CT angiographic study of anatomical variations of inferior phrenic arteries

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Abstract

Introduction: Inferior phrenic arteries (IPA) mostly originate from the abdominal aorta or celiac artery. However, they can originate from renal arteries, splenic arteries, and other sources. Knowledge of existing variations is paramount in surgery and radiology, as right IPAs can be a cause of postoperative bleeding in liver transplantation, and left IPA can be a cause of bleeding in gastroesophageal hemorrhage. The variations in the origins of IPAs in the Kazakh population were investigated in this study. Methods: CT angiographies of 155 patients were retrospectively analyzed. The origins of IPAs were detected using 3D and multiplanar reconstructions. Results: 48 patients had right and left IPAs originating together from either the celiac trunk or the abdominal aorta. 107 cases had separate origins. The most prevalent origins of the right IPA were the celiac artery (42.99%), the abdominal aorta (37.38%), and the right renal artery (15.89%). The most prevalent origins of left IPA were the celiac trunk (61.68%) and the abdominal aorta (32.71%). Overall, 12 combinations of artery origins were noted. Conclusion: The study presents the variations in origins of IPAs which is important in planning surgical and radiological interventions and should increase awareness among surgeons and radiologists during different procedures.

Introduction

Inferior phrenic arteries (IPA) are two arteries, the right inferior phrenic artery (RIPA) and the left inferior phrenic artery (LIPA), supplying the diaphragm. Their small branches also supply the “liver, adrenal glands, esophagus, stomach, inferior vena cava, and retroperitoneum” (Aslaner et al., 2017). They also supply the spleen, suprarenal glands, and adjacent structures (Whitley et al., 2021).

Inferior phrenic arteries have variations in their origin. According to different studies, the most common origins of these arteries are the celiac artery and abdominal aorta. The renal artery, left gastric artery (LGA), and other arteries are less common origins (Pavlov et al., 2024).

In several cases, the right and left IPAs constitute a common trunk, that according to Terayama et al. (2017) can branch either from the celiac trunk or the abdominal aorta or LGA.

Awareness of IPA origin variation is significant during surgical and radiological interventions, as IPA can be the cause of postoperative bleeding or can be used for treatment purposes. IPA can be significant during renal transplantation if it stems from the renal artery as blood flow to the diaphragm, liver, and adrenal glands can decrease if the renal artery is dissected and clamped during kidney transplantation before the point of IPA branching (Kantarci et al., 2013). IPA is known as the major source of postoperative bleeding during liver transplantation as it can give collateral blood supply to hepatocellular carcinoma. Concerning treatment, transcatheter embolization of RIPA is performed when hepatocellular carcinoma (HCC) is unresectable (Szewczyk et al., 2021). LIPA should be considered in gastrectomy and hiatal hernia repair procedures as gastrointestinal bleeding can happen due to gastroesophageal junction being supplied by the LIPA (Aslaner et al.,2017). LIPA embolization was reported to be performed in pericardial tamponade after trauma as tamponade was caused by the anastomosis between the LIPA branch and pericardiophrenic, musculophrenic arteries (Aslaner et al., 2017).

Considering the importance of knowledge about the origins of IPAs in the diagnostics and treatment of different diseases, the study aims to investigate and report the vascular anatomy of IPAs by exploring the origin variations of these arteries in the Kazakh population using computed tomography (CT) angiograms. This data can be used by radiologists before the liver and renal transplantations to guide the procedure and by surgeons in detecting the cause of postoperative bleeding and for transcatheter embolization of RIPA in unresectable HCC.

Methods

Patients

The research was held in the Department of Radiology at the National Cardiac Surgery Research Center (NCSRC), Astana, Kazakhstan between August 2023, and August 2024. Ethical approval was obtained from the Nazarbayev University School of Medicine Institutional Research Ethics Committee (IREC No -2023Apr#01), the Scientific Committee of the University Medical Center, and the Local Ethics Committee of the University Medical Center. The study was conducted retrospectively using the arterial phase of abdominal CT angiograms of NCSRC patients. Patient data were retrieved from the picture archiving and communication system (PACS) of our institution. All patients older than 18, of both genders, were included in the study. All the patient data was anonymized. Informed consent was waived for the study. A total of 156 CT angiograms were used for the current research. Due to the small caliber of the artery, 1 CT angiogram in which inferior phrenic arteries could not be detected was excluded from the study.

CT angiogram

The CT scans were performed using The Somatom Definition AS 64-slice multi-detector CT (MDCT) scanner (Siemens). A bolus injection of the Ultravist 370 contrast medium in the amount of 1.22ml/kg was performed into a peripheral vein at 4 mL/s. CT images in arterial and venous phases were taken. The CT scans were then obtained from the PACS using RadiAnt DICOM Viewer.

Image analysis

Origins of IPAs were observed from the 155 CT scans using the three-dimensional and multiplanar reconstructions in three planes (sagittal, coronal, axial) that were done using the workstation RadiAnt DICOM Viewer. A quantitative analysis of the artery origins was performed. The obtained results were analyzed and the prevalence of different origins for IPA or RIPA and LIPA was calculated. Pictures of the different variants were obtained from the RadiAnt DICOM Viewer.

Results

Overall, 155 CT angiograms were observed, with 65 being male patients and 90 being female patients. The mean patient age was 53.2 years old.

Out of all 155 patients 48 had IPA originating from a common trunk, while 107 arose independently as right and left IPAs. Of those IPAs branching off the common artery, 31 arose out of the celiac trunk (64.58%) and 17 originated from the abdominal aorta (35.42%). Reconstructions of IPA with the common trunk are shown in Figure 1.

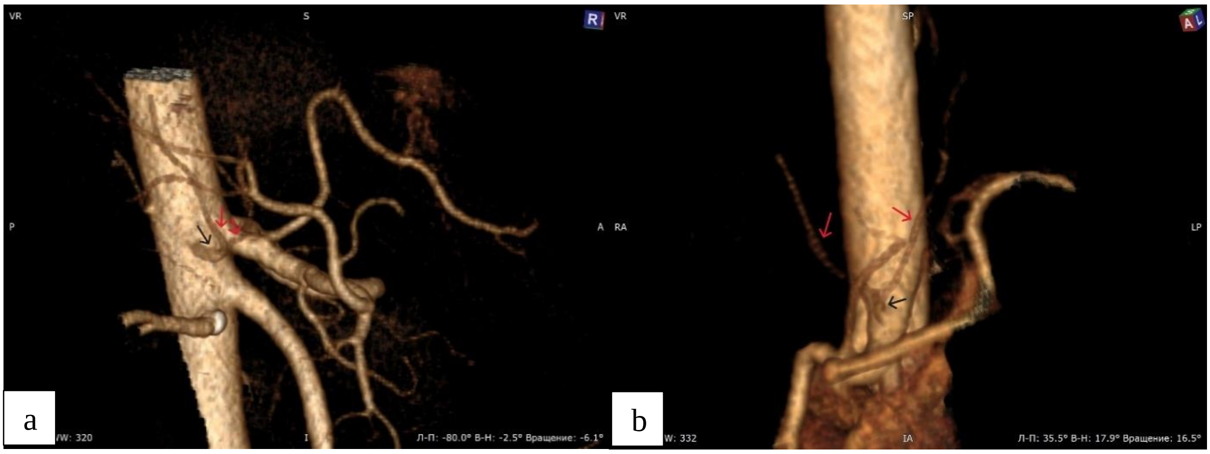

Fig. 1. Three-dimensional reconstructions of the IPAs originating from the common trunk. (a) Right and left IPAs originating together from the abdominal aorta. (b) Right and left IPAs originating together from the celiac trunk. Black arrow-common trunk. Red arrows-right and left IPAs.

As for the arteries that had individual points of origin, there are several variations in their anatomy. Celiac trunk was the origin of RIPA in 46 CT angiograms (42.99%). 40 (37.38%) patients had RIPA branching off from abdominal aorta. Another origin for RIPA was the right renal artery, with 17 (15.89%) patients having arteries arising from it. Rare origins that were identified are the right renal accessory artery (0.93%), the common hepatic artery (0.93%), and the LGA (1.87%). CT angiograms of the arteries having individual origin are presented in Figure 2 and Figure 3.

Fig. 2. Three-dimensional reconstructions of the RIPA. (a) RIPA originating from the celiac trunk. (b) RIPA originating from the abdominal aorta. (c) RIPA originating from the right renal artery. Red arrow-right IPA. Black arrow-celiac trunk. Blue arrow-right renal artery. Violet arrow-abdominal aorta.

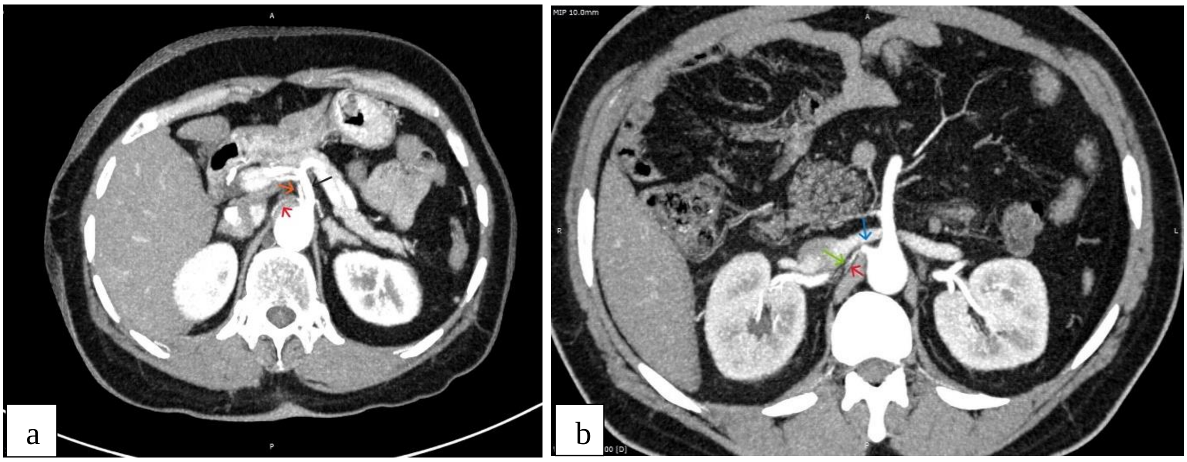

Fig 3. Multiplanar reconstruction of the RIPAs. (a) RIPA originating from the LGA. (b) RIPA originating from the renal accessory artery. Red-right IPA. Black-celiac artery. Orange-LGA. Green- right renal accessory artery. Blue-right renal artery.

LIPA stemmed from the celiac trunk in 66 (61.68%) patients and abdominal aorta was the origin of LIPA in 35 patients (32.71%). In 4 cases (3.74%) splenic artery was the origin of

LIPA, and in 2 cases LIPA arose from LGA (1.87%). Figure 4 and Figure 5 demonstrate the reconstructions of the different variations of LIPA origin.

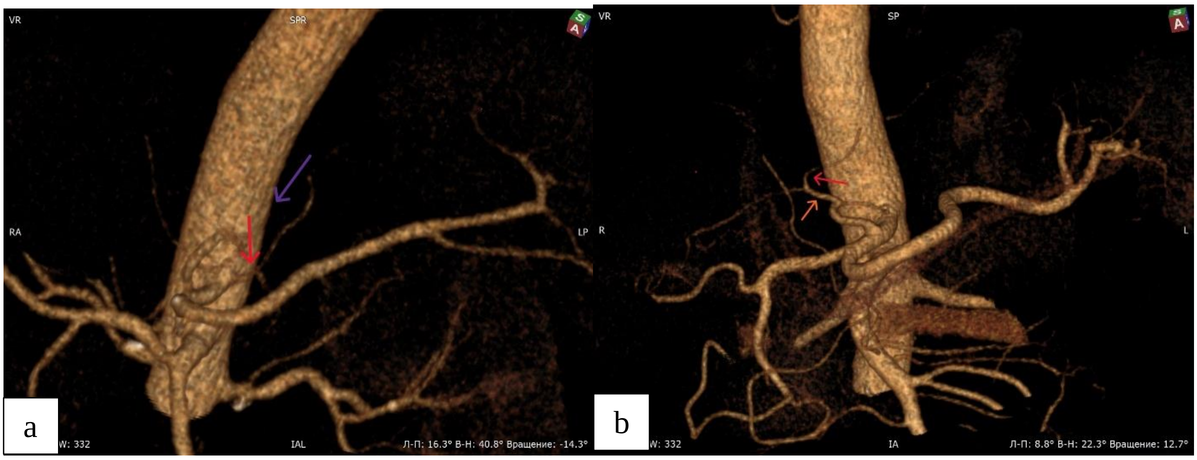

Fig. 4. Three-dimensional reconstructions of the LIPA. (a) LIPA originating from the abdominal aorta. (b) LIPA originating from the LGA. Red arrow-LIPA. Violet arrow-abdominal aorta. Orange arrow-LGA.

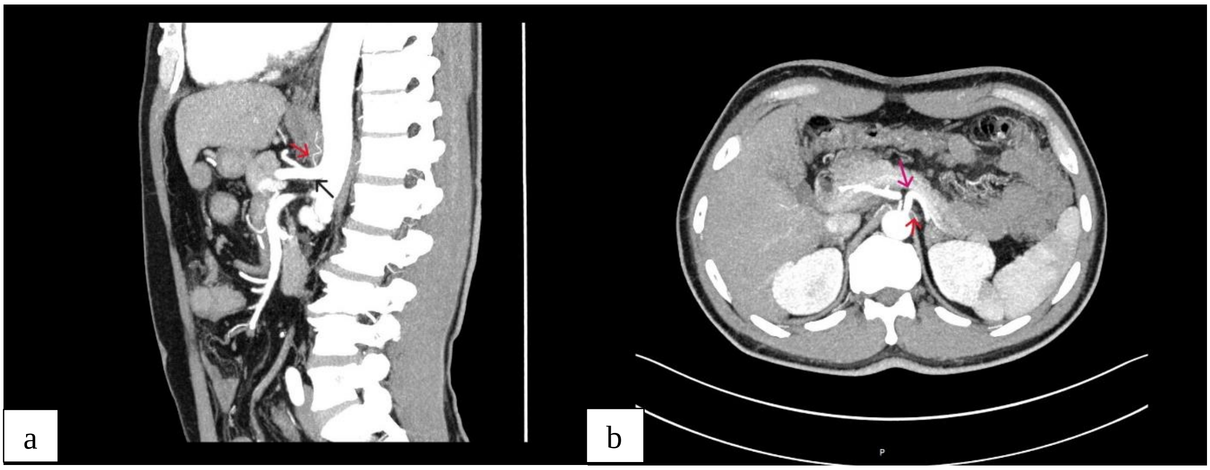

Fig 5. Multiplanar reconstruction of the LIPA. (a) LIPA originating from the celiac trunk. (b) LIPA originating from the splenic artery. Red arrow-LIPA. Black arrow-celiac trunk. Pink arrow-splenic artery.

All these different origins of RIPA and LIPA resulted in 12 combinations presented in Table 1. In Type 1 and Type 2, they stem from one source but separately. In Type 4 there are two subtypes with the 4a subtype being RIPAs originating from the abdominal aorta, LIPA from the celiac trunk and the 4b subtype being the same but vice versa. Type 12 similarly has two subtypes.

Table 1. Combinations of origins of RIPA and LIPA

Anatomy	**Type**	**Number of cases**	**Rate (%)**
Right inferior phrenic artery and left inferior phrenic artery branch separately from the celiac trunk	1	32	29.91
Right inferior phrenic artery and left inferior phrenic artery branch separately from the abdominal aorta	2	18	16.82
Right inferior phrenic artery branches from the celiac trunk; Left inferior phrenic artery branches from the splenic artery	3	2	1.87
Right inferior phrenic artery branches from the abdominal aorta; Left inferior phrenic artery branches from the celiac trunk	4 a	20	18.69
Right inferior phrenic artery branches from the celiac trunk; Left inferior phrenic artery branches from the abdominal aorta	4 b	11	10.28
Right inferior phrenic artery branches from the left gastric artery; Left inferior phrenic artery branches from the aorta	5	1	0.93
Right inferior phrenic artery branches from the common hepatic artery; Left inferior phrenic artery branches from the celiac trunk	6	1	0.93
Right inferior phrenic artery branches from the right renal artery; Left inferior phrenic artery branches from the celiac trunk	7	11	10.28
Right inferior phrenic artery branches from the right renal artery; Left inferior phrenic artery branches from the left gastric artery	8	1	0.93
Right inferior phrenic artery branches from the right renal accessory artery; Left inferior phrenic artery branches from the abdominal aorta	9	1	0.93
Right inferior phrenic artery branches from the aorta;	10	2	1.87

Left inferior phrenic artery branches from the splenic artery			
Right inferior phrenic artery branches from the right renal artery; Left inferior phrenic artery branches from the abdominal aorta	11	5	4.67
Right inferior phrenic artery branches from the celiac trunk; Left inferior phrenic artery branches from the left gastric artery	12 a	1	0.93
Right inferior phrenic artery branches from the left gastric artery; Left inferior phrenic artery branches from the celiac trunk	12 b	1	0.93

Discussion

Variations of IPA origins were analyzed using 155 CT angiograms. Out of those originating together from a common trunk, the celiac trunk (64.58%) was the most frequent origin. It was detected that most IPAs originate separately from each other (69%). The most prevalent origins of RIPA are the celiac trunk (42.99%), the abdominal aorta (37.38%), and the right renal artery (15.89 %). As for the LIPA, the most prevalent origins are the celiac trunk (61.68%) and the abdominal aorta (32.71%).

The current research is comparable to other investigations done on the identification of IPA origin variations. It was observed that IPA had a common trunk in 30.97% of patients while in a study conducted by Aslaner et al. (2017), it was shown that 29.5% of patients had a common trunk. In the current study, out of those having a common trunk, 64.58% originated from the celiac trunk while the rest branched off from the abdominal aorta. In a study by Pavlov et al. (2024), the prevalence of the celiac artery is lower (52.39%) which can be due to the larger sample size of their study with 565 cases analyzed. Moreover, Aslaner et al. (2017) observed that the common trunk can also originate from the LGA and right renal artery. However, these variations were not detected in this research.

In 69.03% of the participants, RIPA and LIPA branch off separately from each other. In our study, 12 combinations were observed (Table 1), though different studies reported various numbers of combinations of arteries. For instance, a cadaveric study by Szewczyk et al. (2021) highlighted 6 types of origin of IPA, while a study using multidetector CT reported 13 IPA variation combinations (Basile et al. 2007). This difference in number also correlates with the number of participants as the study by Szewczyk et al. (2021) had 48 cadavers analyzed and the investigation by Basile et al. (2007) had 200 participants. The largest study which had 1000 participants described 52 types of variations. (Ekingen & Çetinçakmak, 2021). They also reported the IPA stemming separately in 60.90 % of cases.

In the current study, the most prevalent combination of RIPA and LIPA origins is both of them arising individually from the celiac trunk (29.91%) and originating from the abdominal aorta separately (16.82%), which is consistent with the research conducted by Basile et al. (2007) and the existing literature. The other common combinations are the celiac trunk being the origin of LIPA and the abdominal aorta being the origin of RIPA (18.69%).

A Study done by Kumar et al. (2024) suggested another classification of the most common variations. It consists of 4 types subdivided within the group with the first type originating from the abdominal aorta, the second type from the celiac trunk, the third type from LGA, and the fourth type from the renal artery. However, the most prevalent type was the one with both IPAs originating from the abdominal aorta separately, which is not the case in our study. The second most prevalent was the one with RIPA branching out of the abdominal aorta and LIPA out of the celiac trunk, which is consistent with our study.

The prevalence in origin of RIPA was consistent with existing literature. According to Pavlov et al. (2024), most of the studies reported three main origins of RIPA, abdominal aorta, celiac trunk, and the renal artery. The current study had celiac trunk (42.99%), abdominal aorta (37.38%), and renal artery (15.89%) as the most common origins of RIPA. The prevalence was similar to a study by Pavlov et al. (2024) with 51.2%, 29.8%, and 11.4% respectively. The same pattern of prevalence can be observed for LIPA, with celiac trunk and abdominal aorta being the most common origins. In 61.68 % of cases, LIPA branches off from the celiac trunk, and in 32.71% of the participants, LIPA branched off from the abdominal aorta, while in research by Pavlov et al. (2024), 68.6% of cases had the celiac trunk as the origin and less representation by abdominal aorta being the origin in only 21.4% of cases.

Less common origins were identified in our study with RIPA originating from the right renal accessory artery (0.93%), common hepatic artery (0.93%), and the LGA (1.87%). As for LIPA, 4 patients (3.74%) had splenic artery as the origin, and in 2 cases (1.87%) LIPA stemmed from the LGA.

Some of the rare origins were not observed in the current study. For instance, Basile et al. (2007) presented a case with RIPA stemming from the proper hepatic artery. The study by Pavlov et al. (2024) presented several LIPAs branching from the superior mesenteric artery and accessory left hepatic artery, while RIPAs branched off from the right hepatic artery and dorsal pancreatic artery. In a study by Ekingen & Çetinçakmak (2021), 14 patients did not have IPAs at all and 17 had one IPA only. It is possible that in the current study, the one case in which IPA was not detected is an example of a patient without an IPA.

Furthermore, Aslaner et al. (2017) explored the relationship between IPA origin and CT variations and concluded that the variations in CT origin led to differences in IPA origins. It was noted in the current study as well. One of the rare variations in the origin of LIPA was the splenic artery that stemmed from the abdominal aorta with the celiac trunk not being present (Figure 5b).

Numerous studies have been done on describing the variants of IPAs both using CT angiography and cadavers. However, the analysis of these arteries has not been studied in the Kazakh population making this study a useful tool for the surgeons and radiologists practicing in Kazakhstan, especially in the areas of Kazakhstan that do not have CT machines available, as different studies presented cases in which the location of RIPA and LIPA should be considered either for diagnosis or for treatment.

As an example, RIPA can be an extrahepatic collateral artery to HCC meaning it often can be the source of post-operative bleeding. Hong et al. (2006) demonstrated that in the first two weeks after liver transplantation, there is a 5% chance of bleeding from RIPA. To avoid that, physicians should ligate the IPA in the donor during lobectomy and in the recipient during hepatectomy, as failure to do so will lead to active bleeding resulting in a hypotensive crisis. The possible reason for postoperative bleeding of IPA is its enlarged size, probably due to impaired blood flow from the portal vein to the hepatic vein in the cirrhotic liver (Hong et al., 2006). Hong et al. (2006) demonstrated that timely diagnosis can allow control of the bleeding through radiologic intervention (Hong et al., 2006). Therefore, knowing the existence of the different origin variations of the IPA is significant as it ensures better post-operative recovery and outcomes.

Concerning treatment, the right branch of IPA is an extrahepatic supply route to hepatocellular carcinoma (HCC). As IPA supplies the diaphragm, which is in close contact with the liver, IPA can communicate with hepatic artery branches through its branches (Gwon et al., 2007). In a study that involved 383 interventions, 346 had hepatocellular carcinoma that had IPA as a collateral vessel (Gwon et al., 2007). Therefore, the transcatheter embolization procedure is used when carcinoma is unresectable (Szewczyk et al., 2021). This is especially true when hepatocellular carcinoma is in the first, second, or seventh segments of the liver, which makes the angiography of RIPA compulsory. When RIPA is a collateral supply of carcinoma, RIPA is enlarged and may exceed 2.5 mm which can be detected on CTA before the surgery (Aslaner et al., 2017). It was also suggested that patients with HCC have RIPA that is larger in diameter than the left one. This suggestion, however, cannot be used to confirm collateral supply by RIPA to HCC, as normal patients also have RIPA larger in diameter than the LIPA (Gwon et al., 2007). However, according to Kumar et al. (2024), IPA is considered to be the main source of blood supply to the HCC when the diameter is more than 2.5 mm.

LIPA can also be involved in different conditions and knowledge of variations in its origin is paramount. LIPA can serve as a collateral supply for tumors, especially the ones formed in the esophagogastric junction region. It should also be noted that LIPA can also be the collateral supply to HCC, especially if HCC is in the left lobe of the liver or if RIPA is obstructed. LIPA should be studied during upper gastrointestinal bleeding if the common arteries are not the source of the bleeding, as bleeding of LIPA has been reported in cases of gastroesophageal hemorrhage and Mallory-Weiss tear (Gwon et al., 2007).

Moreover, due to the vast organs IPAs supply iatrogenic injuries to the IPAs can lead to

"hemothorax, intraperitoneal hemorrhage, cardiac tamponade." (Kumar et al. 2024). IPAs can also be the cause of hemoptysis due to systemic pulmonary artery anastomosis formed in conditions such as tuberculosis, cystic fibrosis, pneumonia, etc. which are located at the base of the lungs. During these inflammatory diseases, pulmonary circulation decreases, and anastomosis is created leading to an increase in systemic circulation that involves many systemic arteries like IPA, intercostal, thyrocervical, and others that might rupture and lead to bleeding. Therefore, all these arteries should be considered during embolization and the origin should be known to perform the procedure (Gwon et al., 2007).

The current study has limitations, the main one being the small sample size. With a bigger sample size, more variations could have been observed and different prevalences might have been achieved.

For future experiments, studies with a higher sample size can be performed, which can reveal more rare variants. Moreover, the relation of IPA origin to the celiac trunk origin can be studied in the Kazakh population. Also, according to several studies, the diameter of RIPA enlarges when it gives collateral supply to HCC. That can be studied in patients with HCC to determine whether there is a threshold value that signals the existence of collateral.

Overall, the data on the Kazakh population is consistent with the existing studies done in other countries. The celiac trunk and abdominal aorta are the most common origins, however, in some cases, IPAs can arise from other arteries. Therefore, the importance of knowledge of the different origins of IPAs should not be overlooked before the surgical and radiological procedures as IPAs are important in several conditions like HCC, gastrointestinal bleeding, gastrectomy, and other conditions.

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