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Types of inferior phrenic arteries: a new point of view based on a cadaveric study

Inferior phrenic artery

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Abstract

Background: The diaphragm is supplied by the superior and inferior phrenic arteries. This present study focusses on the latter. The inferior phrenic arteries (IPA) usually originate from the abdominal aorta. The two arteries have different origins, and knowledge of these is important when performing related surgical interventions and interventional radiological procedures. The aim of this study was to identify variations in the origin of the IPA and conduct relevant morphometric analyses.

Materials and methods: The anatomical variations in the origins of the Left Inferior Phrenic Artery (LIPA) and the Right Inferior Phrenic Artery (RIPA) were examined in 48 cadavers fixed in 10% formalin solution. A dissection of the abdominal region of the cadavers was performed according to a pre-established protocol using traditional techniques. Morphometric measurements were then taken twice by two of the researchers.

Result: In the cadavers, six types of origin were observed. In Type 1, the most common type, the RIPA and LIPA originate from the abdominal aorta (AA) (14 = 29.12%). In Type 2, the RIPA and the LIPA originate from the celiac trunk (CT) (12 = 24.96%). In Type 3, the RIPA and the LIPA originate from the left gastric artery (LGA), with no CT observed (3 = 6.24%). Type 4 has two subtypes: 4A, in which the LIPA originates from the abdominal aorta (AA) and the RIPA originates from the CT (9 = 18.72%) and 4B, in which the RIPA originates from the AA and the LIPA originates from the CT (6 = 12.48%). In Type 5, the LIPA originates from the AA and the RIPA originates from the AA (1 = 2.08%). Type 6 is characterized by the RIPA and LIPA forming a common trunk originating from the CT (3 = 6.24%).

Conclusions: Our findings suggest the presence of six different types of LIPA and RIPA origin. The most common form is Type 1, characterized by an IPA originating from the abdominal aorta, while the second most common is Type 2, in which the IPA originates from the AA by a common trunk. The diversity of other types of origin is associated with the occurrence of celiac trunk variation (Type 3). No significant differences in RIPA diameter could be found, whereas LIPA diameter could vary significantly. No significant differences in RIPA and the LIPA diameter could be found according to sex.

Key words: inferior phrenic arteries, left inferior phrenic artery, right inferior phrenic artery, diaphragm, celiac trunk

INTRODUCTION

The inferior phrenic artery (IPA) usually originates from the abdominal aorta and consists of two vessels, i.e. the left inferior phrenic artery (LIPA) and the right inferior phrenic artery (RIPA). The two give rise to the ascending (anterior) and the descending (posterior) branches. Although the IPA mainly supplies the diaphragm, it also give small branches to the liver, stomach, the cardiac part of the esophagus, the adrenal glands, and retroperitoneum [1–3].

The anterior branch of the LIPA gives rise to the esophageal and accessory splenic branches while the RIPA rises along with inferior vena cava [1, 2]. However, the posterior branches of both IPAs run to the lateral crus and can form anastomoses with the musculophrenic artery and the lower posterior intercostal arteries [4–6].

The LIPA usually runs behind the esophagus, and goes anteriorly to the left side of the esophageal hiatus. The ascending branch divides into two trunks: the larger anterior and the smaller posterior. The anterior trunk directly supplies the area of the esophagogastric junction and the dome of the diaphragm [7]. Additionally, a small number of branches may also attach to the superior pole of the spleen [8–11].

The RIPA usually passes behind the left hepatic lobe and the inferior vena cava [12, 13]. The ascending branch is usually located cranially and contacts the bare area of the liver [1, 5].

In most cases, the LIPA and RIPA arise separately from the abdominal aorta above the origin of the celiac trunk [1, 9, 13]; however, they may demonstrate various types of origin [12, 14–16]. Information on the possible position of this artery can be valuable for understanding and treating the source of arterial bleeding at the esophagogastric junction [7, 17].

The most commonly recognized clinical feature of the RIPA is that it may serve as an extrahepatic collateral arterial supply route to hepatocellular carcinomas [18, 19]. This is important information for surgeons since, in such a case, transcatheter embolization of RIPA may help in the treatment of unresectable hepatocellular carcinoma [18, 19].

This vessel is one of the main sources of postoperative bleeding in liver transplant recipients. In living donors undergoing right hepatic lobectomy, ligation of the artery is necessary for the donor and for hepatectomy in the recipient [20].

However, previous studies have so far examined each of the arteries separately and none have proposed any classifications. Therefore, the aim of our study was to investigate the anatomy of IPA types by classical anatomical dissection, and to propose a classification based on the origin of both the RIPA and LIPA.

MATERIALS AND METHODS

Anatomical studies

The study was performed on upper abdominal region of 48 adult Caucasian cadavers (29 males and 19 females) that had been fixed in 10% formalin solution before examination. The cadavers were the property of the Department, having been donated to the university anatomy program. Cadavers with any evidence of surgical intervention in the dissected area were excluded from the study.

Description of the dissection protocol

Firstly, the abdominal cavity was opened by making incisions along the linea alba from the xiphoid process to the pubic symphysis. Next, after making sure there was no evidence of trauma, pathology or prior surgery in the upper abdominal organs, the origin of the RIPA and LIPA was recorded

Upon dissection, the morphological features of the IPA were assessed:

- Origin of the LIPA and the RIPA
- Diameter of the LIPA (measurement taken at the origin)
- Diameter of the RIPA (measurement taken at the origin)

All measurements were performed using an electronic digital caliper gauge (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan). Each measurement was carried out twice with an accuracy of up to 0.1 mm. The consent for the anatomical studies was obtained from the Local Bioethical Commission RNN/404/19/KE

Statistical analysis

In the statistical analysis, IPA types were compared according to genders and sides with the Chi^2 test. The normality of the morphometric data distribution was checked with the Shapiro-Wilk test. As the data was not normally distributed, the Mann-Whitney test and the Wilocoxon sign-rank test were used to compare anthropometric measurements between the sexes and sides, respectively. Differences in morphometric measurements between the types was assessed with the Kruskal Wallis ANOVA with a dedicated *post hoc* test. Statistica 13 software (StatSoft Polska, Cracow, Poland) was used for the analysis and a p-value lower than 0.05 was considered significant. The results are presented as mean and standard deviation unless stated otherwise.

RESULTS

In all the specimens, both IPAs were present. Based on the point of branching, six types of IPA could be identified:

- Type 1 – the RIPA and the LIPA originate from the abdominal aorta (Fig. 1). This type occurred in 14 cadavers.
- Type 2 – the RIPA and the LIPA originate from the celiac trunk (Fig. 2). This type was observed in 12 cadavers.
- Type 3 – the RIPA and the LIPA originate from the left gastric artery (Fig. 3). In this type the celiac trunk was absent. This type occurred in three cadavers.
- Type 4 – This type was divided into two subtypes (A-B).
    - A – the LIPA originates from the abdominal aorta, and the RIPA originates from the celiac trunk (Fig. 4a). This type occurred in nine cadavers.
    - B – the RIPA originates from the abdominal aorta, and the LIPA originates from the celiac trunk (Fig. 4b). This type occurred in six cadavers.
- Type 5 – The LIPA originates from the abdominal aorta and the RIPA originates from the accessory hepatic artery (Fig. 5). This type occurred in one cadaver.
- Type 6 – The RIPA and the LIPA form a common trunk which originates from the abdominal aorta (Fig. 6). This type occurred in three cadavers.

In figure 8 we have presented all the types we established in the form of diagrams.

Table 1 presents the origin of LIPA and RIPA according to given type. In almost all types, the LIPA and RIPA are single arteries and have different origins. However, both IPAs originate from the CT by a short common trunk in Type 6.

Table 2 presents the distribution of IPA types according to sex. Although no significant difference in distribution was observed (p=0.4916), it is important to note that types 4b, 5 and 6 did not occur in men.

Table 3 presents diameters of the LIPA and the RIPA according to sex. In general, no significant difference in mean LIPA or RIPA diameter was observed between sexes: LIPA 2.46 mm (SD 0.44 mm) for women compared to 2.66 mm (SD 0.47 mm) for men (p=0.1846); RIPA 2.59 mm (SD 0.46 mm) for women compared to 2.73 mm (SD 0.63 mm) for men (p=0.6830).

Regarding the types, LIPA diameter was significantly greater in Type 4a than in types 1 and 4b (p=0.0045). For the RIPA, the differences were not significant.

DISCUSSION

Vascular abnormalities are very common in the abdomen; the area undergoes many modifications during the formation of the adult vascular system. In addition, it is possible for multiple arterial variants to develop within a single person [21]. The type of IPA varies depending on the occurrence of other abdominal vascular variations; in particular, different origins of both LIPA and RIPA may be observed in the presence of variations of the celiac trunk [22–25].

This correlation can be explained by the embryological development of the celiac trunk [3, 26–31]. The aorta has posterior, lateral and abdominal branches, which form the celiac trunk and the longitudinal anastomoses between them. The growth of the longitudinal anastomoses and regression of the abdominal branches affects the formation of various types of the celiac trunk division. The IPA primarily arises from the abdominal roots of the aorta and most likely from the same level as the CT [12, 32–34].

For example, Olewnik proposes that the variant of the celiac trunk branching into the common hepatic artery (CHA), the left gastric artery (LGA), splenic artery (SA) and LIPA should be called the celiacophrenic trunk. This type was observed in 14.5% of a group of 40 cadavers, i.e. the second most common type [14, 35].

We propose the following six-fold classification of IPA origin based on our findings. In Type 1, the lower diaphragmatic arteries are branches of the abdominal aorta above the celiac trunk. Previous studies have found this type to occur in over 50% of preparations [5], while it was observed in about 29.12% of cases in the present study.

Type 2 is characterized by both lower diaphragmatic arteries forming separate branches arising from the celiac trunk. It was found to be the most common type by Basile et al. (41% of preparations) [18]; however it was present in about 24.96% of cadavers in the present study.

In Type 3, the RIPA and the LIPA arise from the LGA. It was observed in 6.24% of the cadavers, which was much less common than recorded by other authors, e.g. Loukas et al note it was present in about 2% of specimens [11].

In Type 4, one IPA originates from the CT and the other from the AA. This type was divided into two subtypes. Subtype 4A, where the LIPA originates from the AA and the RIPA originates from the CT, was observed in about 18.72% of the cadavers. Subtype B, in which RIPA originates at the AA and the LIPA at the CT, occurred in 12.48% of the tested specimens. As these subtypes have not been discussed in any previous study, it is not possible to make any comparisons regarding the frequency of occurrence.

In Type 5, the LIPA runs directly from the AA, while both RIPA and left accessory hepatic artery (LAHA) originate from the AA. this is a comparatively rare type, occurring in only 2.08% of the examined cadavers. As with Type 4, this type has not been discussed in any other previous study.

In our final proposed type, Type 6, the LIPA and RIPA form a common trunk arising from the AA. This type observed in only 6.24% of the studied cadavers; however, Basile et al., report it in about 21% of specimens [18].

Our proposed Type 4 (A; B), Type 5 and Type 6 and their LIPA and the RIPA origins configurations have not been reported in previous studies (Table 4).

IPAs are one of the most important collateral arteries that provide blood to hepatocellular carcinoma (HCC) located in the peripheral segments and bare area of the liver [18, 36].

One of the priorities for successful treatment of HCC is the complete embolization of the blood supply. To ensure this, and prevent complications due to embolization of the non-targeted branches, CTA identification of the arteries supplying the tumor is an important clinical step [13, 37, 38]. In addition to RIPA embolization, gastroesophageal complications may occur if the ascending branch of the LIPA originates from the RIPA [39, 40]. The same type should also be kept in mind if an IPA embolization is planned in patients with upper gastroesophageal bleeding [41–43]

The present study does have some limitations. Being based on several morphological details, such as type of the origin, the classification is of quite a heterogeneous nature; as this is only an anatomical study, a spectrum of variation could be presented, and further studies should examine the potential value of angiography or CT for this purpose. Nonetheless, our findings help raise awareness of “what and where” to look for, and offers a uniform classification and terminology which can be used as a foundation for communication with surgeons, particularly those harvesting tendons for transplants. Another limitation is the small research sample (48); however, this group is nevertheless larger than used in similar studies of this type.

CONCLUSIONS

Our work adds a new perspective to our understanding of IPA anatomy by measurements its diameter. Our results indicate that while no significant differences can be found in RIPA diameter, LIPA diameter varies significantly. No significant differences in RIPA or LIPA diameter were found according to sex.

We therefore propose a six-fold classification created by analyzing the departure of the RIPA and LIPA. In contrast to previous studies, we considered the arteries as a pair and not as separate vessels.

Declarations

Ethical approval and consent to participate: The cadaver belonged to the Department of Anatomical Dissection and Donation, Medical University of Lodz.

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Table 1. Comparison of particular types of LIPA and RIPA origin.

	LIPA	**RIPA**
Type 1	AA	AA
Type2	CT	CT
Type 3	LGA	LGA
Type 4 a	AA	CT
Type 4 b	CT	AA
Type 5	AA	AHA
Type 6	CT	

Table 2. Comparison of types according to sex [number and % for each gender].

		Men	**Women**
Type 1		5 (35.71)	9 (26.47)
Type 2		5 (35.71)	7 (20.59)
Type 3		1 (7.14)	2 (5.88)
Type 4	A	3 (21.43)	6 (17.65)
	B	-	6 (17.65)
Type 5		-	1 (2.94)
Type 6		-	3 (8.82)

Table 3. Comparison of LIPA and RIPA diameter according to type and sex.

		LIPA [mm]		**RIPA [mm]**	
		Men	**Women**	**Men**	**Women**
Type 1	*Max.*	3.07	3.19	2.90	3.20
	Min.	2.54	1.66	2.21	2.01
	Avg.	2.80	2.45	2.59	2.50
Type 2	*Max.*	3.11	2.14	3.57	2.74
	Min.	1.86	1.88	2.46	1.69
	Avg.	2.36	2.01	3.04	2.25
Type 3	*Max.*	2.61	2.21	3.19	2.41

		Min.	2.31	2.21	2.85	2.41
		Avg.	2.46	2.21	3.02	2.41
Type 4	**A**	*Max.*	3.55	3.49	4.03	3.11
		Min.	2.44	2.61	2.74	2.95
		Avg.	3.02	3.05	3.44	3.01
	B	*Max.*	-	2.50	-	2.70
		Min.	-	1.98	-	2.04
		Avg.	-	2.24	-	2.55
Type 5		*Max.*	-	2.56	-	2.86
		Min.	-	2.56	-	2.86
		Avg.	-	2.56	-	2.86
Type 6		*Max.*	-	2.28	-	2.28
		Min.	-	2.02		2.02
		Avg.	-	2.15		2.15

Table 4. Overview of previous studies which investigated the origin of IPA types and the present study.

	Type 1	**Type 2**	**Type 3**	**Type 4**		**Type 5**	**Type 6**
				A	**B**		
Adachi et al. 1928	11	6	1	-	-	-	-
Pick & Anson et al. 1941	37	26	4	-	-	-	-
Greig et al. 1951	77	52	3	-	-	-	-
Kahn et al. 1967	13	-	-	-	-	-	-
Lippert & Pabst et al. 1985	18%	14%	1%	-	-	-	-
Piao et al. 1998	6	4	-	-	-	-	-
Loukas et al. 2005	22	12	-	-	-	-	-
Gwon et al, 2007	-	-	-	-	-	-	-
Basile et al. 2008	42	32	-	-	-	-	-
Ozbulbul et al. 2011	16	18	-	-	-	-	-
Our Study	14	12	3	9	6	1	3

Figure 1. Type 1 — the RIPA and LIPA originate from the abdominal aorta. PHA — proper hepatic artery; GDA — gastro-duodenal artery; RIPA — right inferior phrenic artery; CHA — common hepatic artery; LGA — left gastric artery; SA — splenic artery; LIPA — left inferior phrenic artery; CT — celiac trunk; SMA — superior mesentery artery; St — stomach; Li — liver; AA — abdominal aorta.

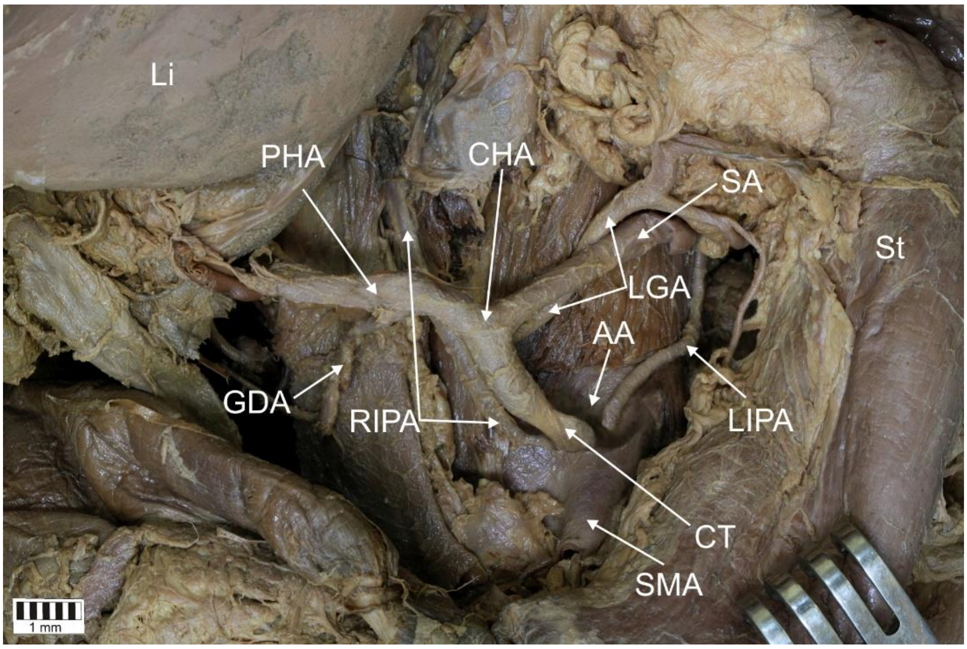

Figure 2. Type 2 — the RIPA and LIPA originate from the celiac trunk. PHA — proper hepatic artery; GDA — gastro-duodenal artery; RIPA — right inferior phrenic artery; CHA — common hepatic artery; LGA — left gastric artery; SA — splenic artery; LIPA — left inferior phrenic artery; CT — celiac trunk; SMA — superior mesentery artery; St — stomach; Li — liver; AA — abdominal aorta; PA — pancreas.

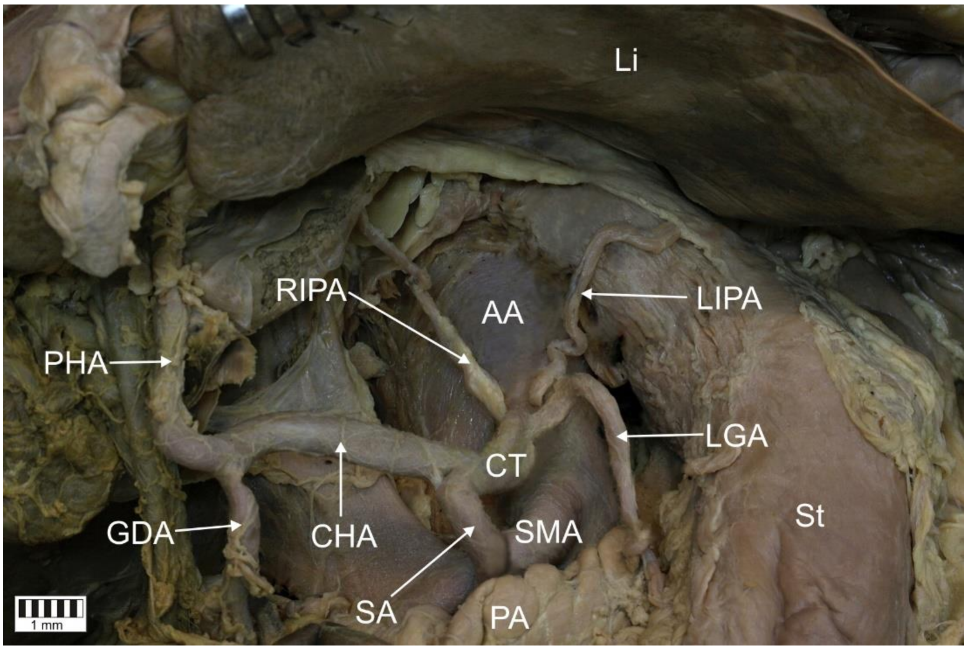

Figure 3. Type 3 — the RIPA and LIPA originate from the left gastric artery. RIPA — right inferior phrenic artery; CHA — common hepatic artery; LGA — left gastric artery; SA — splenic artery; LIPA — left inferior phrenic artery; St — stomach; Li — liver; AA — abdominal aorta.

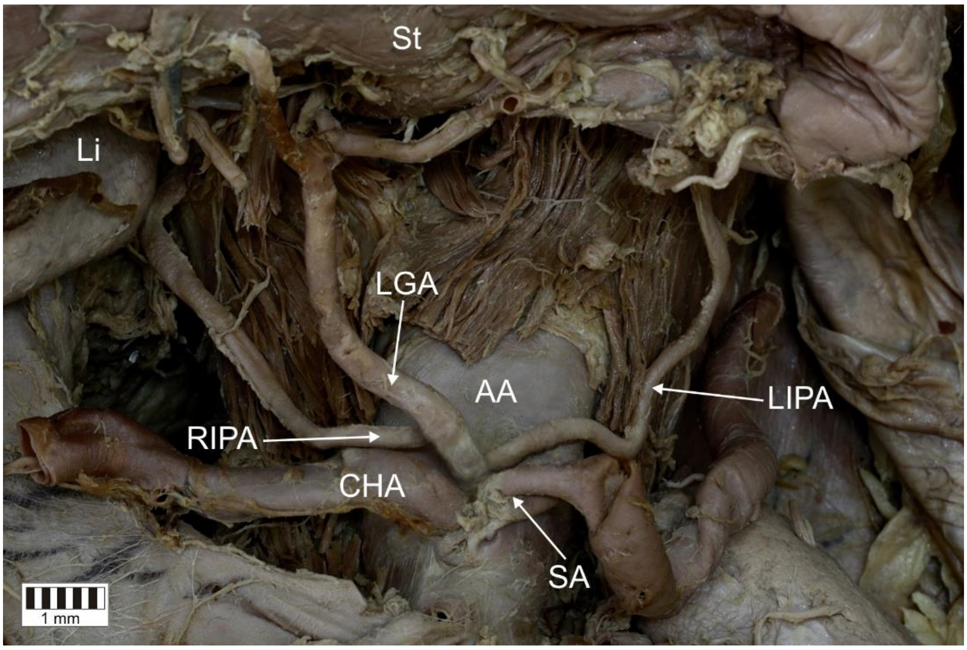

Figure 4. Type 4a — the LIPA originate from the abdominal aorta, and the RIPA originate from the celiac trunk. PHA — proper hepatic artery; GDA — gastro-duodenal artery; RIPA — right inferior phrenic artery; CHA — common hepatic artery; LGA — left gastric artery; SA — splenic artery; LIPA — left inferior phrenic artery; CT — celiac trunk; St — stomach; Li — liver; AA — abdominal aorta.

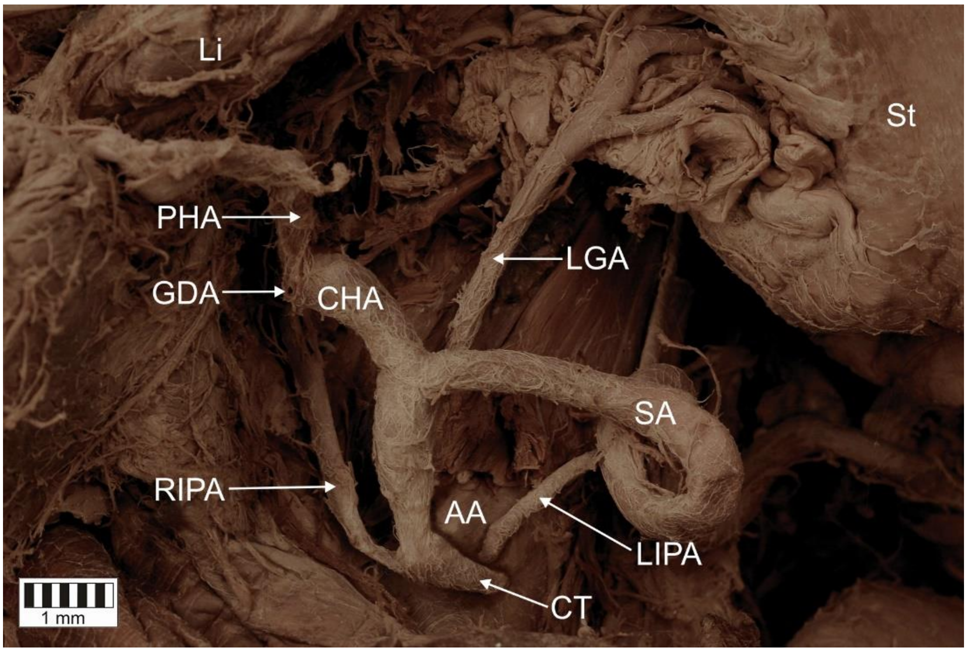

Figure 5. Type 4b — the RIPA originate from the abdominal aorta, and the LIPA originate from the celiac trunk. RIPA — right inferior phrenic artery; CHA — common hepatic artery; LGA — left gastric artery; SA — splenic artery; LIPA — left inferior phrenic artery; CT — celiac trunk; Li — liver; AA — abdominal aorta; Pa — pancreas.

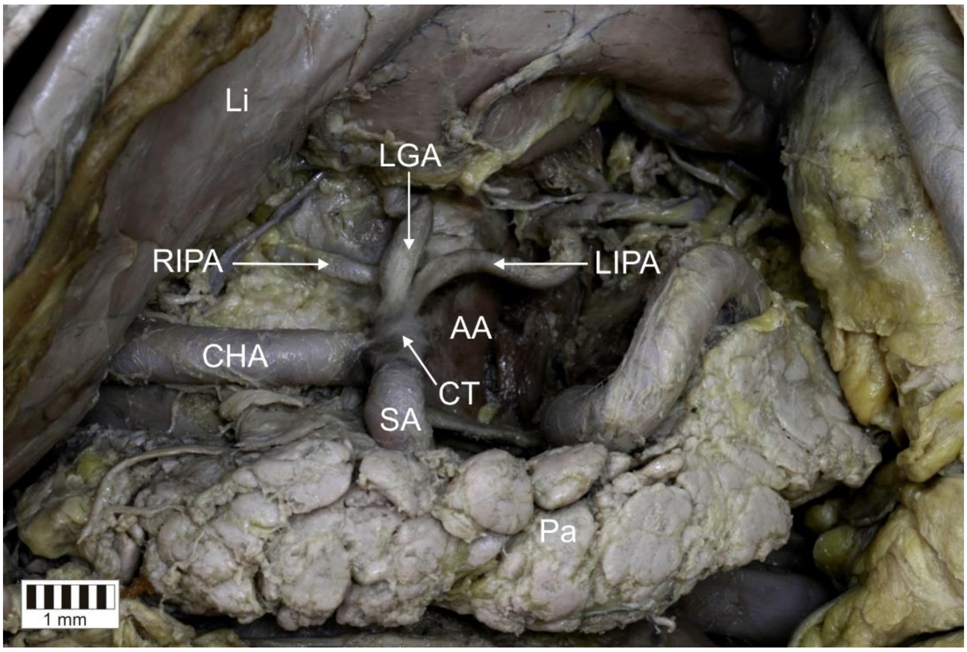

Figure 6. Type 5 — The LIPA originate from the abdominal aorta, and on the right side common trunk for the left accessory hepatic artery and RIPA originate from the abdominal aorta. PHA — proper hepatic artery; GDA — gastro-duodenal artery; RIPA — right inferior phrenic artery; CHA — common hepatic artery; LGA — left gastric artery; SA — splenic artery; LIPA — left inferior phrenic artery; St — stomach; Li — liver; AA — abdominal aorta; LAHA — left accessory hepatic artery; HPV — hepatic portal vein; RGA — right gastric artery.

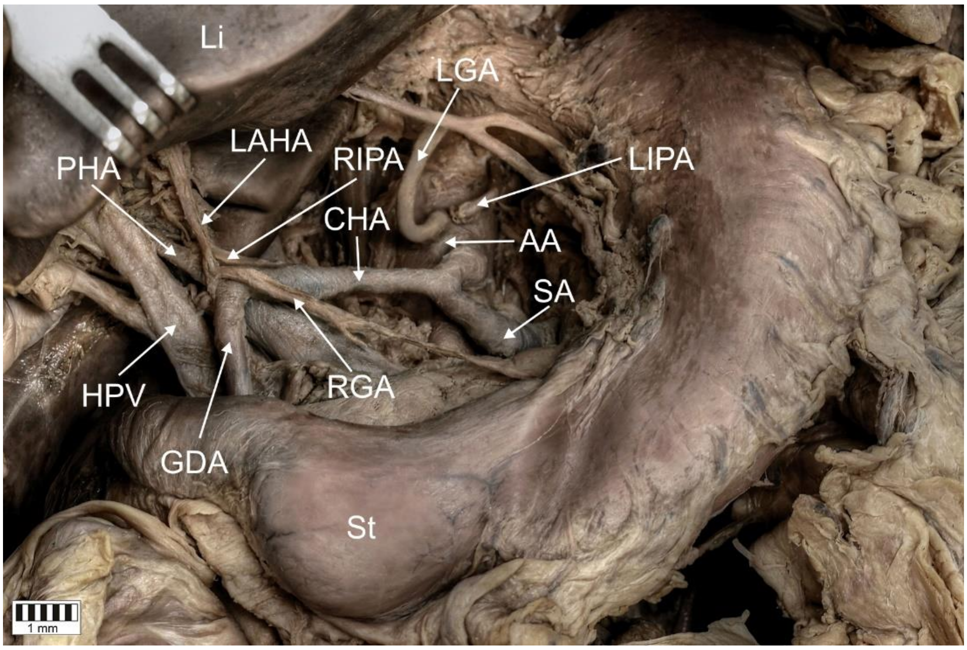

Figure 7. Type 6 — the common trunk for the RIPA and LIPA, which originate from the abdominal aorta. RIPA — right inferior phrenic artery; CHA — common hepatic artery; SA — splenic artery; LIPA — left inferior phrenic artery; Li — liver; AA — abdominal aorta, Pa — pancreas.

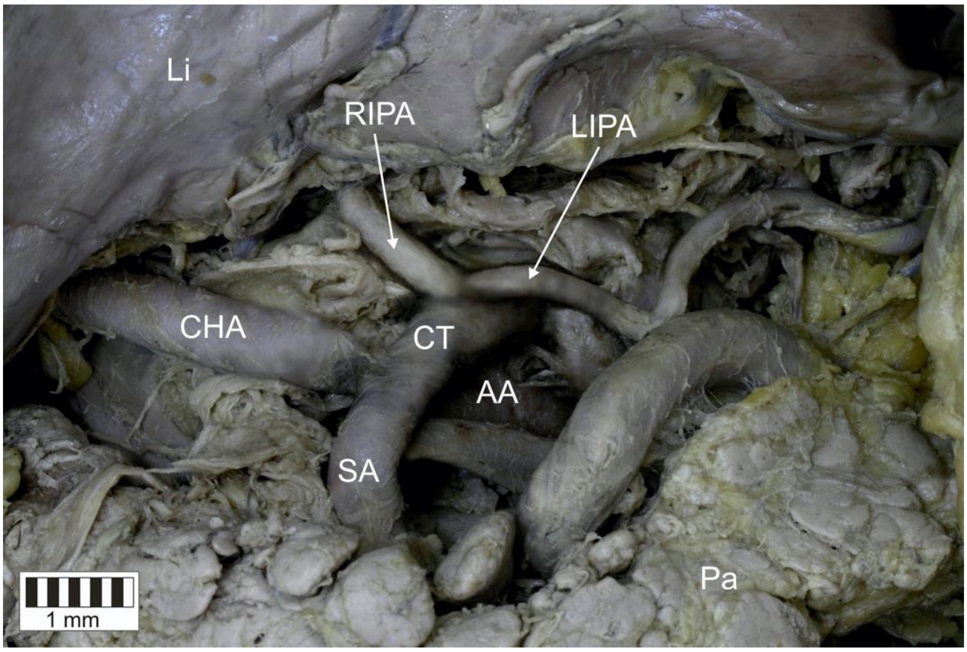

Figure 8. Scheme presents all types of RIPA and LIPA origins; a — type 1; b — type 2; c — type 3; d — type 4a; e — type 4b; f — type 5; g — type 6.