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The Celiac Trunk: Anatomical Variants and Malformations – A Narrative Review

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Rezumat

Trunchiul celiac: variante anatomice și malformații – o recenzie narativă

Trunchiul celiac (TC), prima ramură ventrală majoră a aortei abdominale, reprezintă un reper anatomic esențial, responsabil pentru vascularizația organelor derivate din porțiunea anterioară a intestinul primitiv, precum stomacul, ficatul, splina, pancreasul şi duodenul proximal. Deşi configurația clasică de trifurcație – Tripus Halleri – este întâlnită în majoritatea cazurilor, literatura de specialitate relevă o diversitate impresionantă de variații anatomice, ce depăşeşte cu mult această imagine standardizată. Aceast articol aduce în prim-plan perspective istorice şi contemporane asupra dezvoltării embriologice, morfologiei şi clasificărilor trunchiului celiac, analizând contribuțiile fundamentale ale unor autori precum Haller, Lipshutz, Michels şi Panagouli. Variabilitățile descrise, precum bifurcația, tetrafurcația sau chiar heptafurcația TC, nu sunt simple curiozități anatomice, ci factori cu impact direct în practica clinică – influențând deciziile chirurgicale, interpretările imagistice şi prognosticul în transplantul hepatic. Totodată, datele actuale sugerează că astfel de anomalii pot fi influențate de factori genetici şi etnici, în absența unei diferențieri semnificative între sexe. Prin analiza integrativă a literaturii de specialitate care cuprinde peste patru decenii de studii cadaverice, radiologice şi clinice, această lucrare îşi propune să ofere o perspectivă amplă şi actualizată asupra complexității anatomice a trunchiului celiac, subliniind importanța cunoaşterii detaliate a acestui subiect în medicina modernă.

Cuvinte cheie: trunchi celiac, variații anatomice, malformații, reper anatomic

Abstract

The celiac trunk (CT), as the first major ventral branch of the abdominal aorta, plays a critical role in the vascularization of foregut-derived organs, including the stomach, liver, spleen, pancreas, and proximal duodenum. While the

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classic trifurcation pattern, known as Tripus Halleri, is observed in the majority of individuals, numerous studies have highlighted a remarkable degree of anatomical variability in its branching pattern, origin, and structural characteristics. This narrative review explores the embryological foundations, physiological anatomy, and clinical implications of CT variations, drawing upon historical and contemporary classifications - from Haller's descriptive observations to the structured systems proposed by Lipshutz, Michels, and Panagouli. Notably, deviations such as bifurcation, tetrafurcation, and even heptafurcation of the CT have been documented, with implications ranging from surgical risk in hepatobiliary procedures to complications in liver transplantation. The variability in CT morphology, influenced by developmental, genetic, and potentially ethnic factors, underscores the need for thorough anatomical knowledge in radiological diagnostics and surgical planning. By synthesizing findings from over four decades of cadaveric, radiological, and clinical studies, this review aims to provide a comprehensive understanding of CT anomalies and their relevance in modern clinical practice.

Keywords: celiac trunk, anatomic variants, malformations, anatomical landmark

Introduction

The Celiac Trunk (CT), also referred to as the Celiac Artery, represents the first ventral branch of the Abdominal Aorta (AA) and holds significant surgical and anatomical relevance as a major splanchnic artery (1). Arising at the T12-L1 vertebral level, just inferior to the aortic hiatus, it measures approximately 1.5 to 2 cm in length. Its primary function is the vascularization of the foregut-derived structures, such as the spleen, stomach, pancreas, liver, gallbladder and proximal duodenum (2). The term "Tripus Halleri" designates the classic trifurcation pattern of the CT, which is observed in about 89% of the individuals, regardless of their gender. This nomenclature was first introduced in 1756 by the Swiss anatomist and physiologist Albrecht von Haller, whose contributions to vascular anatomy remain foundational to modern anatomical sciences (3,4).

Over time, observations by various anatomists and clinicians have revealed that the canonical branching pattern of the celiac trunk is far less consistent than initially presumed. Numerous anatomical variants in the origin and configuration of its branches have been documented, making the development of new classification systems not only inevitable but necessary. These classification systems often exhibit subtle differences in their typologies, which are influenced by both the methodology employed by the investigating medical teams and the characteristics of the patient populations studied (2).

Given the critical territories supplied by the celiac trunk - including organs essential to digestion, metabolism, and immune function - precise knowledge of its course and that of its branches is of paramount importance, particularly within surgical disciplines. Such anatomical insight is indispensable for minimizing intraoperative risks and optimizing clinical outcomes (3,4).

Embryology

In utero, the AA originates from the fusion of the paired dorsal aortae. During the early fourth week of embryonic development, the yolk sac receives nourishment via a network of paired vitelline arteries. These vessels progressively undergo fusion, ultimately contributing to the formation of the arterial system within the dorsal mesentery of the gut (5). Additionally, the paired ventral segmental arteries subsequently coalesce to form the median vessels. These vessels ultimately give rise to the 3 main arteries responsible of supplying the abdominal viscera: The Inferior Mesenteric Artery (IMA), The Superior Mesenteric Artery (SMA) and the Celiac Trunk (6).

By the 4^{th} week of embryogenesis, the gastrointestinal tract is structured into three distinct regions, each spanning a specific segment: A. The foregut- from the esophagus to the proximal 1/3 of the duodenum, just beyond the ampulla of Vater; B. The midgut- from the distal 2/3 of the duodenum to the proximal 2/3 of the transverse colon, ending at the Splenic Flexure (SF); C. The hindgut- begins at the SF and extends to the rectum. Notably, each one of these embryonic divisions possesses a unique vascular supply, originating from the AA, ensuring the specialized perfusion required for their functions (6).

Physiological Anatomy of the Celiac Trunk

Origin and Trajectory

The celiac trunk emerges from the anterior surface of the abdominal aorta at the level of the T12-L1 intervertebral disc, just inferior to the aortic hiatus. Its anatomical position remains, in most of the cases, consistent, typically being located deeper to the lesser omentum and more posterior to the parietal peritoneum. Despite its relatively compact form - measuring between 1.25 cm and 2.8 cm - the celiac trunk holds critical surgical and diagnostic significance. Advanced imaging studies, report a mean length of 28.11 mm using computed tomography. Morphologically, the trunk follows a brief anteroinferior course before bifurcating into its terminal branches. Its average diameter approximates 8.05 mm, and it forms an origin angle of about 121.20° with the aorta- a configuration that enhances both surgical approachability and radiological visualization. These anatomical subtleties highlights the importance of accurate identification during dissections and minimally invasive procedures and underscores the indispensable role of detailed preoperative planning (6,7).

Main Branches

The celiac trunk (CT), in its canonical form, manifests a classic trifurcation defined through three principal branches: the left gastric artery (LGA), the splenic artery (SA), and the common hepatic artery (CHA). Each of these vessels projects a distinct role and follows a characteristic trajectory, furthermore establishing an anatomical pattern observed in approximately 90% of individuals. This trifurcation is broadly accepted as the archetypal configuration of the celiac region, though its frequent anatomical variants - explored in subsequent sections - highlights the complexity within this vascular domain (6).

The left gastric artery, the narrowest among celiac trunk's tributaries, ascends towards the abdominal esophagus, where its contribution in blood supplying of the distal esophageal segment is vital. From there, it curves downwards along the lesser curvature of the stomach, where it joins the right gastric artery to form the gastric arterial arch - a crucial anastomotic network that upholds the structural and functional integrity of the gastric mucosa. Its close anatomical relationship with the left vagus nerve underscores the intricate interplay between vascular and neural elements within this anatomically dynamic region (6).

In contrast, the splenic artery presents a sinuous, leftward path, closely paralleling the posterior contour of the pancreatic body, with a variable length that frequently exceeds 10 cm. It courses through the retroperitoneal space while branching into smaller offshoots: short pancreatic and gastric rami, on its way to the splenic hilum, where it branches extensively to supply the spleen. Furthermore, its deep anatomical course and marked tortuosity render it particularly vulnerable during pancreatic surgery, necessitating meticulous operative technique (8).

Following a divergent course, the common hepatic artery proceeds rightward towards the hepatic hilum, reaching a pivotal anatomical landmark at the Calot triangle. At this junction, it bifurcates into the proper hepatic artery, which supplies the liver, and the gastroduodenal artery, responsible for perfusing the proximal duodenum and pancreatic head. The common hepatic artery may occasionally give rise to accessory branches - an anatomical variation that can complicate hepatic resections. Nonetheless, in its classical configuration, it serves as a foundational component of the hepatobiliary vascular framework (9).

Physiological Role

The celiac trunk represents the principal arterial conduit for the vascularization of foregut-derived structures, playing a central role in sustaining essential physiological functions including digestion, metabolic regulation, and immunological defense. Through its major branches, it supplies blood to the stomach, liver, spleen, proximal duodenum, and pancreas- each receiving a tailored vascular input that meets its functional demands. The left gastric artery maintains the integrity of the gastric mucosa and supports acid secretion, initiating protein digestion. Its strategic anastomosis with the right gastric artery provides a crucial collateral route in cases of vascular compromise (3). The splenic artery, known for its substantial blood flow, nourishes the spleen - an organ critical for blood filtration and immune defense. These anatomical and physiological intricacies underscore the critical importance of detailed vascular mapping in both diagnostic assessment and surgical planning within the upper abdominal region (6).

Through its terminal branches, the common hepatic artery delivers critical vascular support to the liver and the biliary system - organs that are vital to systemic metabolic regulation. The liver, as the body's central biochemical hub, orchestrates a range of essential processes including protein synthesis, xenobiotic detoxification, and lipid metabolism via bile secretion. While the proximal duodenum and pancreas receive additional perfusion from the superior mesenteric artery, their functional integrity - particularly in exocrine and endocrine output - remains highly dependent on celiac trunk-derived blood flow. This arterial network not only provides sustenance but also integrates these organs into a highly interdependent system, where any disruption in blood flow - whether due to trauma or iatrogenic injury - can lead to cascading pathophysiological consequences (8). Although collateral contributions from adjacent vascular territories exist, the celiac trunk serves as the primary hemodynamic nexus of the upper abdomen - its role extending beyond nutritive supply to encompass the preservation of homeostatic equilibrium within the gastrointestinal and hepatopancreatobiliary domains (6).

Historical Evolution in Classifying Celiac Trunk Anatomical Variants

Over time, the medical literature has gathered a wide array of descriptions regarding the anatomical variants of the celiac trunk, structured through various successive classifications with the aim of serving as reference frameworks for the identification and understanding of possible malformations at this level. However, the absence of constant and universally applicable anatomical patterns has considerably limited the development of a comprehensive and standardized classification system capable of encompassing the full spectrum of morphological variations. Moreover, the significant variability in the results reported by different studies naturally reflects the influence of factors such as the experience and methodology of the medical team involved, as well as the technological resources available at the time of the investigation (10).

Albrecht von Haller is credited with providing the earliest systematic observations of celiac trunk (CT) variability, laying the foundational groundwork for vascular anatomical research. Although he did not establish a formalized classification system for CT variants, his contributions were pivotal in documenting and illustrating deviations from the classical trifurcation pattern. Haller's work, grounded in meticulous anatomical dissections and detailed illustrative records, offered some of the first comprehensive accounts of interindividual differences in the arterial branching of the upper abdominal vasculature. While primarily descriptive in nature, his findings catalyzed subsequent efforts to categorize and standardize the morphological variants of the celiac trunk, thereby marking a critical moment in the evolution of vascular anatomy as a scientific discipline (10).

Haller described the conventional trifurcation into the left gastric artery (LGA), splenic artery (SA), and common hepatic artery (CHA). Furthermore, he pointed out structural inconsistencies such as branch fusions or independent arterial origins directly from the AA. For instance, he recorded cases in which the LGA arose separately or where atypical connections existed between the hepatic and splenic arteries. However, he neither quantified these variations nor organized them into a systematic framework (10). As noted in the literature, Haller's contributions were primarily qualitative, emphasizing morphological diversity rather than developing a structured typology (11). A historical analysis by further indicates that while Haller observed anomalies such as absent trifurcations or the presence of accessory branches, these were presented descriptively rather than as defined categories. Therefore, his legacy lies in establishing a foundational awareness of celiac trunk variability rather than in creating a formal classification system (12).

Later, Benjamin Lipshutz introduced one of the earliest systematic classifications of celiac trunk variations. He focused his work on the dissection of 83 cadavers, later leading to identifying four distinct branching patterns, centered around deviations from the classical trifurcation involving the LGA, SA, CHA. These configurations were defined as follows:

- Type I: the classical trifurcation, with the celiac trunk dividing into the LGA, SA, and CHA - this was the most frequently observed pattern, present in approximately 75% of specimens;
- Type II: the LGA originates directly from the abdominal aorta, while the celiac trunk bifurcates into the SA and CHA, forming a hepatosplenic trunk;
- Type III: the CHA arises independently from the abdominal aorta or the superior mesenteric artery (SMA), with the celiac trunk giving rise only to the LGA and SA - a gastrosplenic trunk;
- Type IV: a rare pattern in which the celiac trunk is absent, and all three arteries (LGA, SA, CHA) originate separately from the aorta (13).

Moreover, Lipshutz's classification was pioneering for its empirical foundation and its practical implications in surgical anatomy. Although the sample size limited the statistical accuracy of the reported frequencies, Pinal-Garcia et al. emphasize that Lipshutz's work provided a crucial step toward the standardized categorization of celiac trunk variants. His approach marked a transition from purely descriptive anatomy to clinically oriented vascular typology (14).

Norman Michels introduced a comprehensive classification system for variations of the celiac trunk and hepatic arteries, based on 200 cadaveric dissections. His classification, comprising ten distinct types, remains one of the most detailed early frameworks, with a primary emphasis on hepatic artery variants- many of which involve deviations in celiac trunk anatomy. The following types, as explicitly described by Michels and supported by contemporary literature, are particularly relevant to the celiac trunk.

- Type I: the classic trifurcation of the celiac trunk into the left gastric artery (LGA), splenic artery (SA), and common hepatic artery (CHA), with the CHA branching into the proper hepatic artery and gastroduodenal artery (observed in 65-75% of cases) (*Fig. 1*);
- Type II: a replaced left hepatic artery arising from the LGA, while the celiac trunk maintains its standard trifurcation (5-10%);
- Type III: a replaced right hepatic artery originating from the superior mesenteric artery (SMA), with the celiac trunk otherwise demonstrating the typical trifurcation (10-15%) (*Fig. 2*);
- Type IV: both right and left hepatic arteries are replaced (right from SMA, left from LGA), and the CHA becomes functionally limited to the gastroduodenal artery (1-2%);
- Type V: an accessory left hepatic artery arising from the LGA, in addition to a normal CHA originating from the celiac trunk (5-10%);
- Type VI: an accessory right hepatic artery arising from the SMA, with an otherwise typical celiac trunk configuration (5-10%);
- Type VII: a hepatosplenic trunk, where the SA and CHA originate from the celiac trunk, and the LGA arises directly from the aorta (10-15%);
- Type VIII: a gastrosplenic trunk, where the LGA and SA emerge from the celiac trunk, and the CHA originates from the SMA or directly from the aorta (5-10%);
- Type IX: absence of the celiac trunk, with the LGA, SA, and CHA all arising independently from the aorta (<1%);
- Type X: rare and complex variants, including cases where the CHA arises from the SMA along with additional accessory branches (1-2%) and others such as the possibility of the early bifurcation of the CHA (*Fig. 3*) (15).

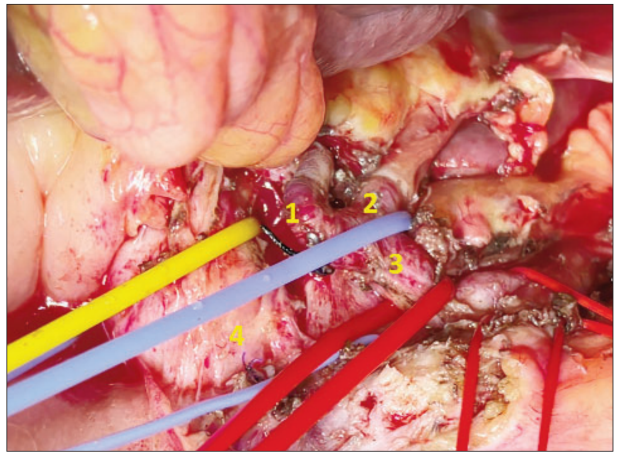

Figure 1. The classic trifurcation of the celiac trunk. 1 – Common hepatic artery, 2 – Left gastric artery, 3 – Splenic artery, 4 – Hepatic pedicle.
(Image courtesy of Professor Dr. Octav Ginghina)

Michels' detailed anatomical descriptions and estimated frequencies were later reaffirmed by Venieratos et al., who emphasized the predominance of Type I and the clinical significance of rarer variants such as Types VII and VIII, which reflected substantial alterations in celiac trunk

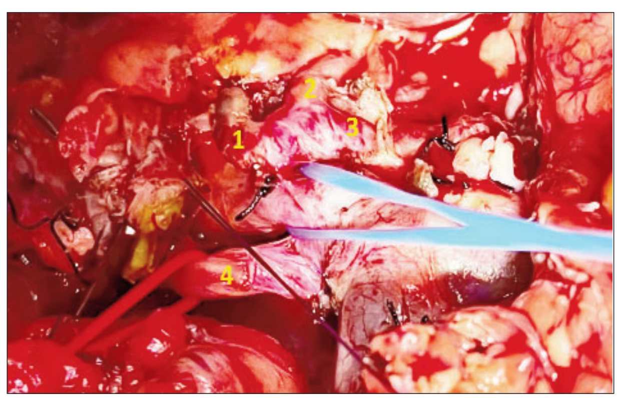

Figure 2. Michels Type III classification. 1 – Common hepatic artery, 2 – Left gastric artery, 3 – Splenic artery, 4 – Right gastric artery originating from the superior mesenteric artery.
(Image courtesy of Professor Dr. Octav Ginghina)

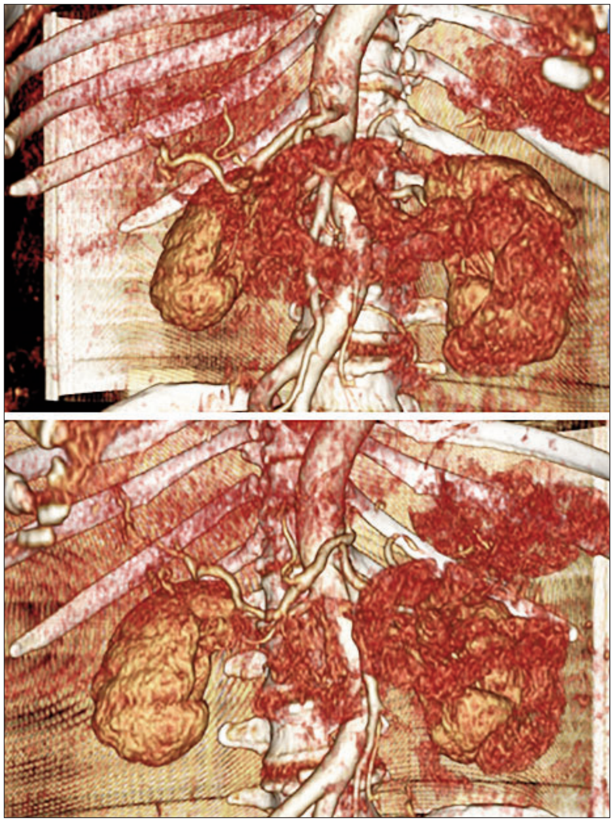

Figure 3. Anatomical variant of the common hepatic artery. Early bifurcation of the common hepatic artery. Invasion of the right branch of the proper hepatic artery by a pancreatic tumor. Duodenopancreatectomy performed.
(Courtesy of Professor Dr. Adrian Miron.)

anatomy (3). According to Pinal-Garcia et al., Michels' classification keeps serveing as one of the foundational references due to its thoroughness and enduring relevance in surgical and radiological practice (14).

Michels' classification, published in 1966, gradually earned recognition as the benchmark for all subsequent contributions in this field. Later, a study conducted on 1,000 liver transplant patients between 1984 and 1993 led to the development of a classification of the Hepatic Artery. The arterial configurations identified in this cohort, presented in descending order of prevalence, comprised the following anatomical variants:

- Type 1: representing the standard anatomical pattern (n = 757), in which the common hepatic artery arises from the celiac axis, giving rise to the gastroduodenal and proper hepatic arteries, with the latter subsequently dividing into right and left hepatic branches;
- Type 2: characterized by a replaced or accessory left hepatic artery arising from the left gastric artery (n = 97);
- Type 3: defined by the presence of a replaced or accessory right hepatic artery originating from the superior mesenteric artery (n = 106);
- Type 4: involving separate origins of the right and left hepatic arteries from the superior mesenteric and left gastric arteries, respectively (n = 23);
- Type 5: in which the entire common hepatic artery originates as a branch of the superior mesenteric artery (n = 15);
- Type 6: a rare variant (n = 2) where the common hepatic artery arises directly from the abdominal aorta (16).

Taken together, these developments indicate that the progression in the understanding of the celiac trunk's anatomical variability has undergone four major conceptual stages, reflecting a shift from purely morphological descriptions to standardized taxonomic frameworks with significant clinical applicability (*Fig. 4*) (16).

Literature Findings - Discussions

As previously mentioned, numerous studies have been conducted over time to improve the understanding of this anatomical region; however, the more findings emerged, the more controversial the subject appeared to become.

A comprehensive meta-analysis published in 2013, encompassing 12,196 cases across 36 studies, introduced a revised classification of celiac trunk (CT) anomalies, differing significantly from previous systems (1). This study reported that the

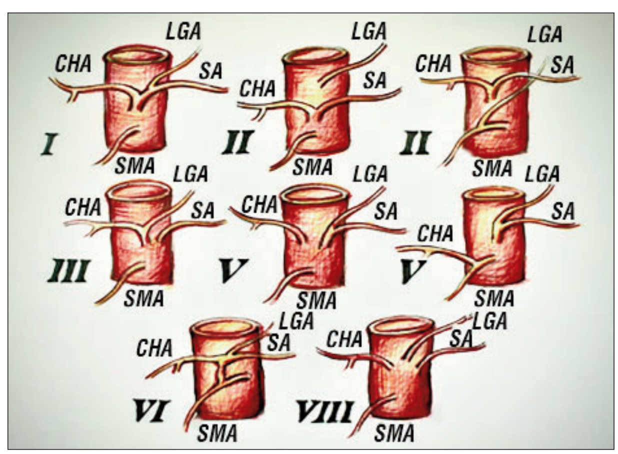

Figure 4. Anatomical Variants of the Celiac Trunk.
LGA- Left gastric artery, CHA - Common hepatic artery, SA- Splenic artery, SMA - Superior mesenteric artery

classic trifurcation of the celiac trunk - Tripus Halleri - was present in 89.42% of cases, making it one of the first large-scale studies to summarize this prevalence so precisely. Similar findings had been previously documented in cadaveric studies, with trifurcation rates ranging from 40% to 94.2%, while radiological and liver transplantation studies have reported even higher frequencies, reaching 95.9% and 98.3%, respectively (17,18).

Additionally, literature indicates that celiac trunk bifurcation - categorized as Type II in Panagouli et al.'s classification - occurs in 1.3% to 25% of cases, with Panagouli et al. specifically noting a prevalence of 7.40%. The most commonly observed bifurcation patterns include the hepato-splenic trunk, in which the left gastric artery arises directly from the abdominal aorta (3.34%); the splenogastric and hepatomesenteric trunks (1.9%); and the splenogastric trunk, where the common hepatic artery originates from the superior mesenteric artery (1.13%). Furthermore, complete absence of the celiac trunk - classified as Type VII in the same system - has been reported in 0% to 2.6% of cases, with an average prevalence of 0.38% (1).

Another noteworthy study was conducted on 50 cadavers through abdominal autopsy and its revealing that in 86% of cases, the three main branches - the left gastric artery (LGA), common hepatic artery (CHA), and splenic artery (SA) - originated from a common celiac trunk, aligning closely with findings from previous research. Vascular anomalies were identified in 14% of the specimens and were categorized into distinct patterns. The most frequent variation involved the celiac trunk dividing into only the CHA and SA, while the LGA originated separately, proximally between the abdominal aorta and the bifurcation of the celiac trunk. This particular variation was observed in 76% of the cadavers with anomalies (19). Similar findings were reported in another study, which documented a comparable pattern in 72% of cases (20).

On the other hand, the celiac trunk (CT) has also been analyzed based on characteristics beyond its branching pattern, including its length, diameter, point of origin, and branch variations. It was reported that the average arterial diameter tends to be smaller when the vessel presents anatomical variations. One particularly interesting observation from this study was the suggestion that the diameters of the CT's main branches may be reduced in the presence of such variants. This finding is clinically significant, as accurate knowledge of normal arterial diameters equips physicians with the necessary reference points for making precise radiological diagnoses of vascular pathologies, such as aneurysms. Moreover, the assessment of arterial diameters is essential for the proper monitoring and follow-up of liver transplant recipients (21,22).

Beyond the previously discussed variations, a rare instance of celiac trunk (CT) tetrafurcation was identified during the dissection of a formalin-preserved cadaver of a 60-year-old Romanian woman. In this specimen, the CT diverged into four distinct branches: a shared trunk for the left and right inferior phrenic arteries, an accessory left gastric artery, the common hepatic artery, and a splenogastric trunk (23). Similarly, another study documented the following abnormalities: tetrafurcation, pentafurcation, and hexafurcation in 36%, 20%, and 4% of cases, respectively (24), while Pinal-Garcia et al. reported corresponding frequencies of 32.9%, 12.9%, and 1.4% (14).

Among the anatomical variations of the celiac trunk, the most frequently encountered is its bifurcation, identified in approximately 11% of cases (9). This deviation from the classic trifurcation often presents in forms such as the hepatosplenic trunk, where the left gastric artery arises directly from the aorta (3.34%), the splenogastric trunk with the common hepatic artery originating from the superior mesenteric artery (1.13%), or the hepatomesenteric trunk (1.9%) (25). Araujo Neto et al. further expanded on this through computed tomography analysis in 60 patients, revealing a splenic-hepatic trunk without a left gastric artery in 8.3% of cases, and a hepato-gastric trunk lacking the splenic artery in 1.7% - a finding particularly relevant in gastric surgeries, where an unrecognized hepatic artery arising from the LGA may place the liver's left lobe at risk of ischemia (26). In nearly half of cases, the celiac trunk also gives rise to collateral arteries, most notably the inferior phrenic arteries, which may originate singly or doubly from the CT itself (41% on the right and 44% on the left), or alternatively from the aorta (49% and 47.5%, respectively) (27). With advances in liver transplantation, detailed anatomical knowledge has become increasingly critical, as studies confirm that formalin-fixed cadavers provide reliable data comparable to fresh specimens and non-invasive imaging methods (28). Moreover, research from Japan indicate that patients with arterial variants face a higher risk of post-transplant complications (29). While some types, such as Type IV (right hepatic artery from the SMA), are less common than others like Type III (left hepatic artery from the SMA), and rare configurations such as Type V - featuring gastrosplenic and hepatomesenteric trunks originating from the aortic arch—have a reported prevalence of around 3% (30). Such insights are essential for clinical decision-making and surgical planning.

Clinical and Surgical Implications

From a clinical perspective, attentiveness to anomalies in the celiac trunk has profound implications. For instance, variations can influence the likelihood of vascular complications during diagnostic procedures such as angiography or interventions like catheterizations (31). Knowledge of the celiac trunk's configuration is crucial for radiologists to ensure accurate imaging and risk assessment. Understanding the presence of aberrant arteries may dictate alternative angiographic routes during interventions (4,32).

Moreover, anatomical variations can affect the hemodynamics of blood flow, which may manifest in patients presenting with abdominal symptoms attributed to vascular insufficiency (33). In cases where celiac trunk variations are present, conditions such as celiac trunk compression syndrome can arise, which may lead to postprandial pain and weight loss due to mesenteric ischemia (34).

An accurate and nuanced understanding of the anatomical variability of the celiac trunk and hepatic arteries is of critical importance in contemporary clinical practice, particularly in the context of abdominal surgery and advanced diagnostic radiology. The ability to accurately observe the possible variants of hepatic artery origins or other branching patterns is fundamental to create the needed procedural safety and efficacy in complex procedures such as: liver transplantation, laparoscopic approaches, and interventions involving the upper abdominal organs (35). Moreover, comprehensive knowledge of the collateral mesenteric circulation is vital in managing cases of mesenteric artery stenosis or occlusion, where the presence of compensatory vascular routes may prevent ischemic complications (36).

Although established classification systems such as those proposed by Michels and Hiatts provide a robust framework for CT anatomy, rare and atypical variants continue to be encountered in clinical practice (16). Such deviations may carry significant implications for both surgical and interventional radiological procedures.

Anatomical variations of the celiac trunk play a critical role in the diagnosis and management of median arcuate ligament syndrome (MALS). Technological advancements have facilitated laparoscopic release of the celiac artery, offering advantages such as reduced invasiveness and lower complication rates; however, the potential for incomplete decompression and aortic injury remains a concern (37). Interventional radiologic approaches like percutaneous transluminal angioplasty (PTA) may serve as adjuncts to surgery, yet their effectiveness as standalone treatments is limited. The complex pathophysiology of MALS encompasses both ischemic and neurogenic components, with compression of the celiac plexus contributing to abdominal pain and mucosal ischemia exacerbating symptoms (38). The high prevalence of asymptomatic individuals with radiologic evidence of celiac compression, further complicates diagnostic accuracy (39). Therapeutic strategies commonly include laparoscopic or open release of the median arcuate ligament, with or without celiac revascularization; both have shown symptom improvement, though revascularization may reduce long-term recurrence. Notably, a more acute angle of celiac trunk origin has been associated with greater MAL overlap, suggesting its potential utility as a diagnostic indicator. Nevertheless, a definitive diagnosis of MALS should rely on a combination of thorough clinical evaluation and supportive paraclinical investigations (38,40).

Anatomical variations of the celiac trunk can significantly influence extensive oncological surgery, especially in the case of pancreatoduodenectomies (PD) and cephalic duodenectomy with arterial resection (PD-CDAR). In PD, celiac trunk stenosis, often caused by MALS or atherosclerosis, can lead to postoperative ischemic complications (20,37). Also, the presence of a hepatic artery with a different anatomical position than normal can complicate the procedure and increase the risk of complications (38). In PD-CDAR, hepatic artery variations and the risk of gastric ischemia are major concerns. Preoperative embolization of the common hepatic artery may be performed to stimulate collateralization and reduce the risk of ischemic complications (21,22,39). However, PD-CRA remains a complex procedure with a higher complication rate than PD (40,41).

Variations in the celiac trunk's anatomy significantly impact complex oncological procedures, such as pancreatoduodenectomy (PD) and cephalic duodenectomy with arterial resection

(PD-CDAR). In PD, stenosis of the celiac trunk - often due to median arcuate ligament syndrome (MALS) or atherosclerotic changes - can result in postoperative ischemic sequelae. Furthermore, an atypically positioned hepatic artery may increase procedural complexity and the likelihood of complications. In PD-CDAR, anomalies in the hepatic artery and the risk of gastric ischemia are critical considerations. To reduce ischemic risks, preoperative embolization of the common hepatic artery may be utilized to enhance collateral circulation. However, PD-CDAR is a more intricate operation than PD, carrying an elevated rate of complications (41,42).

Anatomical variations of the celiac trunk exert a critical influence on the technical feasibility and clinical outcomes of liver transplantation, impacting both donors and recipients. In living donors, certain vascular configurations can complicate hepatectomy and compromise graft viability. A notable example is the origin of the middle hepatic artery from the right hepatic artery; its inadvertent division during right lobe procurement may result in inadequate perfusion of segment IV or the left hepatic lobe, with potential consequences for donor safety and graft function. In recipients, anomalies such as a foreshortened right hepatic artery, celiac axis stenosis, or aberrant origins of the hepatic arteries introduce considerable intraoperative challenges and are associated with an increased risk of vascular complications—most notably hepatic artery stenosis or thrombosis—potentially compromising graft survival. Hence, meticulous preoperative vascular mapping using high-resolution imaging modalities such as computed tomographic angiography is imperative for the identification of such variants and the formulation of tailored arterialization strategies. In selected cases, the surgical team may be required to perform complex vascular reconstructions or employ advanced anastomotic techniques to ensure adequate graft perfusion and minimize the risk of ischemic injury (43-45).

Given the importance of understanding celiac trunk variations, advanced imaging modalities such as multislice computed tomography (CT) angiography have become integral components of preoperative planning (4,31,46). These imaging techniques provide detailed visualization of the celiac trunk's anatomy and its branches, enabling surgeons to anticipate variations and alter surgical approaches accordingly.

In a study examining 100 patients using CT angiography, a significant diversity in celiac trunk configuration was observed, stressing the need for routine imaging when planning surgical or interventional procedures (47). The non-invasive nature of these imaging techniques allows for better patient safety and enhanced surgical outcomes, making them invaluable in modern surgical practice (48).

Conclusions

As a final point, the anatomical definition of the CT as a main arterial branch transcends itself, revealing as a structural and functional epicenter whose variations hold profound implications across multiple domains of clinical medicine. The intricate vascular remodeling processes not only outlines its embryological plasticity but also rise a spectrum of morphological configurations that challenge traditional anatomical dogma and require enhanced awareness in surgical and radiological practice. From Haller's early descriptive dissections to the refined taxonomies of Michels, Hiatt, and Panagouli, the historical trajectory of celiac trunk research traces the advancement of its anatomical understanding.

In contemporary medicine, where precision is essential to acquire therapeutic success, the celiac trunk commands attention as a critical determinant in outcomes of high-stakes interventions - from liver transplantation and complex hepatobiliary resections to the management of rare vascular syndromes such as MALS. Unfortunately, aberrant arterial configurations, which are often detected in asymptomatic individuals, can turn routine procedures into technical minefields, progressively elevating the risk of ischemic injury, graft failure, or even life-threatening complications. Identifying preoperative this broad spectrum of variants through advanced imaging modalities and combining those findings with intraoperative adaptability and anatomical foresight, is essential not only for technical success but for the preservation of organ viability and more important, for patient survival.

Thus, the study of celiac trunk anatomy constitutes one of the cornerstones of modern surgical planning and clinical decision-making. It compels a synthesis of embryological insight, anatomical precision, and procedural pragmatism, reminding us that even within the predictable rhythms of vascular architecture, variability remains the rule rather than the exception. In this context, the celiac trunk is not just an artery - it is a surgical variable, and an enduring reminder of the inextricable link between form, function, and outcome.

The anatomical variation of the celiac trunk carries significant clinical and surgical implications that must be understood by healthcare providers involved in managing abdominal conditions. Recognizing these variations can enhance surgical planning, minimize intraoperative risks, and ultimately improve patient outcomes. As surgical techniques and imaging modalities continue to evolve, further research surrounding the anatomical complexities of the celiac trunk will undoubtedly contribute to more efficient, safe, and effective clinical practices.

Conflict of Interest

The authors declare no conflicts of interests.

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