Original Article

DOI: 10.7860/JCDR/2021/50490.15253

A Study of Anatomical Pattern of Inferior Phrenic Artery using Multidetector CT

Radiology Section

ANIL KUMAR SINGH[1], ARCHNA GUPTA[2], ZAFAR NEYAZ[3], PRABHAKAR MISHRA[4]

ABSTRACT

Introduction: Inferior Phrenic Artery (IPA), though a small artery, is important from several points of view. Apart from being arterial supply to normal structures, it is also involved in many pathological conditions such as tumours, haemoptysis, gastroesophageal bleeding and traumatic conditions where interventional radiology or surgery play an important role in management. A preprocedure idea about variations in its anatomical pattern may help better treatment planning and minimise morbidity.

Aim: To study variations in anatomical pattern of IPA in terms of vessel of origin, vertebral level of origin and diameter of IPA using Multidetector Computed Tomography (MDCT).

Materials and Methods: The present study was a cross-sectional study conducted in Department of Radiodiagnosis, Sanjay Gandhi Postgraduate Institute of Medical Sciences, Lucknow, Uttar Pradesh, India. A retrospective analysis of CT angiography or Triple phase CT abdomen studies of 200 adult patients (M:F 119:81) performed during December 2020 to April 2021 was done to look for anatomical pattern variations in IPA. Vessel of origin and level of origin were recorded. Diameters of IPAs were also recorded and statistical analysis was done.

Results: Common Inferior Phrenic Artery (CIPA) was seen in 23% cases, with independent Right and Left Inferior Phrenic artery (RIPA and LIPA) in remaining 77%. Vessels of origin for CIPA were aorta (n=27; 58.7%), celiac trunk (n=16; 34.8%) and right Main Renal Artery (right MRA) (n=3; 6.5%); for RIPA, celiac trunk (n=69; 44.8%), aorta (n=57; 37.01%), right MRA (n=23;14.94%), Left Gastric Artery (LGA) (n=5; 3.25%), and for LIPA, celiac trunk (n=97; 63%), aorta (n=53; 34.4%), left MRA (n=2; 1.3%) and LGA (n=2; 1.3%), respectively. Level of origin from aorta for RIPA was L1>T12>T12/L1 disc>others; LIPA, T12>T12/L1>L1>others; celiac trunk, T12>L1>T12/L1 disc>others. Mean diameters of apparently normal RIPA and LIPA were 1.75 mm and 1.76 mm, respectively.

Conclusion: The most common vessels of origin for CIPA, RIPA and LIPA were abdominal aorta (58.7%), celiac trunk (44.8%) and celiac trunk (63%), respectively. The predominant vertebral levels of origin for CIPA, RIPA and LIPA arising from aorta were T12, L1, and T12 respectively, and for celiac trunk T12. The mean diameter of IPA was found to be greatest in cirrhotic group followed by chronic pancreatitis and apparently normal IPA group, but not statistically significant. These can be efficiently and readily demonstrated by CT angiography or arterial phase of multiphasic CT study.

Keywords: Abdominal aorta, Celiac trunk, CT angiography, Left gastric artery, Main renal artery, Multiphasic computed tomography

INTRODUCTION

The IPA though small branch of Abdominal Aorta (AA) or its branches, is important from several points of view. It serves as main arterial supply to diaphragm. It also gives branches to oesophagus, stomach, liver, adrenals and retroperitoneum [1]. In recent times, there has been special focus on its role as feeding artery in patients with Hepatocellular Carcinoma (HCC) and implications in management of this tumour (trans-arterial chemoembolisation, TACE) [2-5]. IPA may also supply other tumours in adjoining thoraco-abdominal regions [6,7]. It is also one of the commonly hypertrophied arteries in patients with lung diseases who present with haemoptysis, especially those with lower lobe lung diseases such as tuberculosis and bronchiectasis [8,9]. Both in cases of haemoptysis and tumours where IPA is involved, endovascular embolisation therapy is important tool in management. Its anatomy is also important from surgical point of view. Variations are noted in different aspects of anatomical pattern of IPA i.e. vessel of origin, vertebral level of origin and diameter. A beforehand knowledge of these variations facilitates the surgical explorations or interventional radiological procedures. Aslaner R et al., conducted a research on variations in the origin of IPA and their relationship to celiac axis [3]. Szewczyk B et al., described types of IPA depending on their origin pattern [10]. Many other studies have been published regarding these variations, but majority of these focus on vessel of origin for IPA [1,4,5,11-14]. Literature on vertebral level of origin and diameter of IPA is very sparse. As the scope of treatment options employing IPA as target or conduit (especially interventional radiological procedures) is increasing, a composite knowledge of all these aspects of anatomy of IPA allows better exploration of artery or endovascular intervention via it. The aim of the present study was to study variations in all these aspects of anatomical pattern of IPA using CT angiography or multiphasic CT studies done on MDCT scanner.

MATERIALS AND METHODS

The present study was a retrospective cross-sectional study which was conducted in Department of Radiodiagnosis, Sanjay Gandhi Postgraduate Institute of Medical Sciences, Lucknow, Uttar Pradesh, India, the study was conducted after obtaining Ethical Committee approval with Letter number-PGI/BE/1430/2021. The study focused at studying different origin patterns of IPA and diameter of this artery. Patient population included 200 adult patients (M: 119, F:81) in age range of 18-88 years (mean 45.88 years).

Inclusion criteria: CT angiography or Multiphasic CT abdomen studies of patients aged 18 years or more were included.

Exclusion criteria:

- Significant aortic atherosclerosis limiting visualisation ostium,
- Motion artifacts leading to suboptimal evaluation,
- For diameter evaluation, cases with IPA seen as tumour feeding vessel or ambiguity regarding this status were excluded.

Study Procedure

A retrospective analysis of 200 CT angiography/Multiphasic CT abdomen studies was done by two radiologists having total

work experience of >9 years and >15 years. Analysed cases included studies done for varying abdominal indications, between December 2020 to April 2021 and data was analysed in the month of May 2021. All these included cases were performed on a 64-slice MDCT scanner (Brilliance CT, Philips Medical Systems, Cleveland, OH) or 128 slice MDCT scanner (Ingenuity CT, Philips Medical Systems, Cleveland, OH). In all cases non ionic water soluble iodinated contrast was used, administered intravenously using pressure injector.

Arterial phase CT images were analysed in axial, coronal, sagittal and oblique reformatted planes as required using Multiplanar Reformats (MPRs) as well as Maximum Intensity Projection (MIP) viewing modes. Three dimensional (3D) volume rendered reformats (VRT images) were also made in some cases. Origin pattern and diameters of IPA were recorded. Origin was described as from AA, celiac trunk, right or left main renal artery (MRA), LGA and other if any. Level of origin was defined in terms of vertebral level (upper, mid, lower vertebral body level e.g. L1-U, L1-M, L1-L or disc level eg. T12/L1). Level of origin was described for IPA itself if it was originating directly from aorta, or for aortic branch giving off IPA. IPA take off from aorta was described as anterior/midline, Anterolateral Quadrant (ALQ), lateral, and Posterolateral Quadrant (PLQ) along aortic circumference.

Cases were categorised into three groups: 1) Where IPA was clearly non tumoural vessel, or lesion was in unrelated location, or study was normal; 2) Those with cirrhotic liver; 3) Those with chronic pancreatitis. Chronic pancreatitis subgroup was made keeping in mind chronic retroperitoneal inflammatory changes.

Diameter of RIPA and LIPA was measured in proximal 2.0 cm segment. If there was any common trunk of origin (CIPA) leading to right and left branch, it was recorded. Vessel of origin along with length and diameter of CIPA was also recorded. Accessory IPA, if any, or IPA giving off any accessory artery was documented.

STATISTICAL ANALYSIS

Statistical analysis was done for all three variables ie. vessel of origin, level of origin and diameter of IPA. Chi-square test, independent sample t-test and Fischer exact test were used. The p-value <0.05 was taken as statistically significant.

RESULTS

It was possible to visualise IPA in all cases. Of total 200 cases, in 46 cases (23%) there was CIPA which gave off RIPA and LIPA. In remaining 154 cases (77%), RIPA and LIPA were found to arise independently without CIPA. Vessels of origin for CIPA, LIPA and RIPA ie. AA, celiac trunk, MRA and LGA, are given in [Table/Fig-1]. Comparison was also done for male and female groups [Table/Fig-2].

In [Table/Fig-3], vessel of origin for IPA has been shown as per cases (n=200). In 84 cases RIPA was arising directly from aorta or via CIPA from aorta; this pattern was noted in 80 cases for LIPA. [Table/Fig-4a-d,5a,b]. For IPA arising directly from aorta, location of origin along aortic circumference is given in [Table/Fig-6]. Most common circumferential location was ALQ (52.55%), followed by anterior-midline (30.65%), lateral (14.6%), and PLQ (2.2%). For RIPA and LIPA, locations were anterior-midline to ipsilateral side. For 27 CIPAs arising directly from aorta, locations were anterior-midline (48.15%), right ALQ (18.5%), left ALQ (29.6%) and left lateral (3.7%).

For RIPA arising from celiac trunk (n=85), directly or via CIPA, pattern of origin was as a branch of CIPA (16), one of two branches (58) or single one side branch (11); whereas this pattern for LIPA (n=113) was as a branch of CIPA (16), one of two branches (58) or single one side branch (39). Overall, total 124 celiac trunks were giving off IPA (celiac trunks giving off CIPA or both RIPA and LIPA counted once, along with celiac trunks giving off only RIPA or LIPA). In four cases, celiac trunk was giving off LGA which gave off IPA (2 RIPA, 2 LIPA) [Table/Fig-5b,7a-f].

Vessel of origin	Common trunk (CIPA) (46)	Direct RIPA (154)	Direct LIPA (154)
Abdominal aorta	27 (58.7%)	57 (37.01%)	53 (34.4%)
Celiac trunk	16 (34.8%)	69* (44.80%)	97* (63.0%)
LGA	0	5 (3.25%)	2 (1.3%)
MRA	3 (6.5%)	23 (14.94%)	2 (1.3%)

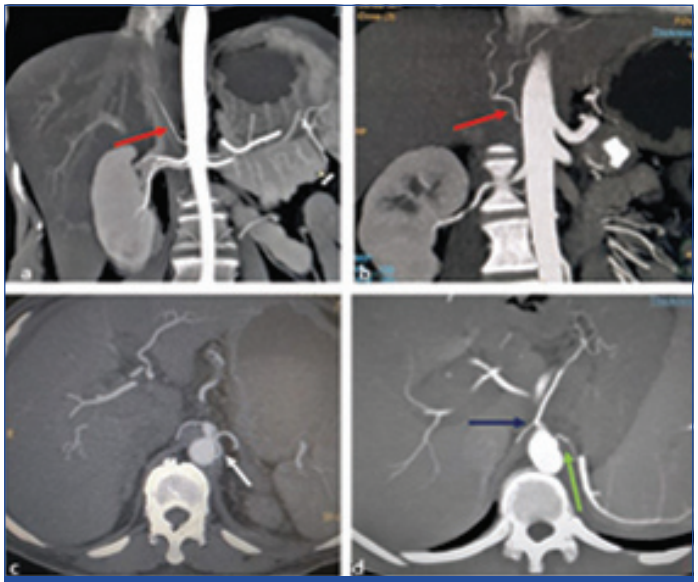
[Table/Fig-1]: Vessel of origin of inferior phrenic artery.
*Includes 58 cases where celiac trunk is giving off both RIPA and LIPA without CIPA; 11 cases only RIPA, 39 cases only LIPA. (RIPA=58+11=69; LIPA 58+39=97); LGA: Left gastric artery; MRA: Main renal artery

Vessel of origin	Common trunk (n=46)		RIPA (n=154)		LIPA (n=154)	
	Male (n=25)	Female (n=21)	Male (n=94)	Female (n=60)	Male (n=94)	Female (n=60)
Abdominal aorta	17 (68.0)	10 (47.6)	37 (39.4)	20 (33.3)	35 (37.2)	18 (19.1)
Celiac trunk	7 (28.0)	9 (42.85)	37 (39.4)	32 (53.3)	57 (60.6)	40 (42.6)
LGA	0	0	3 (3.2)	2 (3.3)	0	2 (2.1)
MRA	1 (4.0)	2 (9.5)	17 (18.1)	6 (9.9)	2 (2.1)	0
p-value	0.355		0.313		0.159	

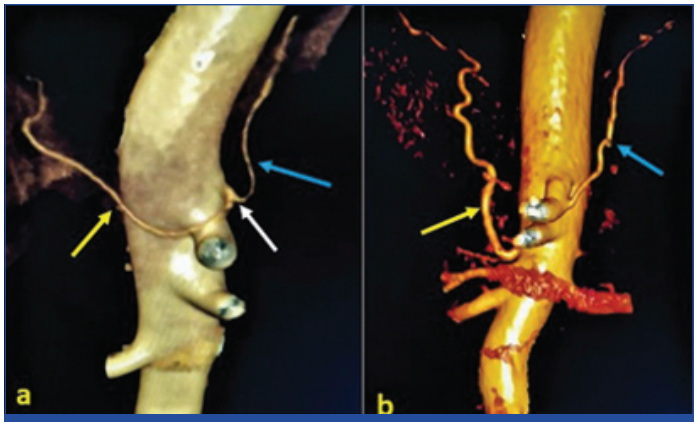
[Table/Fig-2]: Vessel of origin of inferior phrenic artery (Male vs Female).
Chi square test/Fisher exact test used, p<0.05 significant

Vessel of origin for IPA (as per cases)	n (total=200) (%)
RIPA and LIPA originating from AA	33 (16.5)
RIPA and LIPA from celiac trunk	58 (29.0)
RIPA from AA and LIPA from celiac trunk	23 (11.5)
RIPA from CA and LIPA from AA	10 (5.0)
RIPA from AA and LIPA from LGA	1 (0.5)
RIPA from LGA and LIPA from AA	4 (2.0)
RIPA from MRA and LIPA from AA	6 (3.0)
RIPA from MRA and LIPA from celiac trunk	15 (7.5)
RIPA from MRA and LIPA from MRA of corresponding side	2 (1.0)
RIPA from LGA and LIPA from celiac trunk	1 (0.5)
RIPA from CA and LIPA from LGA	1 (0.5)
CIPA from AA	27 (13.5)
CIPA from celiac trunk	16 (8.0)
CIPA from right MRA	3 (1.5)

[Table/Fig-3]: Vessel of origin for inferior phrenic artery (as per cases).
AA: Abdominal aorta; LGA: Left gastric artery; MRA: Main renal artery



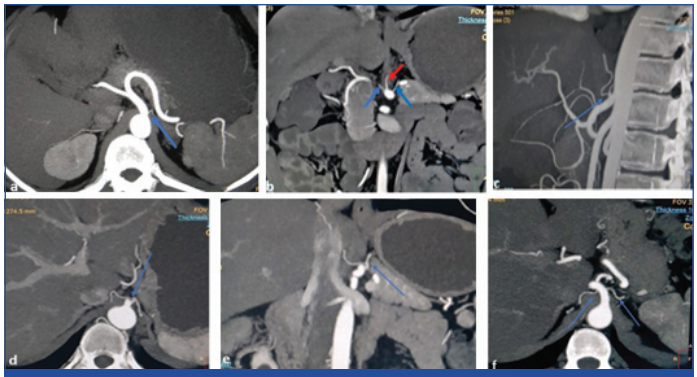
[Table/Fig-4a-d]: CT Angiography MIP images showing origin of IPA from Aorta: Oblique coronal images (a) and (b) respectively showing RIPA and CIPA arising from abdominal aorta (red arrows). CIPA is noted to divide into two branches RIPA and LIPA. Axial image (c) Showing CIPA arising from left lateral aspect of aorta (white arrow) and (d) Showing LIPA arising from aorta (green arrow) and RIPA from LGA (blue arrow).



[Table/Fig-5a-b]: CT angiography images: (a) VRT image showing CIPA (white arrow) arising from abdominal aorta and giving off RIPA (yellow arrow) and LIPA (blue arrow); (b) VRT image showing RIPA arising from abdominal aorta (yellow arrow) and LIPA from celiac trunk (blue arrow).

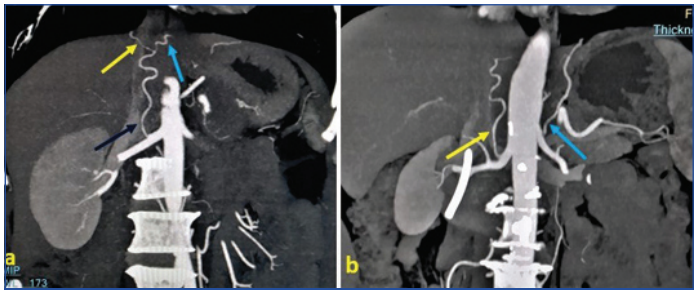
IPA vessel	Anterior/Midline	ALQ	Lateral	PLQ	Total
RIPA (direct origin)	15 (26.32%)	29 (50.87%)	11 (19.3%)	2 (3.5%)	57
LIPA (direct origin)	14 (26.42%)	30 (56.6%)	8 (15.09)	1 (1.89%)	53
CIPA	13 (48.15%)	13 (48.15%)	1 (3.7%)	0 (0%)	27
Total	42 (30.65%)	72 (52.55%)	20 (14.6%)	3 (2.2%)	137

[Table/Fig-6]: IPA origin from abdominal aorta (locations along aortic circumference). ALQ: Anterolateral quadrant; PLQ: Posterolateral quadrant



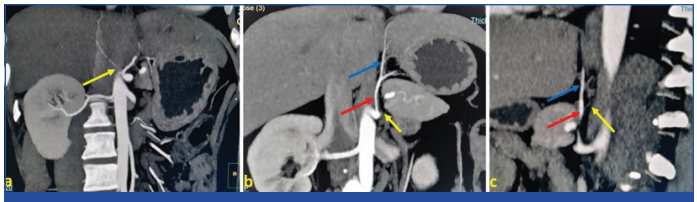
[Table/Fig-7a-f]: CT angiography MIP images showing origin of IPA from celiac trunk: (a) Axial image LIPA arising from celiac trunk (blue arrow); (b) Coronal images showing both RIPA and LIPA arising from celiac trunk (blue arrows), with LGA in middle (red arrow); (c) Sagittal image showing short CIPA arising from celiac trunk (blue arrow); (d) and (e) Axial and oblique coronal images respectively showing short trunk CIPA arising from celiac trunk (blue arrow); (f) Axial image showing RIPA and LIPA arising separately from celiac trunk (blue arrows).

In 26 cases, right MRA was giving off RIPA as single branch (23) or one of two branches via a CIPA (3). On left side, IPA was found to be one of two branches of CIPA from right MRA in three cases, and directly from left MRA in two cases [Table/Fig-8a,b]. LGA was vessel of origin for RIPA in five cases (in three LGA arising from aorta, and in two from celiac trunk) and LIPA in 2 cases (LGA arising from celiac trunk in both) [Table/Fig-9a-c].



[Table/Fig-8a-b]: CT angiography MIP images (a-b) Showing origin of IPA: Coronal image (a) Long trunk CIPA arising from right MRA (black arrow) and dividing into RIPA and LIPA (yellow and blue arrow respectively) and (b) RIPA and LIPA arising from right and left MRA respectively (yellow and blue arrow respectively).

Vertebral level of origin for IPAs arising directly from abdominal aorta and for aortic branches giving off IPAs is shown in [Table/Fig-10].



[Table/Fig-9a-c]: CT angiography MIP images: (a) Coronal image showing RIPA from LGA (yellow arrow); (b and c) Dominant anterior LIPA (blue arrow) arising from LGA (red arrow) and smaller posterior LIPA from celiac trunk (yellow arrow).

Among all cases of IPAs arising directly from aorta at T12 level, T12 sublevel was 49.06% at T12-M (mid-vertebral), 32.07% at T12-L (lower vertebral body), and 18.87% at T12-U (upper vertebral body). Similarly, for celiac trunks arising at T12 level, T12 sublevel was T12-M (44.44%), T12 -L (38.88%) & T12-U (16.68%). Diameters of IPA in different subgroups i.e. apparently normal IPA, IPA in patients with cirrhosis and chronic pancreatitis, are given in [Table/Fig-11].

In apparently normal IPA subgroup (n=157), mean diameters of RIPA and LIPA (also including RIPA and LIPA arising from CIPA) were 1.8 and 1.81 mm in males (n=90), and 1.67 and 1.8 mm in females (n=67), respectively with differences being statistically significant ($p<0.05$).

Mean diameter of apparently normal CIPA was 2.12 mm (range 1.4-2.9 mm). Differences between CIPA and RIPA, and CIPA and LIPA were statistically significant [Table/Fig-12]. In four cases with cirrhosis and four cases with chronic pancreatitis mean CIPA diameters were 2.05 mm (range 1.6-2.5 mm) and 2.13 mm (range 1.8-2.3 mm) respectively.

Of 46 cases with CIPA, mean length of CIPA was 10.15 mm (range 1.8-60 mm); 25 of these having length <5 mm.

Branching pattern of IPA which could be visualised in majority of cases was branching of RIPA into medial and lateral divisions along upper part of right diaphragmatic crus (n=188; 94%), and that of LIPA along left diaphragmatic surface into anterior and posterior branch or multiple branches (n=174; 87%) [Table/Fig-13a-e]. Smaller branches were not readily visible and a detailed analysis was not done as part of this study. In some cases, adrenal branches could be visualised. In one case, LIPA was giving off accessory splenic artery to upper pole of spleen.

In three cases, there were two LIPAs in each (anterior and posterior LIPA). Anterior and posterior LIPA were arising respectively from aorta and RIPA, LGA and celiac trunk, and celiac trunk and abdominal aorta. Dominant one with larger calibre was taken for statistical analysis. In all these cases, posterior LIPA was of smaller calibre [Table/Fig-9b,c,13c]. Among 200 cases, there were seven cases of HCC. One case with large right lobe HCC was having RIPA as feeding vessel, in addition to supply by right hepatic artery (RHA) [Table/Fig-14a,b].

DISCUSSION

Literature on anatomical pattern of IPA is sparse. Most of the literature works focus on vessel of origin of IPA, with data on vertebral level of origin and diameter of IPAs being even more sparse. Present study attempts to discuss all these three points.

Many studies have described aorta and celiac trunk as vessels commonly giving off IPAs which can arise as CIPA or independent RIPA and LIPA. Less commonly, IPAs also arise from MRA, LGA, hepatic artery and superior mesenteric artery (SMA) [1,2,3,4].

Szewczyk B et al., in their study described six types of origin of IPA. Type 1-RIPA and LIPA originating from AA. Type 2-RIPA and the LIPA from the celiac trunk. Type 3-RIPA and the LIPA from left gastric artery. Type 4-4A: LIPA from AA, and RIPA from celiac trunk; 4B: RIPA from the AA and LIPA from celiac trunk. Type 5-LIPA from AA and RIPA from the accessory hepatic artery. Type 6-RIPA and LIPA forming a common trunk which originates from the AA. [10]. In their study, type-1 was most common followed by type-2 and

Variables	T12	L1	T12/L1	T11/12	L1/2	T11	L2	p-value
IPAs directly from aorta-vertebral level of origin								
RIPA (n=57)	17 (29.83%)	23 (40.35%)	14 (24.56%)	0 (0)	3 (5.26%)	0 (0)	0 (0)	<0.001
LIPA (n=53)	24 (45.28%)	11 (20.75%)	13 (24.53%)	3 (5.66%)	0 (0)	1 (1.89%)	1 (1.89%)	<0.001
CIPA (n=27)	12 (44.44%)	6 (22.22%)	6 (22.22%)	3 (11.12)	0 (0)	0 (0)	0 (0)	<0.001
p-value	0.198	0.053	0.970	0.999	0.999	0.999	0.999	
Composite vertebral level of origin for IPAs directly arising from aorta								
CIPA+ RIPA+ LIPA (n=27+57+53=137)	53 (38.68%)	40 (29.2%)	33 (24.09%)	6 (4.38%)	3 (2.19%)	1 (0.73%)	1 (0.73%)	<0.001
Celiac trunk-composite vertebral level of origin (Aorta → Celiac trunk → CIPA or RIPA or LIPA or RIPA and LIPA both) and Aorta → Celiac trunk → LGA → IPA; Total 128 celiac trunks (16+11+39+58+4)								
Composite celiac trunks (n=128)	50 (39.06%)	38 (29.69%)	32 (25.0%)	1 (0.78)	6 (4.69%)	0	1 (0.78)	<0.001
MRA-Level of origin (Aorta → MRA → IPA)								
Right MRA (n=26)	0	14 (53.85%)	0	0	9 (34.62%)	0	3 (11.54%)	<0.001
Left MRA (n=2)	0	2 (100%)	0	0	0	0	0	<0.001
p-value	-	0.212	-	-	0.321	-	0.618	
LGA arising from aorta (n= 3/7) (Aorta → LGA → IPA)								
LGA	1 (33.3)*	0	2 (66.7)*	0	0	0	0	0.507

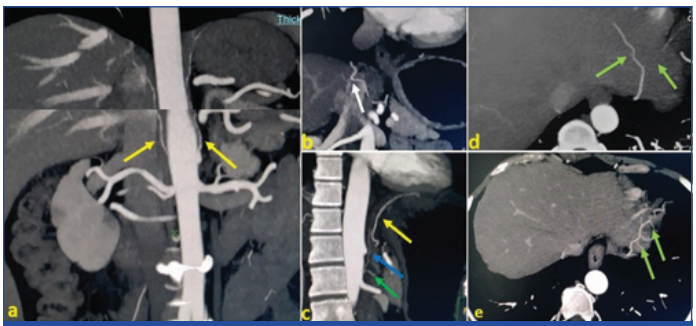
[Table/Fig-10]: Vertebral Level of Origin (for IPA from aorta, for Celiac Trunk, MRA, LGA).
*Of 7 LGAs giving off IPA, 3 were arising from abdominal aorta and 4 from celiac trunk; Fisher exact test used. p<0.05 significant

IPA	Not supplying to lesion (157)			Cirrhotic patients (n=26)			Chronic Pancreatitis (CP) (n=12)			p-value (No lesion Vs Cirrhotic)	p-value (No lesion vs CP)
	Range	Median (IQR)	Mean±SD	Range	Median (IQR)	Mean±SD	Range	Median (IQR)	Mean±SD		
RIPA	1.1-3.0	1.8 (1.5-1.9)	1.75±0.28	1.4-2.3	1.8 (1.6-2.2)	1.82±0.25	1.4-2.1	1.75 (1.53-1.88)	1.73±0.21	0.233	0.809
LIPA	1.0-2.6	1.8 (1.55-2.0)	1.76±0.31	1.4-2.2	1.8 (1.6-2.0)	1.82±0.25	1.2-2.5	1.85 (1.52-1.97)	1.77±0.35	0.350	0.915

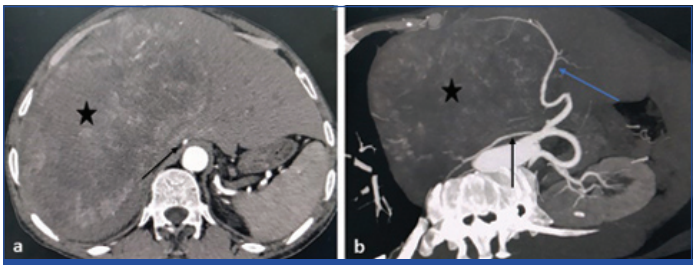
[Table/Fig-11]: Diameter of IPA (including right and left branches of CIPA) in mm.
Independent sample's t-test used, p<0.05 significant

Apparently normal (Not supplying to lesion)			
	Range	Median (IQR)	Mean±SD
RIPA (157)	1.1-3.0	1.8 (1.5-1.9)	1.75±0.28
LIPA (157)	1.0-2.6	1.8 (1.55-2.0)	1.76±0.31
CIPA (38)	1.4-2.9	2(1.9-2.4)	2.12±0.35

[Table/Fig-12]: Diameters of apparently normal RIPA, LIPA and CIPA (in mm).
RIPA vs LIPA: p=0.764, RIPA vs CIPA: p<0.001, LIPA vs CIPA: p<0.001. Independent samples t test used. p<0.05 significant



[Table/Fig-13a-e]: CT angiography images showing course and branching of IPA: (a) Coronal MIP images showing course of RIPA and LIPA along diaphragmatic crura (yellow arrows); (b) Coronal MIP image showing branching of RIPA (white arrow); (c) Oblique coronal MIP image showing anterior (yellow arrow) and posterior LIPA (blue arrow). Anterior LIPA was arising from celiac trunk and posterior LIPA from abdominal aorta. Adrenal branch from posterior LIPA was noted (dark green arrow); (d) and (e) Axial MIP images showing branching of LIPA along left hemidiaphragm (light green arrows).



[Table/Fig-14a-b]: Axial CT angiography image (a) Showing large hepatocellular carcinoma (HCC) involving right lobe of liver (star in center) with enlarged RIPA (black arrow); (b) Oblique axial MIP image showing mass (HCC) receiving arterial supply from RIPA (black arrow) and right hepatic artery (blue arrow).

other types. In present study, type 2 was seen as most common pattern followed by type 1 and others. In classification proposed by Szewczyk et al., type-3 was mentioned as IPA arising from LGA with no visualisation of celiac trunk. In present study there were cases with IPA arising from LGA but celiac trunk was visualised in all these cases. In present study, CIPA was noted in 23% cases, while they reported it in 6.24% cases (in all CIPA arising from AA, and classified as type-VI). They have also mentioned. IPA arising from MRA or CIPA arising from vessels other than AA.

In present study, IPA could be visualised in all cases. Similar results were noted in study by Kulkarni CB et al., [11]. Ito K et al., in their study on depiction of IPA on 3D contrast enhanced dynamic MRI, reported RIPA and LIPA visible in 84% and 73% of the normal subjects, respectively, with depiction of RIPA being more in cirrhotic

patients; no significant difference for depiction of LIPA in two subgroups [12].

Authors found CIPA in 23% cases and independent RIPA and LIPA in 77%. Comparable results were seen in study by Kulkarni CB et al., [11]. In article authored by Kahn PC, CIPA was reported to be in 31% cases [1]. Aslaner R et al., reported frequency of CIPA to be 29.5% [3]. In cadaveric study by Gurses IA et al., it was found to be 19.22 % [5].

In present study, for CIPA (n=46) most common vessel of origin was aorta (58.7%) followed by celiac trunk (34.78%) and MRA (6.52%). For independent RIPA and LIPA most common vessel of origin was celiac trunk (44.8%), aorta (37.01%), MRA (14.94%), LGA (3.25%) and celiac trunk (63.0%), aorta (34.4%), MRA (1.3%), LGA (1.3%) respectively. In study by, Aslaner R et al., similar pattern was noted for CIPA, RIPA and LIPA [3]. Loukas M et al., also reported comparable pattern reported for RIPA and LIPA origin [4]. In a meta-analysis by Whitley A et al, origin pattern for CIPA was similar, however RIPA and LIPA origin from aorta (49.6% and 46.8% respectively) was more frequent than origin from celiac trunk (35.7% and 46.1%) [13]. In study by Kulkarni CB et al., RIPA was found to arise most frequently from abdominal aorta (37.5%) and LIPA from celiac artery (46.3%), and for CIPA from abdominal aorta (68/128) [11]. In present study, there was no case showing origin of IPA from hepatic artery or SMA. Literature search shows many case reports with IPA originating from celiac trunk described as uncommon or rare variation. However, present study and other studies cited under discussion [3,4,11,13] show that origin of IPA from celiac trunk is not uncommon or rare.

Level of origin from aorta has been described for IPA originating from AA, and other visceral arteries arising from aorta and giving off IPA. IPA usually originates between the middle of the T12 and L2 vertebra [2]. In present study, for IPA directly arising from AA most common level of origin was T12 (38.68%) followed by L1 (29.2%), T12/L1 disc (24.09%), T11/T12 (4.38%), L1/L2 disc (2.19%), T11 (0.73%) and L2(0.73%). When analysed separately, most common level of origin for RIPA, LIPA and CIPA was L1 (40.35%), T12 (45.28%) and T12 (44.44%) respectively. In study by Kahn PC, most common vertebral level of origin for IPA was upper L1 followed by other levels: for RIPA, upper L1>lower L1=Lower T12>others; for LIPA, upper L1>lower L2>upper T12>others; for CIPA, upper L1>lower T12>upper L2>others. [1] Authors also categorised two most common vertebral level of origin of IPA from aorta i.e. T12 (n=53) and L1 (n=40) into sublevels- upper (U), mid (M) and lower (L) vertebral body levels. At T12 level, sublevels were T12-M (49.06%)>T12-L (32.07%)>T12-U (18.87%). At L1 level, sublevels were L1-U (50%)>L1-M (45%)>L1-U (5%).

Level of origin of celiac trunk from aorta was T12 (39.06%) followed by L1 (29.69%), T12/L1 disc (25.0%), L1/L2 disc (4.69%), T11/T12 (0.78%) and L2 (0.78%). Sehgal G et al., reported level of celiac trunk as junction of T12-L1 (45.8%), T12 (29.17%), L1 (22.92%) and T11-T12 (08%) [14]. Pinal-Garcia DF et al., reported it as T12 (47.9%) followed by L1 (28.6%), T12/L1 (13.6%), T11 (5.6%), T11/T12 (3.6%), and T10 (0.7%) [15].

In study by Ozkan U et al., level of origin of right MRA was L1 (43%), L2 (23%) and L1/L2 disc level (32%), while for left MRA it was L2 (38%), L1(37%) and L1/L2 (22%) [16]. In present study, for right MRA, most common level of origin was L1 followed by L1/L2 disc and L2. Two cases where LIPA was originating from left MRA, level of origin was L1.

In present study, most common circumferential location of IPA take off from AA was anterolateral quadrant (52.55%), followed by anterior-midline (30.65%), lateral (14.6%), and posterolateral quadrant (2.2%). Kahn PC in their study found RIPA coming most frequently off the right wall of the aorta, while LIPA and CIPA most frequently from the left; other less common locations being anterior and contralateral side of aortic wall [1].

Authors also measured diameters of CIPA, RIPA and LIPA. Mean diameters of apparently normal RIPA and LIPA were 1.75 mm and 1.76 mm respectively, while these diameters in cirrhotic group (n=26) were 1.82 mm and 1.82 mm and in chronic pancreatitis group (n=12) 1.73 mm and 1.77 mm. The differences were not statistically significant. In study by Ito K et al., mean diameter of RIPA in the cirrhotic patients (1.7 mm) was significantly larger than that in the normal subjects (1.3 mm), and no significant difference for LIPA between normal and cirrhotic group (1.4 mm and 1.5 mm respectively). None of normal subjects had RIPA mean diameter >3.0 mm [12]. Kahn PC reported mean diameters of RIPA and LIPA as 2.2 mm (range 1.4-3.2 mm) and 2.0 mm (range 1.4-2.8 mm), respectively [1]. In cadaveric study by Szewczyk B et al., mean diameter of LIPA and RIPA were 2.46 mm and 2.59 mm for women, compared to 2.66 mm and 2.73 mm for men; differences being not statistically significant [10]. These differences in different studies may be partly attributed to patient population being from different geographical areas (USA [1], Poland [10] as compared to this study from India) and differences in sample size. Authors found statistically significant differences in mean diameters of RIPA and LIPA in male and female groups.

The IPA as supply to HCC has been well described in literature and currently focus is more because of option of endovascular embolization therapy (TACE) [2-5]. Gwon DI et al., and Kimura S et al., published studies with large number of cases of HCC deriving supply from IPA and treated with TACE [2,17]. In study by Tanabe et al., blood supply from an IPA was noted in 11% cases of HCC [18]. In 1 of 7 cases of HCC in present study, RIPA (3.2 mm in diameter) was seen as feeding vessel (in addition to RHA) supplying large HCC almost completely replacing right lobe of liver.

In present study, there were three cases with double LIPAs (anterior and posterior LIPA with separate origins). Gurses IA et al., in their study also reported separate origin of anterior and posterior divisions of LIPA in 6 out of 26 cadavers (23.07%) [5].

Loukas M et al., in their study found accessory splenic artery as one of branches of IPA [4]. Authors found one case where LIPA was giving off accessory splenic artery to upper pole of spleen.

Limitations(s)

Main limitation of present study was regarding comparison of IPA diameter in different subgroups. A study focused on this aspect and with larger sample size will yield more information. In general, a larger sample size has potential to reveal few other uncommon or rarer variations in IPA anatomy. Analysis of interobserver variation was also not done.

CONCLUSION(S)

Anatomical pattern of IPA shows a number of variations. The most common vessels of origin for CIPA, RIPA and LIPA were abdominal aorta (58.7%), celiac trunk (44.8%) and celiac trunk (63%), respectively, in this study. The predominant vertebral levels of origin for CIPA, RIPA and LIPA arising from aorta were T12, L1, and T12 respectively, and for celiac trunk T12. The mean diameter of IPA was found to be greatest in cirrhotic group followed by chronic pancreatitis and apparently normal IPA group, but not statistically significant. These variations can be efficiently and readily demonstrated by CT angiography or arterial phase of multiphasic CT study. A beforehand composite knowledge of variations in all these three aspects of anatomical pattern of IPA would allow clinician to be better prepared while dealing with surgical explorations or radiological interventions.

REFERENCES

[1] Kahn PC. Selective angiography of the inferior phrenic arteries. Radiology. 1967;88(1):01-08.
[2] Gwon DI, Ko GY, Yoon HK, Sung KB, Lee JM, Ryu SJ, et al. Inferior phrenic artery: Anatomy, variations, pathologic conditions, and interventional management. Radiographics. 2007;27(3):687-705.
[3] Aslaner R, Pekcevik Y, Sahin H, Toka O. Variations in the origin of Inferior phrenic arteries and their relationship to celiac axis variations on CT angiography. Korean J Radiol. 2017;18(2):336-44.
[4] Loukas M, Hullett J, Wagner T. Clinical anatomy of the inferior phrenic artery. Clin Anat. 2005;18(5):357-65.
[5] Gürses İA, Gayretli Ö, Kale A, Öztürk A, Usta A, Şahinoğlu K. Inferior phrenic arteries and their branches, their anatomy and possible clinical importance: An experimental cadaver study. Balkan Med J. 2015;32(2):189-95.
[6] Zhu LZ, Yang RJ, Zhu X. Role of inferior phrenic artery in the interventional treatment of lung metastases tumor: A report of 11 cases. J Can Res Ther. 2018;14:61-67.
[7] Sakata S, Yoshida C, Saeki S, Hirosako S, Ichiyasu H, Kohrogi H. Primary diaphragmatic dedifferentiated liposarcoma in a young female patient after delivery. Case Rep Oncol Med. 2016;2016:4042719.
[8] Liu FY, Wang MQ, Fan QS, Duan F, Wang ZJ, Song P. Supplementary inferior phrenic artery embolization in the interventional treatment of hemoptysis. Chin Med J (Engl). 2009;122(5):514-20.
[9] Chung MJ, Lee JH, Lee KS, Yoon YC, Kwon OJ, Kim TS. Bronchial and nonbronchial systemic arteries in patients with hemoptysis: Depiction on MDCT angiography. AJR Am J Roentgenol. 2006;186(3):649-55.
[10] Szewczyk B, Karauda P, Olewnik Ł, Podgórski M, Waśniewska A, Haładaj R, et al. Types of inferior phrenic arteries: A new point of view based on a cadaveric study. Folia Morphol (Warsz). 2020. Doi: 10.5603/FM.a2020.0079.
[11] Kulkarni CB, Pullara SK, Prabhu NK, Pillay M, Moorthy S. Variations in the origins of inferior phrenic Arteries-An evaluation with 256 slice multidetector computed tomography. J Clin Interv Radiol. 2020;4:73-82.
[12] Ito K, Kim MJ, Mitchell DG, Honjo K. Inferior phrenic arteries: Depiction with thin-section three-dimensional contrast-enhanced dynamic MR imaging with fat suppression. J MagnReson Imaging. 2001;13(2):201-06.
[13] Whitley A, Křeček J, Kachlík D. The inferior phrenic arteries: A systematic review and meta-analysis. Ann Anat. 2021;235:151679.
[14] Sehgal G, Srivastava AK, Sharma PK, Kumar N, Singh R, Parihar A, et al. Morphometry of the celiac trunk: A multidetector computed tomographic angiographic study. Journal of Anatomical Society of India. 2013;62(1):23-27.
[15] Pinal-Garcia DF, Nuno-Guzman CM, Gonzalez-Gonzalez ME, Ibarra-Hurtado TR. The Celiac Trunk and Its Anatomical Variations: A Cadaveric Study. J Clin Med Res. 2018;10(4):321-29.
[16] Ozkan U, Oğuzkurt L, Tercan F, Kizilkiliç O, Koç Z, Koca N. Renal artery origins and variations: Angiographic evaluation of 855 consecutive patients. Diagn Interv Radiol. 2006;12(4):183-86.
[17] Kimura S, Okazaki M, Higashihara H, Nozaki Y, Haruno M, Urakawa H, et al. Analysis of the origin of the right inferior phrenic artery in 178 patients with hepatocellular carcinoma treated by chemoembolization via the right inferior phrenic artery. Acta Radiol. 2007;48(7):728-33.
[18] Tanabe N, Iwasaki T, Chida N, Suzuki S, Akahane T, Kobayashi N, et al. Hepatocellular carcinomas supplied by inferior phrenic arteries. Acta Radiologica. 1998;39(4):443-46.

PARTICULARS OF CONTRIBUTORS:
1. Assistant Professor, Department of Radiodiagnosis, Sanjay Gandhi Postgraduate Institute of Medical Sciences, Lucknow, Uttar Pradesh, India.
2. Professor, Department of Radiodiagnosis, Sanjay Gandhi Postgraduate Institute of Medical Sciences, Lucknow, Uttar Pradesh, India.
3. Professor, Department of Radiodiagnosis, Sanjay Gandhi Postgraduate Institute of Medical Sciences, Lucknow, Uttar Pradesh, India.
4. Associate Professor, Department of Biostatistics and Health Informatics, Sanjay Gandhi Postgraduate Institute of Medical Sciences, Lucknow, Uttar Pradesh, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. Anil Kumar Singh,
Assistant Professor, Department of Radiodiagnosis, Sanjay Gandhi Postgraduate Institute of Medical Sciences, Raebareli Road,
Lucknow-226014, Uttar Pradesh, India.
E-mail: singh.anil.kr01@gmail.com

PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: May 25, 2021
- Manual Googling: Jun 19, 2021
- iThenticate Software: Jun 22, 2021 (5%)

ETYMOLOGY: Author Origin

AUTHOR DECLARATION:
- Financial or Other Competing Interests: None
- Was Ethics Committee Approval obtained for this study? Yes
- Was informed consent obtained from the subjects involved in the study? NA
- For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: **May 23, 2021**
Date of Peer Review: **Jun 17, 2021**
Date of Acceptance: **Jun 29, 2021**
Date of Publishing: **Aug 01, 2021**