenic trunk
II.b	Gastrosplenic trunk
II.c	Hepatogastric trunk
III.	Absence of celiac trunk
IV.	Celiacomesenteric trunk

Table 5.5. Classification of the celiac trunk by Marco-Clement (2015)

As several classifications of the celiac trunk have been already published, it could be noticed that some authors focus on clear and easy use, while others try to create a detailed version. To create a simple classification for the pattern of the celiac trunk is a challenging task, as the previous systems try to put the different levels of variations in one unit.

Based on detailed observations, the variations of the celiac trunk can appear on three different levels:

1.) Aberrant origin of the celiac trunk. Can be also called as **proximal end variants**. From the previous classifications and many articles, it is known that the celiac trunk may be a separate branch of the aorta, or can share a common origin with the SMA, forming a celiacomesenteric trunk. We could also add to this category those variation, where any primary branch of the celiac trunk has a different origin – many authors don't'

even call the remaining trunk celiac, but the terms gastrosplenic, hepatosplenic or hepatogastric trunk are used depending on the actual variation. The absence of celiac trunk, when all LGA, CHA and SA have separate origin also fits the proximal variant group.

2.) Aberrant branches of celiac trunk. Can be also called as **lateral variations**. This group can be divided into two subgroups. The first option is, when the celiac trunk has its three primary branches, but they don't form a trifurcation, for example when the LGA is the first branch, and the continuation of the celiac trunk bifurcates to CHA and SA, which is the most frequently found pattern. Some authors use the term false tripod for this variant.

The second option is the case, when the celiac trunk has one or more additional branches. Can be a duplicate primary branch, for example a double LGA (Figure 4.6.), but it is more common to find an extra artery, usually an inferior phrenic a., or a bit less frequently both inferior phrenic arteries. In rare cases the extra branch can be a GDA, any PDA, superior suprarenal a., one of the gastroomental arteries or the middle colic artery. From the variants described in the literature, nearly all extra side branches appeared on our series except for the middle colic and gastroomental arteries. Extreme rare variation can be the origin of one of the pulmonary arteries from the celiac trunk. As a developmental disorder called pulmonary sequestration, a non-functioning lung territory receives blood supply from the systematic arteries – the source is usually the thoracic aorta, but can be the celiac trunk in 9,3% of these specific cases [42].

3.) Aberrant split of the celiac trunk. Can also be called as **distal end variants**. The classic description by Haller defines a trifurcation, but in the literature, we may find quadrifurcation, pentafurcation, hexafurcation and even septafurcation as well. In the literature, this category is really confused, as several authors confuse the original meaning of these terms. Trifurcation stands for a vessel, which splits into three at one point, quadrifurcation for splitting into four branches at one point, etc. Misinterpreting these terms, some authors use them as the vessels originating from the celiac trunk [43]. For example, the interesting heptafurcation [44] is really a celiac trunk with three side branches and a quadrifurcation at its end, the authors used heptafurcation just to mention the number of arteries arising from the celiac trunk. The use of trifurcation is also not clear, as several papers use it correctly, but many others name a celiac trunk with its

three primary branches as a trifurcation regardless to their originating pattern. Further problem about the review of the articles, that some use the term tetrafurcation [45] instead of quadrifurcation. As a summary, the over number split of the celiac trunk is rare, on the series of our 50 casts, we found only one case of quadrifurcation.

With the use of the above described three levels, even complex variations could be classified, since an aberrant origin doesn't exclude for example the presence of an additional side branch.

To compare our findings with the international literature, we use the classification of Marco-Clement (Table 5.6.). For a better comparison, main types and subtypes are also presented, as several studies don't provide detailed data for subtypes. In table 5.6., two extra columns are added: main type I. for celiac trunk which contain at least all three primary branches, and main type II. for celiac trunk bifurcation, so one of the primary branches has an aberrant origin. It must be also mentioned that some publications describe variants or different subtypes which cannot fit in Marco-Clement's classification, therefore in some cases the sum of subtypes won't reach the number of the main type, and the total sum will be less than 100%.

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Author	Year	Method*	Sample No	I.	I.a	I.b	I.c	II.	II.a	II.b	II.c	III	IV.
Rossi-Cova	1904	1	102	84,3%				11,8%				2%	2%
Leriche-Villemin	1907	1	55	89%				10,8%				0%	0%
Descomps	1910	1	50	88%				12%				0%	0%
Rio Branco	1912	1	50	90%				8%				0%	2%
Lipshutz	1917	1	83	73,4%		25,3%		24,1%	13,3%	4,8%	6%	0%	2,4%
Eaton	1917	1	206	90,2%				9,2%	4,4%	4,9%	0%	0%	0%
Adachi	1928	1	252	87,7%	55,6%		32,1%	10%	7,6%	2,4%	0%	0%	2,4%
Tsukamoto	1929	1	100	82%	47%		35%	4%	1%	3%	0%	0%	11%
Imakoshi	1949	1	107	90,7%	67,3%		23,4%	7,4%	4,6%	2,8%	0%	0%	0,9%
Michels	1955	1	200	89%		25%		11%	4%	5,5%	1,5%	0%	0%
Kozhevnikova	1977	1	155	87,1%	76,8%		10,3%	7,7%	7,7%	0%	0%	0%	0%
Vandamme	1985	1	156	86%				12%	6%	6%	0%	1,3%	0%
Shoumara	1991	1	450	90,6%	65,3%		25,3%	7,1%	3,3%	3,8%	0%	0%	1,1%
Matsuki	2004	2	36	88,9%				11,1%	5,5%	2,8%	2,8%	0%	0%
Petrella	2007	1	89	82%	51,7%	20,2%	10,1%	5,7%	2,3%	3,4%	0%	1,1%	0%
Ferrari	2007	2	60	88,4%				3,4%	3,4%			1,7%	1,7%
Iezzi	2008	2	524	72,1%	50,4%	19,4%		11,7%	3,1%	3,6%	5%	0,6%	0%
Chen	2009	1	974	89,8%	66,6%		23,2%	8,3%	5%	3,3%	0%	0%	0,7%
Mburu	2010	1	123	82%	29,3%	32,5%	20,3%	18%	13,1%	4,9%	0%	0%	0%
Song	2010	2	5002	89,1%				7,5%	4,4%	2,9%	0,2%	0%	1,8%
Ugurel	2010	2	100	89%				8%	3%	4%	1%	1%	2%
Natsume	2011	2	175	90,6%				8,6%	5,2%	3,4%	0%	0%	0,6%
Prakash	2012	1	50	86%	76%	10%		10%	8%	0%	2%	4%	0%
Venieratos	2012	1	77	94,8%	16,9%	74%	3,9%	2,6%	1,3%	1,3%	0%	2,6%	0%
Araujo	2015	2	60	90%				10%	8,3%	0%	1,7%	0%	0%
Marco-Clement	2015	1, 2	639	90,5%	57,6%	32,1%	0,8%	9,5%	4,5%	5%	0%	0%	0%
Selvaraj	2015	2	75	90,6%	12%	78,6%		9,3%	8%	1,3%	0%	0%	0%
Olewnik	2016	1	40	82,5%	62,5%		20%	15%	15%	0%	0%	2,5%	0%
Pinal-Garcia	2018	1	140	91,5%	35%	7,1%	47,9%	5,7%	2,9%	2,1%	0,7%	0%	0%
Our series		1	50	84%	36%	10%	36%	16%	12%	4%	0%	0%	0%

Table 5.6. Our findings compared with the international literature by the Marco-Clement classification

Method: 1: macroscopic, anatomical study;2: radiology study (angiography or CT)

5.3. Left gastric artery

Variations of the LGA is not discussed in the literature as a separate topic. Data on variant LGA can be found in papers mentioning aberrant celiac trunk arborization. LGA branching off from the aorta is the most common variation of the origin. We encountered this pattern in 12%, other authors found 1-15% frequency (Table 5.6., II.a column). From the possible side branches of the LGA, extrahepatic arteries have important clinical role.

Accessory or replaced LHA was present in 24% of our series, which variations occur 4,4-28% in the international literature.

5.4. Splenic artery

Variations of the SA are rare, on the series of our 50 casts, we couldn't observe any variation of origin nor of possible extra side branches. In the literature, the variations are usually published as case reports. More authors found SA given off by the SMA [46-49], but the SA can have its origin from the LGA [50], the CHA [51] or from the abdominal aorta – as we discussed the latter above with the variations of the celiac trunk.

The SA splits to several branches at the hilum of the spleen, but proximal origin of the polar arteries may occur [52]. These polar arteries can also have variant origin, which are often named as accessory splenic arteries in the literature. Variant polar a. can arise from the LGA [53, 54] or from the left gastoomental a. [55, 56]. In one case study, a duplicated SA [57] is published, which may be a result of an extreme early split of the SA to superior and inferior polar arteries.

Various possible side branches of the SA have been also published, which can be GDA [58], superior anterior or posterior PDA [59], inferior anterior PDA [60], inferior posterior PDA [61], middle colic a. [34], accessory middle colic a. [62], or accessory hepatic a. [34].

As the variations of the SA are rare, only few authors provide statistic data on their occurrence. Pandey [51] found SA arising from the celiac trunk in 90,6%, from the abdominal aorta in 8,1%, while the remaining 1,3% was SMA or CHA – this study was based on dissection of 320 cadavers. We can also find data in the classic description of the variations of the celiac trunk by Lipshutz [34], based on 83 dissections. Lipshutz found SA arising from the abdominal aorta in 6%, he also observed middle colic a. given off by the SA in two cases, and also described accessory hepatic a. arising from the SA in 6%. Latter data seems doubtable, as a century later, Caruso [63] published one case of accessory hepatic artery arising from the SA as an extreme rare variation – he made a systematic review of the literature analyzing more than 11000 cases reporting hepatic a. anatomy and found no other publication.

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5.5. Common hepatic artery

Variant origin of the CHA is already mentioned at the discussion of the celiac trunk. The CHA splits to PHA and GDA, but occurrence of extrahepatic arteries influence the pattern. Extrahepatic arteries can be classified as replaced, when the blood supply of the adjacent lobe is supplied only by the aberrant branch, or accessory, when the blood is supplied by both the aberrant branch, and the CHA system. Detailed classification of the extrahepatic arteries was first done in 1966 by Michels [64], based on a series of 200 dissections (Table 5.7.). Later, in 1994, Hiatt [65] simplified it by putting the replaced and accessory groups together (Table 5.8.).

type	
I.	normal variant
II.	replaced LHA from LGA
III.	replaced RHA from SMA
IV.	replaced LHA from LGA + replaced RHA from SMA
V.	accessory LHA from LGA
VI.	accessory RHA from SMA
VII.	accessory LHA from LGA + accessory RHA from SMA
VIII.	accessory LHA from LGA + replaced RHA from SMA
IX.	CHA from SMA
X.	CHA from LGA

Table 5.7. Classification of extrahepatic arteries by Michels (1966)

Michels X. is an extreme rare variation, before Michaels' classification, one case was published by Adachi [36], based on a dissection of 252 cadavers. Michels also mentions only one case out of his 200 autopsies. In later literature, Okada published 3 cases in 2010 [66], and 5 more cases can be found in the angiographic study by Saba [67] in 2011. Several variations cannot fit Michels' classification, for example the Hiatt VI. type, which we also found in one of our casts (Figure 4.2.). Our research group did a detailed

examination of the extrahepatic arteries [29], therefore in this thesis, only main results are shown. The extrahepatic arteries on our specimens are compared with the data in the literature using the classification by Michels (Table 5.9.).

type	
I.	normal variant
II.	replaced or accessory LHA from LGA
III.	replaced or accessory RHA from SMA
IV.	replaced/accessory LHA from LGA + replaced/accessory RHA from SMA
V.	CHA from SMA
VI.	CHA from abdominal aorta

Table 5.8. Classification of extrahepatic arteries by Hiatt (1994)

Author	**Yea**	**Samples**	**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**	**X.**	**other**
Michels	1966	200	55%	10%	11%	1%	8%	7%	1%	2%	2,5%	0,5%	0%
Rygaard	1986	216	75,5%	4,6%	13,4%	0,9%	0%	0%	0,5%	0,5%	1,4%	0%	3,2%
De Santis	2000	150	52%	10%	15,5%	0,6%	0,6%	2%	0,6%	0%	4%	0%	14,7%
Kamel	2001	40	70%	5%	7,5%	2,5%	7,5%	2,5%	0%	5%	0%	0%	0%
Covey	2002	600	61,3%	3,8%	8,7%	0,5%	10,7%	1,5%	1%	3%	2%	0%	7,5%
Koops	2004	604	79,1%	2,5%	8,6%	1%	0,5%	3,3%	0,2%	0,2%	2,8%	0%	1,8%
Stemmler	2004	63	80,9%	0%	6,3%	0%	7,9%	0%	1,6%	1,6%	1,6%	0%	0%
Varotti	2004	96	70,8%	6,3%	10,4%	2,1%	6,3%	3,1%	0%	0%	1,1%	0%	0%
Kishi	2004	223	61%	14%	4%	0%	12%	3%	2%	0%	6%	0%	0%
Coşkun	2005	48	54,1%	0%	6,3%	0%	16,6%	2,1%	4,2%	0%	0%	0%	16,6%
López-A.	2007	1081	70%	9,7%	7,8%	3,1%	3,9%	0,6%	0,6%	0,3%	2,5%	0%	1%
Winston	2007	371	50,7%	14,5%	8,1%	0%	3,5%	0%	0%	0%	1,6%	0%	12,5%
Ferrari	2007	60	60%	10%	18,3%	5%	1,7%	0%	0%	1,7%	0%	0%	3,3%
De Cecco	2009	250	66%	5,2%	9,2%	2%	5,2%	4%	2%	0,6%	2%	0%	3,3%
Kishi	2010	361	68,6%	10,2%	6,9%	4,2%	4,7%	1,4%	0,6%	0,6%	2,5%	0%	0,3%
Ugurel	2010	100	52%	11%	17%	1%	10%	1%	1%	1%	2%	0%	4%
Saba	2011	1629	61,4%	7,5%	10,6%	1,4%	6,7%	7%	0,7%	1,9%	1,6%	0,3%	1,1%
Our series		50	32%	6%	8%	2%	10%	0%	2%	4%	2%	0%	34%

Table 5.9. Our findings compared with the literature by the Michels classification [29, 64, 67, 68-82]

The CHA in normal case terminates in a bifurcation to PHA and GDA, but variations may occur. CHA trifurcation can be formed by the RHA, LHA and GDA, which variation is well known [71, 76, 78 83-85], its frequency is found 2-10,4% in the literature, our finding (6%) fits into the international data (Figure 4.16.). The CHA trifurcation can be formed also by the PHA, GDA and right gastric a., which variation was previously published only by Abdullah [86], who found this pattern in 0,1% on a series of 932 cases. On our series, we found three cases on a series of 50 casts, which represents a much higher occurrence (Figure 4.17.). The trifurcation formed by the PHA, GDA and superior posterior PDA (Figure 4.18.) has never been published before according to our knowledge.

Less information can be found according to CHA quadrifurcation. Occurrence was found 0,5-2,15% [71, 85], where the CHA splits into GDA, RHA, LHA and an a. supplying segment 4 of the liver. CHA quadrifurcation is also published in some case studies: in 2006, during an open abdominal surgery, a quadrifurcation formed by RHA, LHA, and two accessory arteries supplying the liver [87] was documented, and in 2017, another CHA quadrifurcation was noticed during laparoscopy [88], but with the limited surgical approach, the branches couldn't be specified. Our findings alter from the published data with higher frequency, as we came over 3 cases (6%), and also with a different pattern, as in all 3 cases the CHA split to RHA, LHA, right gastric a. and GDA (Figure 4.19.).

CHA pentafurcation was first published by our research group [29], which is formed by the LHA, RHA, a. supplying segment 4, right gastric a. and GDA.

5.6. Gastroduodenal artery

The term gastroduodenal a. was first used in 1745 by Haller [33], earlier, Vesalius named it as duodenal branch. As this artery is involved in many clinical interventions, a new term, gastro-duodeno-pancreatic trunk was proposed in 2017 [89], but this name didn't spread. In case of a normal variation, the CHA terminates in bifurcation, and the caudal branch is defined as GDA. The variations, which are not having a bifurcation at the end of the CHA are discussed in chapter 5.5., but variations occur in case of a bifurcation as well. CHA bifurcation can be formed by the RHA and LHA, therefore no PHA is formed and the GDA branches off from either the LHA or the RHA – 8% and 4% respectively in

our series. The GDA may have other aberrant origin, which can be the celiac trunk, the SMA or SA.

On our series of 50 casts, we observed one case of GDA arising from the celiac trunk (Figure 4.8.), which variants are observed in 2,5%-6,74% [34, 64, 90] or published in case studies [91, 92].

SMA as a source of GDA is found in 1% [93, 94], we didn't observe this variation. In the literature, we may find higher frequencies published [95-97], which papers mention GDA arising from SMA, but the aberrant GDA later gives off an accessory hepatic artery – it is debatable if the term GDA can be used for these variations, as it gives a branch to the liver. In ordinary anatomical description, the GDA branches off from the arteries supplying the liver, so in the published cases the artery arising from the SMA should be called the accessory hepatic artery, and only after the split, the distal part could be named GDA.

The GDA can arise from the SA, which is a rare variation, which we couldn't observe on our series. Interesting coincidence is that GDA from SA variations are usually present with variant hepatic arteries. In a case study [98], an unusual pattern is published: PHA is given off by the SMA, LGA and SA were direct branches from the aorta, and the GDA arose from the SA. Okada [66] found three cases of CHA arising from the LGA (Michels type X), and two of these cases had the GDA branching from the SA.

5.7. Pancreaticoduodenal arteries

In the past decades-centuries, the nomenclature of the arteries supplying the head of the pancreas was chaotic. In my thesis, I use the most common terms, but it should be mentioned how the most used terms differ from the official Terminologia Anatomica [5-7].

The official terminology contains posterior superior PDA and anterior superior PDA at the branches of the GDA, the superior PDA is not mentioned, though the latter is described in several anatomy books. When browsing the international literature before 1955 (year of the Paris anatomical nomenclature), several different terms can be found for each pancreaticoduodenal vessel [99-102]. There is also a confusion in the order of adjectives in the names, as the Latin names are formed "a. pancreaticoduodenalis superior posterior", "… superior anterior", but the official English version swaps the adjectives,

so the correct terms are posterior superior PDA and anterior superior PDA. Although superior posterior PDA and superior anterior PDA are not the correct forms, they are also widely used, and makes comparison easier with literature using the Latin forms, therefore these forms are also used in my thesis.

The first branch of the SMA is the inferior PDA, but instead of the generally used inferior anterior PDA and inferior posterior PDA, the terminology names these arteries as anterior and posterior branches of the inferior PDA, but the official terms are not used widespread. The retroduodenal arteries should be also mentioned, as it is an existing entity in the terminology for arteries supplying the duodenum which are branching off by the GDA before it gives off the superior pancreaticoduodenal arteries. The problem with this term is that earlier some authors identified the superior posterior PDA as retroduodenal artery.

5.7.1. Superior pancreaticoduodenal artery

The occurrence of a superior PDA is 5,3-9,1% [60, 103], our finding of 10% frequency fits these data, but some authors don't mention it at all [94, 104, 105]. Only early, 19th-century textbooks describe it as a constant vessel [106, 107]. Variant origin has only been described in one case, when the superior PDA branched off from a hepatic a. [60].

The superior anterior PDA is usually the branch of the GDA [59, 103, 108, 109], or branch of the superior PDA if present. Absence of the superior anterior PDA may occur in 1-2,5% [61, 110], only Milon found an incredibly low occurrence (64%) [98], which may be the consequence of the angiographic technique – probably the summation images made the vessel unseen under projection of other arteries. Rare, unique origins of the superior anterior PDA are also known, it can branch off from a replaced RHA [84], from the celiac trunk [111], from an anastomosis between the SMA and SA [112], from the SMA [108], from the PHA [60], from the SA [59], from an anastomosis between the CHA and SMA [99, 112] or with two origins from the GDA and the right gastroomental a. [61].

More data can be found about the superior posterior PDA, which is almost always present, only some author mention its absence [61, 109, 113, 114], but even these papers found the occurrence above 96%. The most common origin of the superior posterior PDA is the GDA, which pattern is present between 58% [98] and 96,9% [113], or branch of the superior PDA if present. Variant origin of the superior posterior PDA was first described in 1745, as a branch of a hepatic artery [33]. Only two early sources mention variant

origin from the CHA with 0,67-7,5% occurrence [61, 103], we observed this variation in 4% (Figures 4.15. and 4.18.). Various data can be found about the origin from the PHA (0-8% [103, 115]), which pattern appeared on one of our cases (Figure 4.26.). The superior posterior PDA can branch off from the proximal part of the RHA, which variation is not mentioned by several authors, some researchers mention it, but don't provide statistics on occurrence rate, others mention 2-4% frequency [115, 116], and one source gives an unusual high 7,7% [117]. Superior posterior PDA given off by the LHA is an extreme rare variation [33, 100]. Combination of variations are also known, in these cases, an aberrant hepatic a. gives off the superior posterior PDA. We found this variation (Figure 4.25.) in 4%, other sources mention 3-7% occurrence [105, 113-115]. The international literature mentions other possible origins: the replaced CHA [118], which may occur in 3% [115]; the SMA, which is mentioned by few authors, but they found it in 3-5% [94, 115, 119]; the dorsal pancreatic a. in 1-2% [114, 115, 118]; the SA [59, 108]; an aberrant cystic a. from GDA [60]; the right gastroomental a. [103]; the celiac trunk [119]; an anastomosis between SA and an aberrant hepatic a. [120]; or may branch off with two trunks from both SA and GDA [108]. Multiple occurrences of the superior posterior PDA are also known. Studies, which provide statistics, found double superior posterior PDA in 10,7-20% [108, 121], triple superior posterior PDA in 5% [121], but quadruple appearance is only mentioned by one author [118].

5.7.2. Inferior pancreaticoduodenal artery

The inferior PDA is usually the first branch of the SMA, the most frequent variation is its common origin with the 1st jejunal a., which variation is called as PDJ trunk by some authors. As the inferior anterior PDA and inferior posterior PDA can arise separately, any of them can share a common origin with the 1st jejunal a., which variations are also mentioned as PDJ trunk. Occurrence of PDJ trunk is ranges 20-64,7% [122, 123]. The inferior PDA can be a branch of a variant hepatic a. from the SMA, which we observed in one case, other authors also mention it, but none of them provides data on frequency [9, 118, 124]. The dorsal pancreatic a. and the inferior PDA can origin with common trunk from various places: celiac trunk, 2nd jejunal a., SA or middle colic a. [60]. In rare cases, the inferior PDA can arise from 2nd or 3rd jejunal arteries [61, 101] or from transverse pancreatic a. [125]. Most authors agree that inferior PDA from middle colic a.

is a rare variation, but Ferrari found inferior PDA branching off from right or middle colic a. in 3,3 and 8,3% respectively [79]. Inferior PDA arising from the celiac trunk (Figure 4.10.) was found in one of our cases, which variation hasn't been published elsewhere according to our knowledge.

The inferior anterior PDA is usually a branch of the inferior PDA, if the latter is present, but the data in the literature is controversial, as the occurrence ranges from 0% [59, 104] to 82% [60, 94]. It is also confusing that different authors interpret common origin with the 1st jejunal a. as PDJ, or common origin is mentioned, or inferior anterior arising from 1st jejunal a. is published, but the pattern is the same in these cases, which may be present in 17,1-40% [59, 61, 122]. The inferior anterior PDA can also arise from the SMA, which is found between 1,8% [60] and 50% [59]. Origin from the 2nd jejunal a. ranges from 2% [60] to 6,6% [103], and origin from 3rd jejunal a. is also known [103]. In rare cases, the inferior anterior PDA can be a branch of the dorsal pancreatic a. [103, 114], the celiac trunk [60], the middle colic a. [60], the SA [60], the right gastoomental a. [60] or even an aberrant hepatic a. from the SMA [60, 114, 118]. The presence of the inferior anterior PDA is constant, only Calas and Thomford published its absence in 2-6,7% [103, 59].

The inferior posterior PDA is usually the artery with the greatest diameter, according to Evrard, this is the main artery supplying the pancreatic head [61]. It has similar variations as the inferior anterior PDA, so it is usually a branch of the inferior PDA, if present, and common origin with 1st jejunal a. is also a common finding [60, 126]. The inferior posterior PDA can have variant origin from the SMA in 8,6-56,6% [59, 126], from the SA [61], from the right gastroomental a. [60], from the dorsal pancreatic a. [103, 114, 122], from the transverse pancreatic a. [122, 126], from the 2nd jejunal a. [103], or from an aberrant hepatic a. from the SMA [60, 103, 114, 115, 118, 122, 126] – we observed the last pattern is one of our casts (Figure 4.27.). We also observed two variations which haven't been published yet: the inferior posterior PDA branched off from the celiac trunk (Figure 4.11.) in one case and from the CHA (Figure 4.13.) in another case. Most researchers found the inferior posterior PDA as a constant vessel, but some sources mention its absence [103, 105, 114], with the highest rate of 10% [59].

5.7.3. Arterial arches in pancreaticoduodenal system

Variant origin of the pancreaticoduodenal arteries has been widely investigated by several authors, but less publications can be found about the variations in the arterial arches. According to the number of arches, Chavan [127] described absence of the anterior and posterior arches in 1-1 specimen based on 50 dissections. In comparison, Donatini [104] found missing arcades to be more frequent (despite the smaller sample size of 40): anterior arch was detected only in 20 (50%), posterior arch in 30 (75%) dissected specimens. Kimura [128] published absent arcades only posteriorly in 5 out of 40 (12,5%) dissections. Sakagami [129] found that only one out of 20 fetal dissections exhibited a missing anterior arch. None of the authors mentioned above published two or more arches. We discovered that double posterior arches were more common than anterior ones, similar to Woodburne's [114] 150 dissections; however, the paper provides no data of how frequently these variations appeared. Krakowiak [130] studied 60 fetuses in dissection and found that only two of them had anterior double arches. Macchi [117] found double posterior arch in 7,7%, and double anterior arch in 12%, while the posterior arch was missing in 30,8%, and the anterior arch was absent in 32% - the study was based on corrosion casts and CT scans. Michels [118] described triple arterial arches based on 200 dissections, furthermore Nebesar [94] mentioned even quadruple arcades in his atlas of angiograms, but the occurrence was not provided. We detected three arches in 15 casts, four arches in one specimen, and five arches in two cases out of our series of 50 human abdominal corrosion casts.

Presence of a third, middle pancreaticoduodenal arch connecting the two original arches is detected in different (5-81%) frequencies in review papers [62, 99]. Falconer [105] described it in 11 instances of a series consisting of 27 dissections and 23 corrosion casts. While Yamaguchi [131] found this anastomotic arch to be an almost constant vascular variation (86%) in 51 analyzed Japanese samples, it appeared only in 20% of our series.

The luminal diameters of simple and multiple pancreaticoduodenal arches determine their clinically significant vascular flow capacity. The pancreaticoduodenal arteries' vascular dimensions were surveyed by a small number of authors, who only measured the arteries' outer diameters. Bertelli [99] reports only the diameter of the superior anterior PDA (1-3 mm), but diameters were not mentioned according to any other PDA. Donatini [104] gauged the calibers of both pancreaticoduodenal arteries and veins, however, only the

number of cases with a diameter of 3 mm or more was described; no detailed results were provided. Yamaguchi [131] reported comprehensive data on the dimensions of the communicating artery that connects the anterior and posterior PD arches. Macchi provided detailed measurements based on 30 CT angiographies and 10 corrosion casts: diameter of superior posterior PDA was 2,3 ± 0,9 mm, diameter of superior anterior PDA was 2 ± 0,5 mm, diameter of inferior PDA was 2,7 ± 1,7 mm, diameter of inferior anterior PDA was 2,1 ± 0,7 mm and the diameter of inferior posterior PDA was 2 ± 1,1 mm.

5.7.4. Intrapancreatic vasculature – measurements in theoretical resection planes

According to our knowledge, our study [23] is the first approach to assess the surgical plane in pancreaticoduodenectomy based on detailed anatomical specimens.

Our findings - based on the simulated theoretical surgical resection planes - correspond with current surgical studies on pancreatic resection. In instances of modified resection lines to the left, Matsui et al. [132] detected less bleeding, and Partelli et al. [133] found that the amount of blood loss is correlated with the thickness of the cut parenchyma, however, distal pancreatectomies were the subject of research by both writers.

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6. CONCLUSIONS

The upper abdominal arterial variations - focusing on the blood supply of the pancreas – are discussed in detail in this research. However, to get a view of the whole upper abdominal complex system, frequency of normal variants (as described in classic anatomy [131-133]) must also be taken into account.

Celiac trunk with the typical three tributaries (LGA, CHA and SA) was found in 42 of our cases (84%). The most frequently observed branching pattern was the early origin of the LGA, which appeared on 56% of our casts. Trifurcation of the celiac trunk – which is the described normal pattern by classic anatomy books – only occurred in 26% of our series. In most of our casts, the CHA was branching to GDA and PHA (58%), and the GDA was branching from the CHA in 86%. The most frequently observed variations of the pancreaticoduodenal arteries were: superior anterior PDA and superior posterior PDA stem from the GDA separately (68%), a common inferior PDA appeared in 80%, and shared common origin with jejunal arteries in 70%.

If we consider the most frequent patterns are normal variations, there is no variation on different branching levels in 84%, 56%, 58%, 86%, 68%, 80% and 70%. It is characteristic in the international literature, that one branching level is under focus, therefore occurrence of normal variation is published in similarly high numbers. But if we check the casts one by one, a variation will usually occur in one of the branching levels. Only 3 out of our 50 specimens didn't show any alterations related to the most frequent patterns, which underlines the importance of vascular variations. The high ratio of normal variants published could cause a false illusion of the vascular variants being rare, while occurrence of vascular variants is almost constant.

We encountered 4 new variations, which – according to our knowledge – haven't been published elsewhere:

-PHA, GDA and superior posterior PDA arising from the CHA with trifurcation (Figure 4.18)

-inferior PDA arising from the celiac trunk (Figure 4.10.)

-inferior posterior PDA arising from the celiac trunk (Figure 4.11.)

-inferior posterior PDA arising from the CHA (Figure 4.13.)

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After detailed investigation of the blood supply of the pancreas, we examined the intrapancreatic vasculature focusing on the surgical approach of pancreatic head resection. Anatomical corrosion cast specimens were used to simulate various resection planes using CT, but the technique is repeatable in clinical settings. Our measurements and simulations demonstrated that selecting a transection plane on the left side of the SMV, which exhibits lower values of cut vessel surface, could optimize pancreatic resections in over half of our cases. This might suggest a decreased chance of bleeding after surgery. Therefore, since abdominal CT or MR are nearly always performed on patients undergoing pancreatic resection, it is advised that the resection plane should be established by the preoperative imaging techniques. In clinical practice, the resection planes can be simulated by using DICOM viewer software with the multiplanar reconstruction option. Reducing postoperative bleeding may be possible with an assessed preoperative CT angiography and multiplanar reconstruction.

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7. SUMMARY

Introduction: Pancreatic interventions are technically challenging for both surgeons and interventional radiologists due to the complex arterial system. The arterial variants may change the tumor's ability to be removed and result in difficulties during arterial embolization. The pancreatic head and body are separated at the level of the SMV by recent surgical standards.

Our goal was to determine how frequently pancreaticoduodenal arterial arcade variations occur. The other goal is to identify the best resection line with the fewest number of cut vessels by simulating pancreatic head resections in various planes.

Materials and Methods: Arteries of fifty human abdominal organ complexes were injected with a mixture of resin, in 25 cases, the PV was also filled up. After a corrosion procedure, CT scans were made with 3D reconstructions; diameters of pancreaticoduodenal arcades were measured and - in the 25 cases with the PV – particular planes that simulated various resection lines were reconstructed. The total quantity of vessel cross sections was obtained in each of the various planes.

Results: Two pancreaticoduodenal arches were detected in 58% of our cases, three in 30%, one in three specimens, four in one cast, and five in two cases. The anterior arch's average diameter in the casts with two arcades was 1.472±0.432 mm, while the posterior arch's average diameter was 1.383±0.343 mm. By using a criterion of 25% cross-section difference, the anterior arch was dominant in 52% of the cases, and in 35 % the posterior arch.

The optimal plane is the SMV in 11/25, 2 cm left in 10/25, 1 cm left in 4/25, 1 cm right in 1/25 and 2 cm right in none of our series. More than half of the cases belong to the category of left-sided extensions. The cut surface of the vessels may be reduced to even 29% in comparison to the SMV plane with left-sided resections.

Conclusions: Our studies underline that CT/MR-angiography is essential before pancreatic interventions, which helps to reveal arterial variations and enables planning of the optimal resection line. The latter should be considered to be extended to the left side of the SMV based on our series.

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