



CELIAC ARTERY VARIATIONS ON CT ANGIOGRAPHY: VALIDATION OF THE ETHIRAJ EMBRYOLOGY-BASED CLASSIFICATION WITH EXPANSION OF TYPE II & IV SUBCATEGORIES

¹Dr Sindhu Rashmi .G.A, ²Dr. Geetha M.J*, ³Dr Rajesh R

¹Junior Resident, Department of Radiology Mandya Institute of Medical Sciences, Mandya, Karnataka 571401 Email: rashmisindhu21@gmail.com,

²Associate Professor, Department of Radiology Mandya Institute of Medical Sciences, Mandya, Karnataka 571401 Email: gitadesh2006@gmail.com,

³Professor and HOD Department of Radiology Mandya Institute of Medical Sciences, Mandya, Karnataka 571401 Email: rajeshiyer81@gmail.com

*Corresponding Mail: gitadesh2006@gmail.com

Abstract

Background: The primordial ventral splanchnic arteries' embryological remodelling causes the coeliac trunk (CT) to exhibit significant morphological diversity. For transplantation, hepatopancreatobiliary surgery, and interventional radiology, accurate identification of these differences is critical.

Material and Method: The CT angiography of 1008 patients was examined in this retrospective single-centre investigation using 3D volume-rendered imaging, maximum intensity projection, and multiplanar reformations. The Ethiraj approach was used to evaluate and categorise the origin and branching pattern of the inferior phrenic artery (IPA), superior mesenteric artery (SMA), and CT. Variants that were recently discovered were classified using embryological interpretation.

Result: Classical Type 1 trifurcation occurred in 46.4% of cases. The most common atypical pattern was Type VI celiophrenic variations (37.9%), of which Type VI(c) (CT +left IPA) was the most common (17.5%). Type IV variations were present in 11.3% of the samples, the most common of which was Type IV(c) right hepatomesenteric trunk (9.0%). The type II variations were detected in 3.76% and mostly in the hepatosplenic trunk. There were two other rare types: hepatosplenic trunk (Type II (d), 0.4%) and splenomesenteric trunk (Type IV (h), 0.3%).

Conclusion: Coeliac trunk anatomy is extremely varied. The classification by Ethiraj is simple, comprehensive, and useful, and the inclusion of Type II(d) and IV(h) improves the accuracy of classification, which aids in performing accurate preoperative vascular mapping and surgical planning.

Keywords: Celiac trunk, celiophrenic trunk, hepatomesenteric trunk, Tomography angiography (CTA), inferior phrenic artery

1. Introduction:

The coeliac trunk (CT), also known as the coeliac artery, is the abdominal aorta's first unpaired major ventral branch, which normally arises near the T12-L1 vertebrae [1]. It provides the primary

artery supply to foregut-derived abdominal organs such as the lower esophagus, stomach, liver, spleen, pancreas, proximal duodenum, and bile system [2]. Traditionally, the coeliac trunk is divided into three principal branches: the left gastric artery (LGA), common hepatic artery (CHA), and splenic artery (SA), establishing the well-known "tripus Halleri" or normal trifurcation pattern [3]. Rao et al., (2024) reported that it is an uncommon variant of multiple cystic arteries, including an auxiliary branch from the SMA that was previously unknown. Such anatomy raises the possibility of arterial damage during hepatobiliary and cholecystectomy procedures, highlighting the significance of preoperative imaging and anatomical knowledge for better surgical planning [4]. Despite this canonical definition, anatomical studies repeatedly show that coeliac trunk branching patterns vary greatly, with multiple variances including the superior mesenteric artery (SMA), inferior phrenic arteries (IPA), and hepatic arterial branches [5].

1.1. Embryological basis of celiac artery variation

Coeliac trunk anatomy varies depending on embryological development. During fetal life, the ventral splanchnic arteries develop from several primitive ventral segmental roots linked by longitudinal ventral anastomoses [6]. The final artery shape is determined by whether these roots and anastomotic channels remain or regress selectively. Atypical embryological channels cause variations such as hepatosplenic trunks, celiomesenteric trunks, missing coeliac trunks, and celiophrenic trunks [7]. Understanding this developmental base is critical since it explains not just frequent variations, but also uncommon and previously unknown vascular patterns.

The most reliable noninvasive imaging technique for assessing the vascular architecture of the abdomen is multidetector computed tomography angiography (CTA) [8]. CTA can accurately represent arterial origins, branching patterns, and uncommon vascular variants thanks to its high spatial resolution, multiplanar reformations (MPR), maximum intensity projection (MIP), and three-dimensional volume rendering (3D VR) [9]. This has greatly improved the capacity to verify categorization schemes, find variants that were previously unknown, and offer accurate vascular roadmaps for preoperative planning [10]. Similar to the study by Cappabianca et al., (2012) reported that carotid artery branch anomalies occurred in 53.3% of patients, demonstrating that CTA was superior to MRA in identifying these differences. The results show that the best preoperative imaging technique for detecting ECA branching abnormalities before head and neck surgeries is CTA [11].

1.2. Role of CT angiography in the evaluation of celiac trunk variation

Multidetector computed tomography angiography (MDCTA) is presently regarded as the preferred imaging technique for assessing abdominal vascular architecture [12]. The integration of multiplanar reformations (MPR), maximum intensity projection (MIP), and three-dimensional volume-rendered (3D VR) reconstruction facilitate precise visualization of arterial origins and branching configurations [13].

CT angiography can help to accurately map the blood vessels preoperatively, detect rare variations in the arteries, and improve surgical planning. It is also crucial for evaluating anatomical classification systems and minimising operational problems linked to unforeseen vascular anatomy [14].

CT angiography plays a vital role in the planning of transarterial chemoembolization (TACE), selective embolization, angioplasty, and catheter-based procedures in interventional radiology. [15] Inferior phrenic arteries are frequently additional collaterals in hepatocellular carcinoma, particularly in subscapular tumours [16]. Therefore, the identification of celiac trunk variations by CTA is essential for successful embolisation of the tumour and prevention of the presence of residual tumour vascularity [17]. Furthermore, CTA can help to determine the optimal catheterisation path, reduce procedure duration, and minimise contrast-related complications [18].

1.3. Aim

To evaluate celiac trunk branching variations on CT angiography using the embryology-based Ethiraj classification and identify additional variant subtypes.

1.4. Objective:

- To evaluate the branching patterns of the celiac trunk using CT angiography
- To classify celiac trunk variations according to the embryology-based Ethiraj classification
- To identify additional variant subtypes and correlate them with their embryological basis

2. Materials and methods:

2.1. Study design and setting:

This retrospective, single-centre observational study was performed in the Department of Radio Diagnosis at a tertiary care institution over a duration of 12 months. Approval of the study was granted by the Institutional Ethics Committee, and the necessity for informed consent was waived owing to the retrospective nature of the research. Imaging data were obtained from the departmental Picture Archiving and Communication System (PACS).

2.2. Study population:

Patients who consecutively received CT angiography (CTA) of the abdomen for diverse clinical causes over the study period were incorporated into the study.

➤ Inclusion criteria

- Patients who underwent abdominal CT angiography during the study period
- Adequate arterial phase imaging available for evaluation

➤ Exclusion criteria

- Studies with significant motion artefacts
- Suboptimal arterial contrast opacification
- Presence of major acquired vascular pathology distorting normal arterial anatomy.

2.3. CT angiography protocol

All assessments were conducted on a 168-slice multidetector CT scanner (United Imaging). Non-ionic iodinated contrast agent (100–120 mL) was supplied intravenously via an antecubital vein with a power injector at a flow rate of 3–3.5 mL/s.

CT angiography was conducted in accordance with standardized departmental practice. The arterial-phase acquisition was conducted with bolus tracking, with the region of interest (ROI) positioned in the abdominal aorta. Image capture commenced roughly 3 seconds after attaining the specified attenuation threshold.

➤ Scanning was performed in the craniocaudal direction using the following parameters

- Detector configuration: 168×0.6
- Tube voltage: 120 kVp
- Tube current: 200 – 250 mAs
- Pitch: 0.8-1.0

2.4. Image reconstruction and post-processing

Post-processing of the image was carried out on a dedicated workstation. The following reconstruction techniques were utilized:

- Multiplane reformations (MPR)
- Maximum intensity projections (MIP)
- Three- dimensional volume – rendered (3D VR) reconstruction.

2.5. Image analysis

The origin and branching configurations of the coeliac trunk were assessed, including the evaluation of the:

- Left gastric artery
- Splenic artery
- Common hepatic artery
- Superior mesenteric artery
- Inferior phrenic arteries

The vascular anatomy was classified according to the embryology-based CTA categorization established by Ethiraj. An initial evaluation was conducted on axial pictures at the coeliac trunk origin, subsequently verified using MIP and volume-rendered images.

Supplementary subcategories under Type II and Type IV were designated whenever the observed branching patterns could not be integrated into the existing subtypes of the categorization system.

2.6. Statistical analysis

The frequency and percentage distribution of various coeliac trunk branching patterns were computed and analysed descriptively. Data were organised and displayed using suitable charts and tables as required.

3. Results:

3.1. Distribution of celiac trunk branching patterns

The embryology-based classification suggested by Ethiraj et al. was used to assess the coeliac trunk branching architecture of 1008 consecutive individuals who had abdominal CT angiography.

The most prevalent coeliac trunk architecture, with trifurcation into the left gastric, common hepatic and splenic arteries, was reported in 468 cases (46.4%). The remaining 540 individuals (53.6%) had variable branching anatomy, indicating significant anatomical heterogeneity within the study population.

Type VI variants with inferior phrenic artery origin from the coeliac trunk were the most common, accounting for 37.9% of all cases. Type IV variants involving the superior mesenteric artery were the second most common, accounting for 11.3% of all cases, whereas Type II variants involving foregut arterial rearrangements without superior mesenteric artery involvement accounted for 3.76%. Type III configuration, defined by the absence of a genuine coeliac trunk, was unusual, occurring in only 0.5% of patients. The current analysis found no Type V (celio-colic trunk) variations.

The overall distribution of celiac trunk branching patterns according to the embryology-based Ethiraj classification is summarized in Table 1.

Table 1: Frequency of celiac trunk variations based on the new embryological classification by Ethiraj et al., [19] in correlation with computed tomography angiography

Sr no.	Type	CT Branching Pattern	Num ber (n)	Percentage (%)	Incidence in main types
1.	I	Normal trifurcation	468	46.4	46.4
2.	IIA	Hepatosplenic trunk	27	2.7	3.76
3.	IIB	Hepato-gastric	3	0.3	
4.	IIC	Gastrosplenic	4	0.4	
5.	IID	Hepatosplenic with aberrant left gastric artery	4	0.4	
6.	III	No celiac trunk	5	0.5	0.49
7.	IVA	Celiac-mesenteric trunk	7	0.7	11.3
8.	IVB	Hepatomesenteric trunk	12	1.2	
9.	IVC	Right hepatomesenteric trunk	91	9.0	

10.	IVD	Gastro-mesenteric trunk	0	0	
11.	IVE	Splenomesenteric trunk	0	0	
12.	IVF	Hepatospleno-mesenteric trunk	1	0.1	
13.	IVG	Gastrospleno-mesenteric trunk	0	0	
14.	IVH	Splenomesenteric-hepatogastric trunk	3	0.3	
15.	V	Celio-colic trunk	0	0	0
16.	VIA	Celiophrenic trunk (CT + CIPA)	62	6.2	37.9
17.	VIB	Celiophrenic trunk (CT+RIPA)	64	6.3	
18.	VIC	Celiophrenic trunk (CT+LIPA)	176	17.5	
19.	VID	Celiophrenic trunk (CT+RIPA+LIPA)	81	8.0	

Interpretation: In the present study, define that incidence of coeliac trunk branching configurations in 1008 cases is shown in Table 1. The most common was type I classical trifurcation (46.4%). The type VI celiophrenic trunk variations were the most common (37.9%), with Type IV (11.3%) and Type II (3.76%) variants also being observed. Type III configuration was rare (0.5%), and not one Type V was found. The novel Type IID and Type IVH variants were also found among the study group.

3.2. Type 1 configuration (classical trifurcation pattern)

A Type I configuration, typical of the standard trifurcation pattern, was found in 468 cases (46.4%). The coeliac trunk is divided into the left gastric, common hepatic and splenic arteries in this arrangement, which conforms to the classic “Tripus Halleri” pattern.

Although it is considered normal vascular anatomy, it is important to identify precisely during hepatopancreatobiliary surgery, liver transplantation, and interventional radiological procedures, particularly for maintaining hepatic arterial inflow during gastroduodenal artery ligation. Given in (Figure 1a type I).

TYPE –I



Fig 1a: Type 1

3.3. Type II variants: foregut rearrangement without SMA involvement

There were 38 cases of type II variations (3.76%). The differences included abnormal branching patterns of the foregut arteries, but not the superior mesenteric artery.

The hepatosplenic type (Type IIA) was the most common subtype of this group, being found in 27 patients (2.7%). The common hepatic artery and the splenic artery were seen coming from a single trunk, and the left gastric artery was seen to be coming from its origin.

Three patients (0.3%) had Type IIB – hepatogastric trunk, and four patients (0.4%) had Type IIC – gastrosplenic trunk.

A new, previously uncharacterized mutant type called Type II D was found in 4 patients (0.4%). In this design, the hepatosplenic trunk was connected with an aberrant left gastric artery originating from the splenic artery. The other configuration was not included in the already defined subtypes of the Ethiraj classification and was thus suggested as a new, embryologically coherent classification. Given in (Figure 1b type II) (Figure 1c Type IIB) (Figure 1d type IIC) (Figure 1e Type IID).

TYPE - II

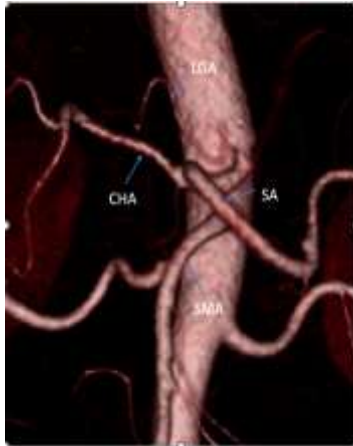


Fig 1b: Type IIA



Fig 1c: Type IIB



Fig 1d: Type IIC

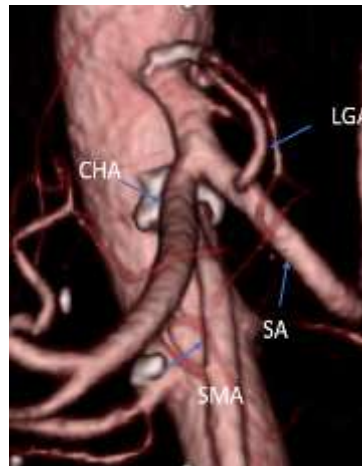


Fig 1e: Type IID

3.4. Type III variant: absence of celiac trunk

In 5 cases (0.5%), the coeliac trunk was completely absent (configuration III). In these instances, the left gastric artery, the common hepatic artery, and the splenic artery came off the abdominal aorta individually and without a common arterial trunk. This pattern is a sign of a lack of embryonic persistence of the primordial ventral anastomotic channel. Given in Figure 1f type III).

TYPE -III

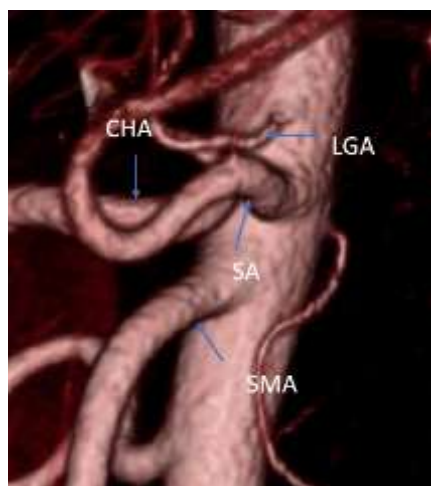


Fig 1f: Type III

3.5. Type IV variants: variants associated with the superior mesenteric

Type IV variants were identified in 114 patients (11.3%) and were the second most common variant group after Type VI patterns.

The most common variant was the right hepatomesenteric trunk (Type IVC), seen in 91 patients (9.0%). The right hepatic artery was from a common trunk with the superior mesenteric artery.

The hepatomesenteric trunk (Type IVB) was observed in 12 patients (1.2%), while the celiomesenteric trunk (Type IVA) was found in 7 patients (0.7%).

One case was observed (0.1%) with a hepatosplenomesenteric trunk (Type IVF). No cases of gastromesenteric trunk (Type IVD), splenomesenteric trunk (Type IVE) or gastrosplenomesenteric trunk (Type IVG) were found in the present study group.

In 3 cases (0.3%), a new variant (Type IVH) was recognised. In this, it possessed a splenomesenteric trunk and a clearly defined hepatogastric trunk. The embryological consistency of the primitive ventral segmental arteries' persistence/ regression pattern seen in the observed configuration made it an additional subtype in the classification system. Given in (Figure 1g Type IVA), (Figure 1h Type IVB), (Figure 1i Type IVF), and (Figure 1j IVH).

Type IV

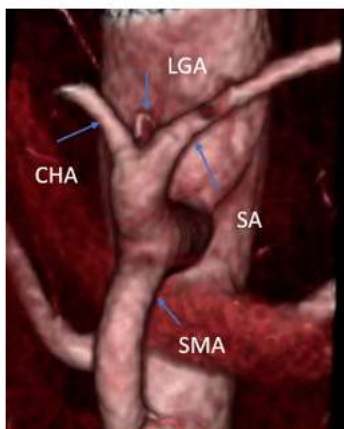


Fig 1g: Type IVA

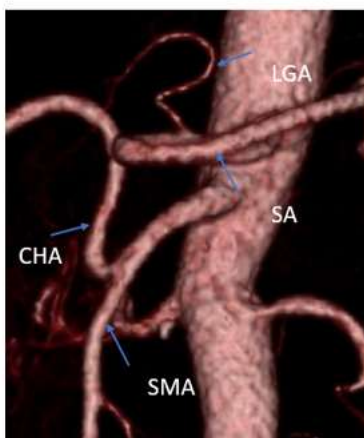


Fig 1h: Type IVB

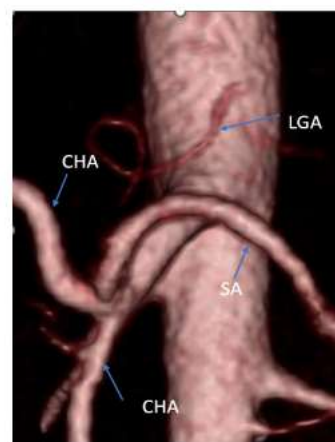


Fig 1i: Type IVF

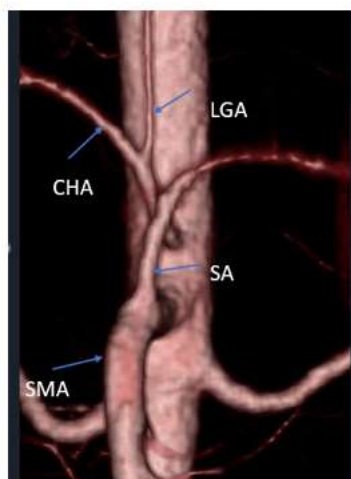


Fig 1j: Type IVH

3.6. Type VI variants: Celiophrenic trunk variants

The inferior phrenic arteries arising from the coeliac trunk were the most common variant type (type VI) in 383 cases (37.9%).

The left inferior phrenic artery arising from the coeliac trunk (Type VIC) was the most common single variant type (176 cases, 17.5%).

The VID configuration (both right and left inferior phrenic arteries are derived from the coeliac trunk) occurred in 81 cases (8.0%). The percentages of Type VIB and Type VIA variations were found to be 6.3% and 6.2%, respectively, in the 64 and 62 patients.

The results showed that phrenic artery changes were found in a high percentage of the study group and emphasized the importance of careful preoperative evaluation of the vascular structures by CT angiography.

3.7. Newly identified variant subtypes

In the present study, there were two additional vascular patterns that were not observed in the original Embryology-based classification. The first type (Type IID) consisted of a hepatosplenic trunk with an abnormal left stomach artery from the splenic artery. The second form, called Type IVH, involved the splenomesenteric trunk connected to a separate hepatogastric trunk.

Both newly identified configurations correlated embryologically on the basis of the persistence or regression of the ventral segmental roots and longitudinal ventral anastomoses. The embryological basis of these newly identified variants is summarized in Table 2. Given in (Figure 2a: Type IId and 2b: Type 4h)

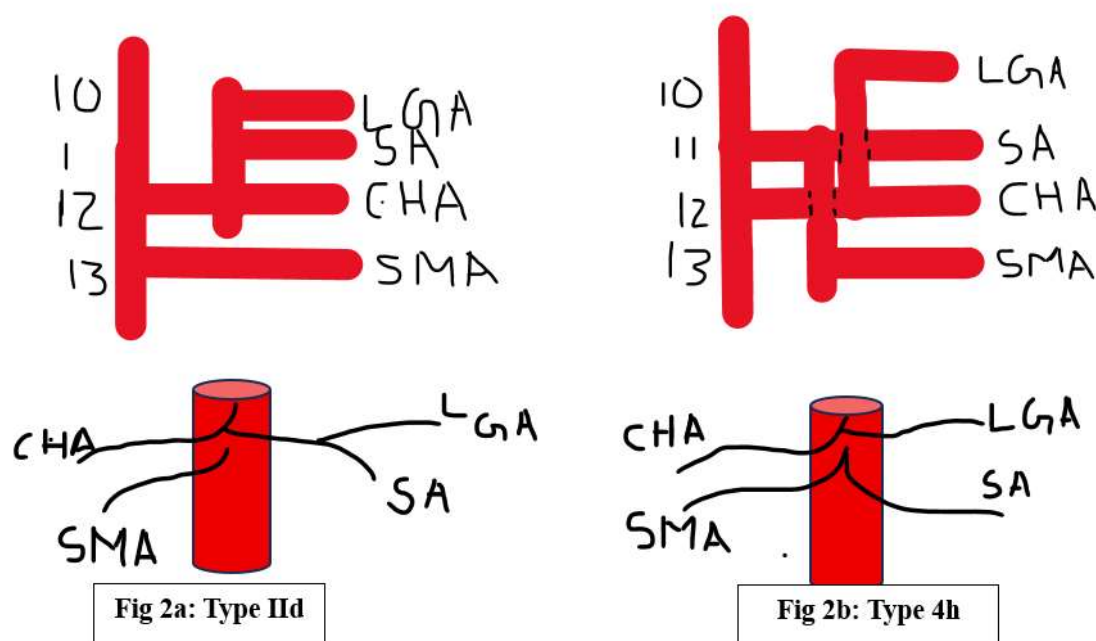
Table 2: Embryological basis of the new variants

Types	CT branching pattern	Embryological basis
II(d)	Hepatosplenic trunk with left gastric artery arising from splenic artery	Persistence of 10 th , 11 th , and 13 th ventral segmental roots with regression of the primitive aortic origin of the left gastric artery and persistence of ventral anastomosis between the 10 th and 11 th roots, resulting in secondary origin of the left gastric artery from the splenic artery
IV(h)	Splenomesenteric trunk with separate hepatogastric trunk	Regression of horizontal segment between 10 th and 11 th roots with persistence of ventral anastomosis between the 11 th and 13 th roots forming the splenomesenteric trunk, along with independent persistence and fusion of the 10 th and 12 th roots

forming the hepatogastric trunk

Interpretation:

Table 2 defines the embryological foundation of the recently recognized Type II(d) and Type IV(h) coeliac trunk variations. The Type II(d) variant arises from the retention of the 10th, 11th, and 13th ventral segmental roots, accompanied by the regression of the primitive aortic origin of the left gastric artery, resulting in its secondary origin from the splenic artery. The Type IV(h) variety arises from the regression of the ventral anastomosis between the 10th and 11th roots, while the 11th–13th connection persists, resulting in the formation of the splenomesenteric trunk, alongside the continued presence of the 10th and 12th roots, which create a distinct hepatogastric trunk. The findings substantiate the embryological validity of the suggested supplementary subtypes within the Ethiraj categorisation scheme.



4. Discussion

The study does confirm that there is a fair amount of anatomical variation in the structure of the coeliac trunk, with more than expected incidences of atypical branching. The traditional type I trifurcation was the most common architecture (46.4%), but there were also patients with other architectures. A total of 1050 people were evaluated for coeliac trunk architecture and alterations during liver and renal donor workup. Ethiraj et al., (2022) reported. 39% of patients demonstrated normal trifurcation, the commonest of which was the presence of CA + left inferior phrenic artery. To provide a more detailed anatomical classification of the arteries not covered by previous systems, a new classification was formulated by the authors, based on the embryology of the arteries, into six main types and subtypes according to the patterns of branching of the inferior phrenic artery, superior mesenteric artery and coeliac artery [19].

According to the study, longitudinal anastomoses and the expected embryological persistence of primitive ventral roots are the causes of recently discovered Type IID and Type IVH variants. Persistence between the 10th and 11th roots gives rise to Type IID, whereas persistence between the 11th and 13th roots with a distinct hepatogastric trunk gives rise to Type IVH. These results lend credence to a classification based on embryology that provides a better explanation for uncommon variations in coeliac trunks. Triantafyllou et al., (2025) reported that two uncommon examples (0.4%) of arterial rings at the vertebrobasilar junction were found in this retrospective CTA

investigation of 505 individuals. These cases most likely indicate persisting primitive lateral vertebral anastomosis (PLBVA) rather than actual fenestrations. Multiplanar and 3D imaging were used to anatomically characterize these embryological vascular remains, and no basilar artery or vertebral asymmetry was seen [20].

The study corroborates the rare Type II (d) variant in which the CHA and the SA are the hepatosplenic trunk, and the LGA is abnormally formed from the splenic artery, whereas the SMA emerges separately. This lends credence to the embryology-based designation of a separate developmental coeliac trunk variant. Uraoka et al., (2024) discovered that this retrospective CT analysis of 759 hepatobiliary-pancreatic surgical patients discovered aberrant right hepatic arteries (aRHA) in 21.4% of the cases, revealing five structural types. RHA from SMA was the most common (12.7%), followed by CHA from SMA (3.5%). In Types 1-3, the middle hepatic artery (MHA) did not originate from aRHAs; in Type 4, the MHA may originate from either the RHA or LHA. The results highlight the importance of preoperative vascular mapping to prevent the possible ischaemic effect on the liver, following a pancreatoduodenectomy [21].

5. Conclusion

This study found that the coeliac trunk morphology is quite variable: the typical trifurcation pattern was seen in less than half of the patients (46.4%), and alternate configurations were seen more often. The embryology-based classification developed by Ethiraj et al. was found to be a useful and complete system for the systematic classification of coeliac trunk branching patterns, especially the celiophrenic variants (Type VI) and celiophrenic variants associated with the mesenteries (Type IV). The identification of new Type II(d) and Type IV(h) subtypes extends categorisation and indicates that uncommon vascular patterns can be accounted for by predictable embryological persistence and regression of primitive ventral segmental roots and longitudinal anastomoses. The results emphasize the importance of the extensive preoperative computed tomography angiography evaluation for proper vascular mapping, reduced surgical and interventional risks, and better planning in hepatopancreatobiliary, transplant, and endovascular surgery.

This expanded classification not only aids in understanding the processes of vascular morphogenesis but also enhances the precision in the diagnosis for orthopaedic surgeons and radiologists in cases of anomalous arterial anatomy.

Limitation:

There are several limitations to the study. First, there may be selection bias due to the retrospective single-centre design, which may not be generalizable to larger populations. Second, the number of patients was small and only included those undergoing hepatobiliary-pancreatic surgery, which may not represent the entire population of the general population about vascular anatomy. Third, although contrast-enhanced computed tomography, combined with 3D reconstruction, is extremely useful, it can fail to identify very small artery branches, or if compared to intra-operative or cadaver confirmation, it may only show slight variations. Fourth, the study evaluated morphological patterns rather than compared variants with respect to surgical outcomes or complication rates, and so the real therapeutic effect of any given variant is not known. Finally, embryological interpretations were not empirical, but rather inferential, with a lack of definite conclusions on developmental pathways.

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