Short Narrative Review
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Anatomical Variations in the Celiac Trunk: A Short Review

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Abstract
Objective. The objective of the current study was the examination of possible variants of the celiac trunk. **Methods.** An advanced review of the literature search was undertaken by means of the PubMed database and Google Scholar, searching for new studies published up to October 2022. Additional articles provided useful information in relation to the aim of this review. Hence, articles that met the inclusion criteria were included in this review and the collected data were organized into a table. **Results.** The search of the literature retrieved 10 articles that referred to the anatomical variations of the celiac trunk. According to the available literature, the most common anatomical variations are: hepatosplenic trunk where the left gastric artery originates from the abdominal aorta, hepatosplenic trunk, where the left gastric artery originates from the splenic artery, and hepatogastric trunk and splenic artery origin from the superior mesenteric artery. Many other anatomical variations of the celiac trunk may exist, such as tetrafurcation, pentafurcation and hexafurcation, that refer to the division of the celiac trunk into four, five or six branches, respectively, and should be reported as they can affect surgical approaches and the development of the appropriate treatment strategy in patients. **Conclusion.** Every visceral surgeon, interventional radiologist and abdominal imager should be familiar with these variants.

Key Words: Celiac Trunk ▪ Aorta ▪ Variations ▪ Surgery ▪ Anatomical Variation.

Introduction

The celiac trunk (CT) is the anterior branch of the abdominal aorta, which arises at the level of the vertebral bodies thoracic 12 (T12) to lumbar 1 (L1) and mainly supplies the foregut (1). In general, the CT measures approximately 1.5–2 cm and supplies blood to the distal esophagus, liver, pancreas, gallbladder and spleen (1). It splits into three major branches, namely: the left gastric, which runs through the smaller curvature of the stomach; the splenic, which follows a tortuous route along the posterior superior margin of the pancreas to the spleen; and the hepatic arteries, which divide into the gastroduodenal for pancreas and duodenum vascularization (1). The hepatic artery also gives rise to the gastroduodenal artery, which later becomes the right gastroepiploic artery. This artery runs along the greater curvature and supplies the lateral stomach, with two branches of the splenic artery, the left gastroepiploic and short gastric arteries (2). This trifurcation was described by von Haller back in 1917, and is considered the classic presentation of the CT, known as "tripus Halleri" (2, 3). It is reported in approximately 89% of individuals irrespective of their sex (2, 3). Two trifurcation forms have been described to date: the first is named a "true" tripod and corresponds to cases in which the hepatic, left gastric and splenic arteries have a common origin, constituting a hepatogastrosplenic trunk (4, 5). In cases where at least one of these arteries arises before the remaining two in the course of the CT, it is called a false tripod. In most cases, the celiac trunk and the superior mesenteric artery are formed by the 10th and

13th vitelline arteries, with the remaining segments regressing before birth.

However, the ventral vertebral aorta and the celiac artery may often exhibit significant anatomical variations, as well as total absence of one of the branches, which may affect the surgical approaches performed, such as during organ transplantation or organ/tumor resection (3). In the literature, several variations of the CT have been documented (2, 6 –10). In particular, multiple studies and research have been reported that explain and assess the various forms of the CT, whereas innumerable attempts have been undertaken to characterize its consequence forms. However, each author reports their own experience and findings and, therefore, it may be difficult to include the overall knowledge up to the present.

Nevertheless, this knowledge is important for surgeons, as changes in the celiac artery may increase the difficulty and risk of performing surgical procedures, such as radical gastrectomy. Thus, as it is important to gain knowledge that will help in the preparation for a particular surgical operation and mitigate post-operative complications, we present the findings of previous studies that focused on the variations of the CT.

Our aim was to shed light on this important issue and provide the currently available knowledge to clinicians and surgeons worldwide.

Methods

An advanced executive literature search was conducted in PubMed and Google scholar databases using the following terms: "celiac trunk AND anatomical variations OR tripus Halleri AND anatomical variations". The resulting literature was carefully screened. Only studies in English and referring to humans were included. No additional search filters, such as text availability, article type and publication date, were applied. Through the snowballing technique, further references taken from the initial articles with useful information relating to the aim of the review were also screened and taken into consideration. The extracted data were classified in a table according to the anatomical variations of the CT in adults.

Results

The search of the literature retrieved 10 articles that referred to the anatomical variation in question in adults and they are summarized in Table 1.

An interesting work on this issue was published by Panagouli et al. in 2013. In particular in their study they presented an entirely new categorization of abnormalities of the CT, which encompassed all previously documented abnormalities (7). Especially, they examined 12,196 cases from a total of 36 studies reported up to 2013, and stated that the CT was trifurcated into the common hepatic artery, the left gastric artery, and the splenic artery in 89.42% of cases (7). A similar observation was reported in 40–94.2% of cases in previous cadaveric studies, and the figures reached 95.9% and 98.3% in radiological and liver transplantation studies, respectively (11, 20). Moreover, according to the literature, CT bifurcation (type II according to Panagouli et al.'s classification) may exist in 1.3–25% of cases (7.40% according to Panagouli et al. (7)) with the most common types of bifurcation being the following: hepatosplenic trunk (the left gastric artery originated from the abdominal aorta [3.34%]), splenogastric and hepatomesenteric trunk (1.9%) as well as the splenogastric trunk (the common hepatic artery arises from the superior mesenteric artery [1.13%]) (Figure 1). The CT may be absent (type VII according to Panagouli et al.'s classification) in 0–2.6% of cases (mean prevalence: 0.38%) (7, 12, 13).

An interesting study was conducted by Chen et al. back in 2019 (13). The authors examined the anatomic variations of the CT and the hepatic artery in a large homogeneous sample from a Japanese population. They analyzed the branching modes of the CT, as well as the anatomy of the CT and hepatic artery in 974 cadavers. Interestingly, CT trifurcation was observed in 89.8% of cases, while the normal pattern of the CT and the hepatic artery was observed in 66% and 72.4% of cadavers, respectively (13). Moreover, alternative

Table 1. Variations of Celiac Trunk in Adults

Researchers	Year of publication	No of cases	Celiac Trunk			Other variations
			Bifurcation	Trifurcation	Absence	
Panagouli et al. (7)	2013	12196	7.40% (903/12196)	89.42% (10906 /12196)	0.38% (46 /12196)	Hepatosplenomesenteric trunk 0.40% (49/12,196). Celiacomesenteric trunk 0.76% (93/12,196). Other variations 1.64% (199/12,196) variations in the cadaveric series 14.9% (489/3278). In the imaging series the 10.5% (675/6501). In the liver transplantation series 4.6% (104/2261)
Chitra (11)	2010	50	The hepatosplenic trunk 0.02% (1/50) The gastrosplenic trunk 0.04% (2/50)	40% (20/50)	NA	95.9% radiological & liver transplantation studies. Division of CT into four branches: the inferior phrenic artery, either one-sided or on the common trunk of both sides 20% (10/50) or the additional branch was the gastroduodenal artery 2% (1/50) or the middle colic artery 4% (2/50) or the duodenal or the pancreatic branches 10% (5/50). The left hepatic artery arising from the left gastric artery 14% (7/50). The five branches of the coeliac trunk included the inferior phrenic and middle colic artery 2% (1/50). The six branches of the coeliac trunk also included the duodenal branch in addition to the abovementioned branches 2% (1/50).
Venieratos et al. (12)	2013	77	Splenogastric trunk 1.3% (1/77) the common hepatic artery emerged directly from the aorta.	90.9% (70/77)	2.6% (2/77)	5.2% (4/77) additional branches (lumbar and inferior phrenic arteries)
Chen et al. (13)	2009	974	Common hepatosplenic trunk 4.4% gastrohepatic trunk 0.3%	89.8% (875/974)	NA	A common hepatic artery (CHA) arising from the superior mesenteric artery (SMA) 3.5% or directly from the aorta 0.5%. A hepatosplenomesenteric trunk 0.7% (7/974) a celiomesenteric trunk 0.7% (7/974).
Prakash et al. (14)	2012	50	NA	NA	NA	The left gastric, common hepatic & splenic arteries were found to arise from the coeliac trunk 86% (43/50) the origin of the gastric artery was proximal to the bifurcation of the coeliac trunk into the common hepatic and splenic arteries 76% (38/50) all three branches arose directly from the abdominal aorta 2% (1/50) the common hepatic and left gastric arteries arose from the coeliac trunk 2% (1/50).
Malnar et al. (15)	2010	90	72%	NA	NA	Anatomical variations 4.4% (4/90).
Grigoriță et al. (16)	2019	CR	NA	NA	NA	Tetrafurcation of CT: - a common trunk for left & right inferior phrenic arteries - an accessory left gastric artery - the common hepatic artery - a splenogastric trunk-
Srivastava et al. (17)	2012	50	28%	8%	4%	Tetrafurcation 36%; pentafurcation 20%; hexafurcation 4%.
Pinal-Garcia et al. (18)	2018	140	7.1%	NA	NA	Additional branches 47.9%. One or both phrenic arteries originated from the celiac trunk 41.4%. Celiac trunk tetrafurcation 12.9%; Pentafurcation 12.9%; Hexafurcation 1.4%; Heptafurcation 0.7%.
Astik and Dave (19)	2011	CR	NA	NA	NA	Heptafurcation of CT

CT=Celiac trunk; CHA=Common hepatic artery; SMA=Superior mesenteric artery; NA=Not available; CR=Case report.

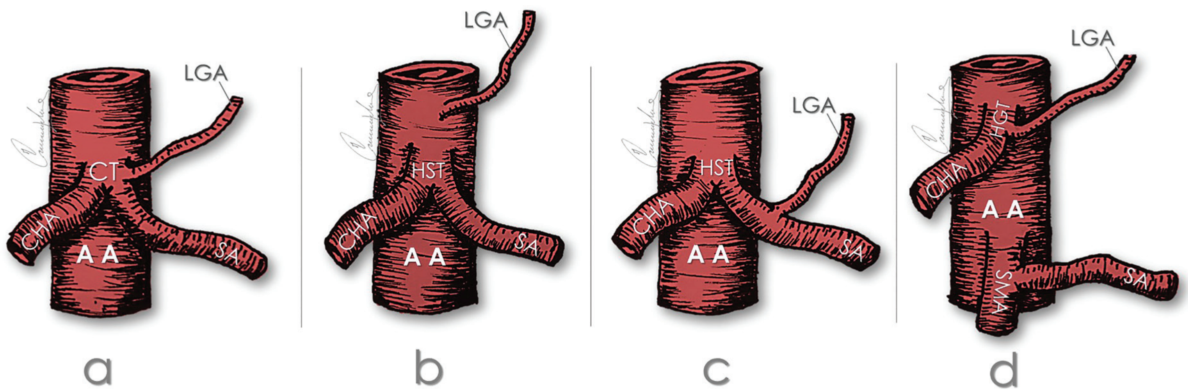

Figure 1. The most common anatomical variations of CT (the celiac trunk): a) the normal celiac trunk ("Haller's tripod") from which CHA (the common hepatic artery), SA (the splenic artery) and LGA (the left gastric artery arise), b) HST (hepatosplenic trunk) where the LGA originates from AA (the abdominal aorta), c) HST (Hepatosplenic trunk) where the LGA originates from the SA, d) HGT (Hepatogastric trunk) and SA origin from SMA (The superior mesenteric artery).

left and right hepatic arteries were observed in 11.0% and 4.9% of cadavers, respectively. In 1.5% of cases, the anatomy of the two hepatic arteries differed. Further, the gastrohepatic body part was observed in 4.4% of the cases, whereas the hepatosplenic stem was discovered in only 0.3% (13). Moreover, a common hepatic artery was observed, arising from the superior mesenteric artery (SMA) or directly from the aorta in 3.5% and 0.5% of the examined cadavers, respectively (13). Finally, a hepatosplenomesenteric trunk and a celiomesenteric trunk were encountered in 0.7% of cases.

Another interesting article was published in 2012 by Prakash et al. (14). In this study, an abdominal autopsy was performed on 50 cadavers and the corresponding structure of the vessels was recorded. All anatomical variations observed were photographed and documented. The left gastric, common hepatic, and splenic arteries were found to arise from the CT in 86% of the cadavers, similar to the prevalence rate of a normal coeliac axis reported by Song et al (89.1%) (21). According to Prakash et al., structural abnormalities were observed in 14% of cases, and can be divided into three groups: (1) a separate branching of the abdominal-hepatic aorta leading to the left stomach, common hepatic, and splenic arteries; (2) the left gastric aorta formed when the dominant hepatic and left gastrointestinal veins split from the celiac stem; and (3) the vein of the gastric system originating from the abdominal aorta (14). In their study, the division of the CT into the common hepatic and splenic arteries was the most common vascular pattern in their study, whereas the origin of the left gastric artery was relatively proximal, between the abdominal aorta and the bifurcation of the coeliac trunk in 76% of the cadavers, similar to the findings of a Croatian study published by Malnar et al, which reported a rate of 72% (15).

In terms of embryology, the above-mentioned alterations have been discussed previously (22, 23).In particular, it was highlighted that the yolk sac is nourished by a network of paired vessels, described as vitelline arteries, at the beginning of the 4th week of prenatal development. The paired vessels gradually fuse and form arteries in the dorsal mesentery of the gut. These present as celiac, superior mesenteric, and inferior mesenteric arteries during adult life (24). Moreover, it was stated that incomplete fusion or malfusion of the vitelline arteries during the developmental stage might have resulted in the observed variations (24).

Distal gastric bypass surgery with laparoscopic assistance, and open total or partial gastrectomy both require ligation and cutting of the gastric arteries, but they are different procedures. As laparoscopic surgery is performed in a small area, there is a risk that the wrong vessel will be cut or ligated, which could contribute to inflammation, ischemia, or necrotizing of the tissue or organ being irrigated (25).

An interesting Brazilian study was published in 2007, in which the authors analyzed the CT structure by measuring its diameter, length, emission, and branch variations (26). This study reported that the average arterial diameter was smaller for variable vessels, after comparing the normal and variable groups. Therefore, an interesting observation of this study was that there may be a diameter reduction of the CT main branches in the presence of anatomical variations. This may be insightful information as the knowledge of normal arterial diameters can help physicians make correct and precise radiological diagnosis of arterial aneurysms, while assessment of arterial diameters is mandatory for liver transplantation follow up (27, 28).

Further, a recent study by a Turkish team examined the prevalence of CT and common hepatic artery variations in children (29, 30). Among 174 children who underwent abdominal multi detector computed tomography angiography, either because of trauma or liver transplantation, 157 (90.2%) had normal CT anatomy, similar to other studies including adults (13, 14, 21). The hepatosplenic trunk giving rise to the branch of the left gastric artery and superior mesenteric artery was the most common variation (4%), in consistency with previous findings (7).

Apart from the aforementioned cases of variations, an unusual case of tetrafurcation of the CT was observed during the dissection of the formalin-fixed cadaver of a 60-year-old Romanian female (16). In this case, the CT gave rise to four branches: a common trunk for the left and right inferior phrenic arteries, an accessory left gastric artery, the common hepatic artery, and a splenogastric trunk (16). Along the same lines, cases of tetrafurcation, pentafurcation and hexafurcation were reported by Srivastava et al. in their CT-angiographic study in 36%, 20%, and 4% of cases, respectively (17), as well as by Pinal-Garcia et al in 32.9%, 12.9%, and 1.4% of cases, respectively (18). Importantly, the latter study also reported one case of heptafurcation. According to our findings, only one such case has been reported in the literature to date (19).

Finally, another interesting issue that should be noted is the effect of ethnicity on CT variation. Interestingly, Panagouli et al. reported that variations in the CT were more common in the Japanese and Korean populations than in Caucasians, while negro, colored and black populations presented more variations than the Indian population (P>0.05) (7).

Discussion

In this study, we aimed to provide a short overview of the knowledge concerning the variants of CT reported in cadaveric and/or diagnostic imaging studies. According to our findings, cases of the absence of the CT are rare, and in these cases the common gastric, splenic and hepatic arteries originate independently directly from the abdominal aorta (7, 12, 31). This variation occurred because of the complete regression of the anastomoses of the primitive arteries. Nevertheless, the segmental arteries did not regress and emerge directly from the abdominal aorta (14, 32, 33).

Bifurcation of the CT seems to be the most common variant form. This variant is observed in approximately 11% of cases (34, 35). Among the most common bifurcation types are the hepatosplenic trunk (the left gastric artery originates from the abdominal aorta), the splenogastric and hepatomesenteric trunk, and the splenogastric trunk (the common hepatic artery arises from the superior mesenteric artery) observed in 3.34%, 1.9% and 1.13% of cases, respectively (34, 35). Interestingly, Araujo Neto et al. examined 60 patients using computed tomography and found that 8.3% of them had a splenic hepatic trunk with the absence of the left gastric artery, while only 1.7% of the participants had a hepatogastric trunk with the absence of the splenic artery (36). These findings should be considered by physicians during gastrectomy because the left hepatic artery may emerge from the left gastric artery and, therefore, there is a possibility of developing ischemia in the entire functional yellow liver lobe (9).

It is worth mentioning that Panagouli et al. stated that the CT trifurcates into the common hepatic artery, the left gastric artery and the splenic artery (Type I) in 89.42% of cases (7). This presentation has a prevalence of 40–94.2% in cadaveric studies, but can reach 95.9% and 98.3% of cases in radiological and liver transplantation studies (11, 37, 20).

The CT may also provide >1 collateral arteries in 50% of cases. The most frequent additional branches are the single or double inferior phrenic arteries (approximately 40% of cases) (38). It has been reported that the right and left inferior phrenic arteries arose from the CT in 41% and 44% of the examined cadavers, respectively; the abdominal aorta was their origin in 49% and 47.5% of cases (18).

Further, there has been a great deal of research into the higher incidence of structural versions in the celiac stem and its branches (37). Interestingly, as Santos et al. reported, there may be differences in the anatomy of both the central part and the branches of the CT (9). Recent advances in liver transplantation have necessitated an accurate understanding of the incidence of anatomical changes in the arteries involved. Despite the fact that formalin-fixed cadavers were used, the results are trustworthy because they are comparable to those obtained in fresh cadavers or *in vivo* using non-invasive approaches to assess the vascular caliber (39). Moreover, a study by Japanese investigators stated that patients with a variable arterial anatomy had a greater rate of post-transplantation complications than those with standard arterial morphology (40). Indeed, according to Santos et al. as well patients with variable arterial anatomy may have a higher risk of problems following liver transplantation (9).

However, despite the fact that the Type IV variant (right hepatic artery source from superior mesenteric artery) has been documented, it is significantly less prevalent than the Type III variant (left hepatic artery origin from the superior mesenteric artery) (28). No data suggest that this polymorphism is related to the occurrence of two left hepatobiliary vessels splitting off from the central hepatobiliary aorta. A prevalence equivalent to that of the Type V form (which consists of two trunks from the aortic arch: a gastrosplenic and a hepatomesenteric) (3%) has been previously reported (41).

According to the literature, these differences in the rates of observed CT variations may be related to genetic factors and ethnicity (7, 29). However, no differences between sexes have been observed in previous works (12, 13), which is interesting information that should be considered by physicians.

Limitations of the Study

Concerning the limitations of our study, it should be mentioned that most of the research that exists relies on case reports/small case series. Finally, it is equally important to highlight that most anatomical variations, and vascular anomalies of the celiac trunk in general, even though they are not common in the general population, should be of high clinical significance and lead to surgical vigilance.

Conclusion

Differences in the CT are not uncommon; nonetheless, various anatomical variations have been documented. In this way, the importance of being able to recognize and account for structural changes in the celiac stem cannot be overstated. It is important to educate clinicians and surgeons appropriately so they have sufficient knowledge of the CT's anatomic patterns and variations in order to perform image-guided interventional procedures safely, as well as esophageal, gastroduodenal, hepatic, biliary, pancreatic, splenic and colonic surgical procedures.

What Is Already Known on This Topic:
The CT is a major abdominal branch of the aorta arising from the T12-L1 level. However, anatomical variations may exist and should be mentioned as they can determine surgical approaches and the development of the appropriate treatment strategy in patients. Therefore, each physician should be familiar with the existence of such variants.

What This Study Adds:
This study summarizes the current literature, confirming the presence of a variety of anatomical variations of the CT. It should be underlined that the recognition of these variations is very important as the correct and early diagnosis can lead to the appropriate treatment, preventing potentially life-threatening complications.

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Conflict of Interest: The authors declare that they have no conflict of interest.

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