ORIGINAL ARTICLE

Anatomical Variations of the Celiac Trunk and Hepatic Arteries with a New Classification, Based on CT Angiography

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ABSTRACT

Objectives: To analyse the distribution of anatomical variations in both celiac trunk (CeT) and hepatic artery (HA) branching patterns on computed tomography (CT) angiography images; as well as to propose a new classification by unifying the already reported classifications of the CeT and HA vascular anatomy.

Study Design: Observational study.

Place and Duration of Study: Department of Radiology, Faculty of Medicine, Selçuk University, Konya, Turkey, from February 2019 to March 2020.

Methodology: CT angiography-based evaluation of the CeT and HA branching patterns was performed in patient undergoing routine contrast-enhauced CT of abdomen. Types of variation were determined and classified into five types (1–5) and ten subtypes. Distribution was also sorted by age and gender.

Results: Type 1 (classic CeT and HA branching pattern) was detected in 240 (70.6%) out of 340 cases (126 females, 214 males). Sixty-five (19.12%) had Type 2 subtypes, in which HA branching pattern coexists with normal CeT configuration; whereas, Type 3a and 3d, Type 4 and 5 having anomalous CeT variants, with typical HA pattern, were observed in 5.87% (20/340) of the cases. The frequency of the concurrent variations (Type 3b and 3c) was 4.41% (15/340). The least frequent subtypes, Type 4 and 5, were observed in one (0.29%) and three (0.88%) cases, respectively. There was no significant differences in branching types frequency by gender and age ($p>0.05$).

Conclusion: Awareness of the range of anatomical variation in both the CeT and HA branching patterns, especially concurrent variations, is vital when planning surgical and radiological interventions to prevent possible iatrogenic injury and complications.

Key Words: *Branching pattern, Celiac trunk, Concurrent variations, CT angiography, Hepatic artery.*

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INTRODUCTION

Open surgical and endovascular interventions play an important role in the treatment of abdominal pathologies and angiographic examinations. The current techniques, such as transcatheter hepatic arterial chemoembolisation, abdominal endovascular aortic repair, hepatic resection and transplantation, allow for reimplantation or revascularisation of a great part of the upper abdominal structures. The correct surgical planning and success of these procedures require a detailed knowledge of the diferent variations of the celiac trunkus (CeT) and hepatic arterial (HA) anatomy.[1,2]

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Morphological variations of the CeT are not rare and their embryological bases have been well-defined. During embryonic period, a complete regression of the anastomoses of the primitive arteries results in the absence of the CeT, in which all branches originate directly from the AA.[3,4] In previous studies, the incidence of this rare anomaly was reported as ranging from 0.1 to 2.6%; whereas, the presence of normal anatomical confuguration of the CeT was determined in a range 43.6 - 90.5%.[3,5] Apart from the CeT branching variations, described by numerous authors, an accurate definition of the HA variants is of utmost importance in the preoperative imaging of living liver donor, and planning surgical or endovascular procedures.

In classic anatomical arterial branching pattern, the abdominal aorta gives rise to the CeT, superior mesenteric artery (SMA), and inferior mesenteric artery (IMA), anteriorly. The CeT originates directly from the AA just below the aortic hiatus, most commonly at the level of the T12 vertebra, and gives off three branches: the left gastric artery (LGA), splenic artery (SA), and common hepatic artery (CHA). Then, CHA bifurcates into the gastroduodenal artery (GDA) and hepatic artery proper (PHA), which divides into the right hepatic artery (RHA) and the left hepatic artery (LHA).[6,7] CT angiography is widely used to provide a comprehensive and non-invasive assessment of the abdominal vasculature. In the literature, numerous radiologic studies have evaluated the variations in the CeT and HA branching patterns for surgery of the upper abdominal cavity. There are significant differences between the results of these studies and discrepancies in their classifications. Most of the previous studies have predominantly focused on analysing the variations of either the CeT or HA branching pattern; but the correlation between these variations, as the prevalence of the concurrency, was not evaluated.[1-8]

To address major clinical needs, an in-depth knowledge of the considerably different concurrent variations of the CeT and the HA branching patterns are important, when performing surgical procedures in relation to the treatment of significant pathologies, as well as when planning endovascular interventions.

The aim of this study was to identify the anatomical variations in both CeT and HA branching patterns with their prevalence, and to unify the classifications of the CeT and HA vascular anatomy, already reported in literature.

METHODOLOGY

This study was performed at the Department of Radiology, Faculty of Medicine, Selcuk University, Konya, Turkey, from February 2019 to March 2020. A total of 340 adults with age ranging from 18 to 82 years, who had undergone intravenous contrast-enhanced vascular abdominal CT angiographic examination for routine diagnostic and surgical conditions were included. This observational study was approved by the Institutional Ethics Committee with an approval No. 2019/2182; and written informed consents were obtained for all CT examinations. The exclusion criteria were previous history of known abdominal vascular surgery, having pathological conditions, which compress the AA or its branches, and whose images with low-resolution or incomplete visualisation. Using a dual-source 128-multidetector CT scanner (Siemens Somatom Definition Flash, Munich, Germany), all examinations were performed; and the scan included all abdominal cavity from the level of the diaphragm to the iliac bifurcation. The scanning parameters were collimation 128 x 0.625, tomogram-lateral 120 kV, slice thickness 1 mm, rotation time 0.5 seconds, algorithm: 160 mA and field of view: 220 mm. All CT angiographic images were evaluated and interactively processed on dedicated Syngovia (Siemens, Germany) workstations to build multiplanar reformatted images and maximum intensity projections, which required a three-dimensional reconstruction. The eligibility of each CT image was decided by one anatomist and two experienced radiologists in consensus whether it was suitable for inclusion in this study. Based on the classifications of Marco-Clement and Michels,[4,9] the anatomical variations of the CeT and hepatic branching patterns were evaluated. On the basis of the above mentioned two types of classification, the branching variations of the CeT together with that of the HA, were classified into five groups according to the origin of the branches.

Data were then analysed using SPSS (version 25.0 Inc., Chicago, IL, USA). Categorical data are given as percentages and patient age was expressed as mean ± SD, minimum and maximum values. Along with descriptive statistics, Chi-square test was applied to search for association between the variations in terms of frequencies and groups (age and gender). A p-value <0.05 regarded as statistically significant.

RESULTS

A total of 340 patients with the mean age of 60.8 ± 15.9 years (59.4 ± 16.8 years in females, 61.7 ± 15.3 years in males), [126 (37.06%) females and 214 (62.94%) males] were evaluated. Both the CeT and HA had typical branching pattern in 240 out of 340 cases (88 females and 152 males, 70.6%); whereas, an anomalous branching variations in either CeT or HA were identified in remaining 29.4% of cases.

According to the proposed classification, the findings were described in five types (Table I).

Type 1 (Normal trifurcated CeT coexisting with typical hepatic branching pattern) with both of the CeT and HA branching patterns are in classic anatomical configuration. The CeT gives off three branches including the LGA, SA, and CHA, or there is a common origin for these branches.

The PHA bifurcates into the LHA and RHA. This type was divided into two subtypes: Type 1a, in which the LGA arises from the CeT prior to the bifurcation point (Figure 1a); Type 1b, in which the CeT trifurcated into the LGA, SA, and CHA (Figure 1b).

In 240 patients with Type 1 configuration, Type 1a was detected in 207 (86.3%, 76 females, 131 males); whereas Type 1b was identified in remaining 13.7% (12 females, 21 males) of the cases.

Type 2 (Normal trifurcated CeT coexisting with an anomalous hepatic branching pattern), had normal CeT branching pattern and was divided into four subtypes according to an aberrant hepatic branching pattern:

In Type 2a, the LHA arises from the PHA; whereas, the RHA originates from the SMA, an ectopic location, and is called as replaced RHA (RRHA) (Figure 1c). In our study, it was observed in 28 patients (10 female and 18 male, 8.2%).

Type 2b, in which the RLHA originating from the LGA coexists with the RHA arising from the PHA (Figure 1d), was detected in 23 patients (9 females and 14 males, 6.8%).

In Type 2c and 2d, there is an accessory HA arising from other AA branches. Type 2c includes accessory LHA (ALHA) originating from the LGA (Figure 1e); whereas, an accessory RHA (ARHA) originating from the SMA is found in Type 2d (Figure 1f). They were observed in 6 and 8 patients (1.76% and 2.35%), respectively.

Table I: Proposed new classification of the celiac trunk and hepatic artery branching patterns.

Types	Branches arising proximal to distal
Type 1 (Normal trifurcated CeT with typical hepatic branching pattern)	CeT branches: LGA-CHA-SA Type 1a (LGA arises from the CeT prior to the bifurcation point of the CHA and SA) (Figure 1a) Type 1b (CeT trifurcates into the LGA, CHA and SA) (Figure 1b)
Type 2 (Normal trifurcated CeT with anomalous hepatic branching pattern)	Type 2a [LHA arises from the PHA and replaced RHA (RRHA) originates from the SMA] (Figure 1c) Type 2b [Replaced LHA (RLHA) originates from the LGA and RHA arises from the PHA] (Figure 1d) Type 2c [PHA bifurcates into LHA and RHA and accessory LHA (ALHA) originates from the LGA] (Figure 1e) Type 2d [PHA bifurcates into LHA and RHA and accessory RHA (ARHA) originates from the SMA] (Figure 1f)
Type 3 (Incomplete or bifurcated CeT with typical or anomalous hepatic branching pattern)	Type 3a [Hepatosplenik trunk (LGA arises from the AA and CeT bifurcates into the CHA and SA) with typical hepatic branching pattern] (Figure 2a) Type 3b [Hepatosplenik trunk (LGA arises from the AA and CeT bifurcates into the CHA and SA) with RRHA originating from the SMA] (Figure 2b) Type 3c [Gastrosplenik trunk (CeT bifurcates into the LGA and SA) with CHA originating from the SMA] (Figure 2c) Type 3d [Hepatogastrik trunk (SA arises from the AA and CeT bifurcates into the CHA and LGA) with typical hepatic branching pattern] (Figure 2d)
Type 4 (No CeT)	All of the branches (CeT, LGA and SA) originate directly from the abdominal aorta. CHA has typical hepatic branching pattern (Figure 2e)
Type 5 (Celiacomesen teric trunk)	There is a common trunk for the CHA, LGA, SA and SMA (Figure 2f)

CeT: celiac trunk, LGA: left gastric artery, CHA: common hepatic artery, SA: splenic artery, PHA: proper hepatic artery, SMA: superior mesenteric artery, RHA: right hepatic artery, LHA: left hepatic artery.

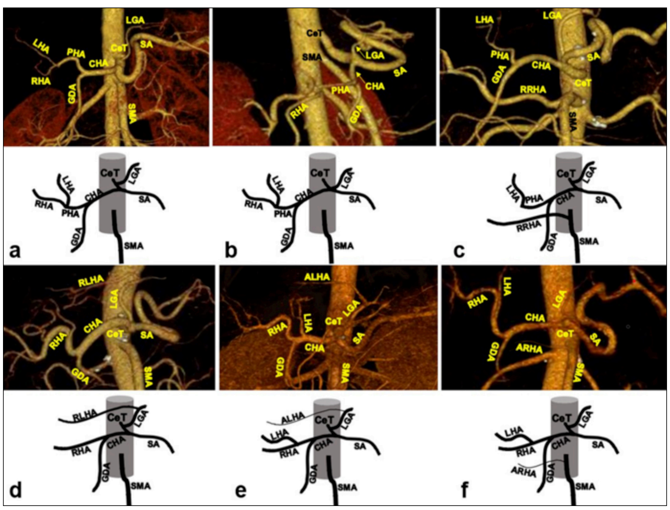

Figure 1: Computed tomography angiography three-dimensional volume rendering (3D VR) images showing normal trifurcated CeT with typical hepatic branching pattern (a-b). Normal trifurcated CeT with anomalous hepatic branching pattern (c-f). CeT, celiac trunk; LGA, left gastric artery; SA, splenic artery; CHA, common hepatic artery; GDA, gastroduodenal artery; PHA, proper hepatic artery; RHA right hepatic artery; LHA, left hepatic artery; RRHA, replaced right hepatic artery; RLHA, replaced left hepatic artery; ARHA, accessory right hepatic artery; ALHA, accessory right hepatic artery; SMA, superior mesenteric artery.

In Type 3 (Incomplete or bifurcated CeT coexisting with typical or an anomalous hepatic branching pattern); four different subtypes were observed and identified as Type 3a, 3b, 3c and 3d. Type 3a corresponds to hepatosplenik trunk, in which the LGA arises from the AA and CeT bifurcates into the CHA and SA, coexisting with typical hepatic branching pattern (Figure 2a). Six females and 9 males presented with Type 3a with a total result of 15/340 cases (4.4%). Type 3a associated with RRHA originating from the SMA was categorised as Type 3b (Figure 2b) and observed in two females (0.59%). In Type 3c, there is gastrosplenik trunk, in which the CeT bifurcates into the LGA and SA, associated with the CHA arising from the SMA (Figure 2c). It was detected in 4 females and 9 males (3.82%). Type 3d involves hepatogastrik trunk, in which the SA arises from the AA and the CeT bifurcates into the CHA and LGA (Figure 2d). Only one male (0.29%) presented Type 3d coexisting with typical hepatic branching pattern.

In type 4 (An absent CeT coexisting with typical hepatic branching pattern), each of the CeT branches arises separately from the AA with no common trunk (Figure 2e). Only one male (0.29%) showed Type 4 associated with typical hepatic branching pattern in this study. In type 5 (celiacomesenteric trunk=tetrafurcated CeT), there is a common origin for the celiac axis and the superior mesenteric artery (Figure 2f). Type 5 with typical hepatic branching pattern was observed in one female and two male patients (0.88%).

Sixty-five (19.12%) of the patients presented an anomalous HA branching pattern coexisting with normal CeT anatomic configuration (Type 2 subtypes); whereas, the CeT variants with typical HA branching pattern (Type 3a and 3d, Type 4 and 5) were observed in 5.87% (20/340) of the cases. The most common HA variations were Type 2a (the RRHA originates from the SMA) and 2b (the RLHA originates from the LGA) with the frequency of 8.2% and 6.8%, respectively. Furthermore, the most common CeT branching variant was Type 3a (hepatosplenik trunk) with the frequency of 4.41%. Concurrent variations of the CeT and HA branching patterns (Type 3b and 3c) were observed in 4.41% (15/340) of the study population.

Table II: Distribution of the frequency of the celiac trunkus and hepatic branching pattern variations according to gender.

Variation types	Female (n=126)	Male (n=214)	Total (n=340)
Branching patterns			
Type 1a	60.8% (76/126)	61.2% (131/214)	60.9% (207/340)
Type 1b	9.5% (12/126)	9.9% (21/214)	9.7% (33/340)
Type 2a	7.9% (10/126)	8.4% (18/214)	8.2% (28/340)
Type 2b	7.1% (9/126)	6.54% (14/214)	6.8% (23/340)
Type 2c	1.58% (2/126)	1.86% (4/214)	1.77% (6/340)
Type 2d	2.38% (3/126)	2.32% (5/214)	2.35% (8/340)
Type 3a	4.9% (6/126)	4.2% (9/214)	4.41% (15/340)
Type 3b	1.58% (2/126)	0	0.59% (2/340)
Type 3c	3.18% (4/126)	4.2% (9/214)	3.82% (13/340)
Type 3d		0.46% (1/214)	0.29% (1/340)
Type 4	0	0.46% (1/214)	0.29% (1/340)
Type 5	0.79% (1/126)	0.93% (2/214)	0.88% (3/340)

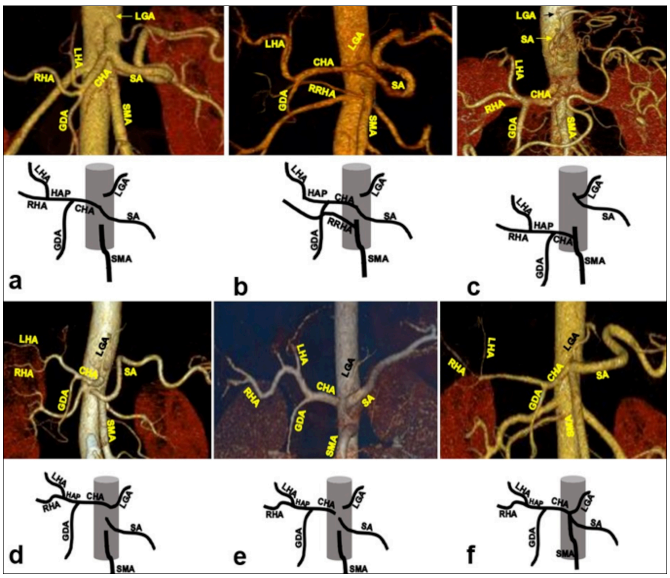

Figure 2: Computed tomography angiography three-dimensional volume rendering (3D VR) images showing incomplete or bifurcated CeT with typical or anomalous hepatic branching pattern (a-d). Type 4 (No CeT) and Type 5 (celiacomesenteric trunk) (e-f). CeT, celiac trunk; LGA, left gastric artery; SA, splenic artery; CHA, common hepatic artery; GDA, gastroduodenal artery; PHA, proper hepatic artery; RHA right hepatic artery; LHA, left hepatic artery; RRHA, replaced right hepatic artery; SMA, superior mesenteric artery.

Type 3c (3.82%), in which gastrosplenik trunk associated with the CHA arising from the SMA, was the most common variant of the concurrent variations. The least frequent subtypes, Type 4 and 5, were observed in 0.29% (1/340) and 0.88% (3/340), respectively. Table II summarizes the distribution of each frequency of the branching types according to sex. There was no statistically significant association of these subtypes with age in either sex ($p>0.05$, χ^2 test).

DISCUSSION

This study presented that there might be a significant correlation between the variations of the CeT and HA, incorporating and combining the classifications reported in previous studies based upon the analysis of a large sample of CT images. The CeT and HA branching patterns are characterised by normal trifurcated CeT and the bifurcated PHA into the LHA and RHA from that classically described in literature, respectively.[4,9,10] However, previous cadaveric and radiologic studies revealed variations from this classic anatomical configuration are not rare and usually detected incidentally. Awareness of the range of anatomical variations in both the CeT and HA branching patterns, in particular concurrent variations, is vital when planning surgical or radiologic hepatic procedures, since the lack of recognition of the possibility that these variations may be present in any one patient can result in serious iatrogenic injury and surgical complications.[8,11,12] Even if the median arcuate ligament syndrome is commonly asymptomatic, the variations in celiac and hepatic vascular mapping should be taken into consideration before any surgical procedure against possible accidental vascular injury.[4,12] Therefore, the authors used a new classification that is sufficiently comprehensive to enable a simpler unifying classification to be devised in this study.

Although numerous authors have evaluated the branching pattern of the CeT resulting in various proposed classifications, the most common subtype of the classic pattern of the CeT is controversial.[4,6,8-13] These results are in agreement with previous studies in reporting that Type 1a, in which the LGA arose from the CeT prior to the bifurcation point, is the most common subtype followed by Type 1b, in which the CeT trifurcated into the LGA, SA, and CHA through the same point of branching.[4,10-14] In literature, the prevalence of the classic pattern of the HA branching, in which the PHA bifurcates into the LHA and RHA, was reported in a range 57–79.6%.[15-17] In the present study, both the CeT and HA had normal anatomical configuration in 70.6% of cases.

In the present sample, the most common variant of the combined CeT and HA branching pattern was Type 2a (Normal trifurcated CeT coexisted with RRHA originating from the SMA, 8.2%) closely followed by Type 2b (normal trifurcated CeT coexisted with RLHA originating from the LGA, 6.8%) and Type 3a (hepatosplenik trunk coexisted with typical hepatic branching pattern, 4.41%) configuration. Similar to the present findings, Zagyapan *et al.* reported that Type II, in which the RHA arising from the SMA with the frequency of 17.8% was the most common variant of the CeT and hepatic arterial system followed by Type III, in which the LHA arising from the LGA (13.1%) in their study population.[6] It is also mentioned in radiological studies that incomplete or bifurcated CeT was the most common variant of the CeT branching pattern. Among subtypes of this variant, gastrosplenic trunk was reported as the most common variant in some studies;[2,4,12,18] whereas, the prevalence of hepatosplenic trunk was found to be higher than gastrosplenic trunk by numerous authors.[8,19,20] This data is consistent with previous studies in finding that hepatosplenic trunk, Types 3a of this classification, is the most common variant followed by Type 3c amongst the infrequent subtypes. Furthermore, it has been reported that the most frequent variant of the HA branching pattern was the replaced RHA, arising from the SMA, followed by the replaced LHA, arising from the LGA, in accordance with the present results including the frequency of 8.79% (Type 2a and 3b) and 6.8% (Type 2b), respectively.[2,6,14,18,19]

Concurrent variations having the frequency of 4.41% (Type 3b and 3c) reported in this study are an example of the presence of multiple variations in both CeT and HA branching patterns. Awareness of the range of anatomical variations in the CeT and HA is vital when planning surgical or radiologic upper abdominal procedures, since the lack of recognition of the possibility that the concurrent variation may be present in any one individual, can lead to severe iatrogenic vascular injury and surgical complications.

A potential limitation of this study is the lack of the comparison of completely healthy group with the patients having hepatobiliary tract malignancies and the retrospective design. In addition, a larger sample size involving different ethnicities may give researchers more variations. To the best of authors' knowledge, this is the first report of the prevalence of the concurrency among the CeT or HA branching pattern variations. It must be noted that the current study carried out is one of the largest CT-based studies and proposes a classification, which allows unifying all classifications described in the literature.

CONCLUSION

The origin of the CeT branches and hepatic arteries, as well as the type-specific reference points of subtypes, provided a comprehensive understanding of both the CeT and HA anatomical variations for vessels' identification and flexible for practical meanings during surgical interventions. Recognising a significant correlation between the variations of the CeT and HA branching patterns and classification of them during endovascular interventions, liver resection or transplantation and laparoscopic procedures, should be taken into account preoperatively.

ETHICAL APPROVAL:
This observational study was approved by the Institutional Ethics Committee with an approval No. 2019/2182.

CONFLICT OF INTEREST:
The authors declared no conflict of interest.

AUTHORS' CONTRIBUTION:
GA: Conception and design, analysis and interpretation of data, drafting of the manuscript, revision of the paper and advices.
AEC: Conception and design, drafting of the manuscript and advices.
MK, NS: Analysis and interpretation of data, and revision of the paper.
All authors gave final approval for publication of the manuscript.

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