Research Paper: Computed Tomography Angiography-Based Evaluation of Anatomical Variations of the Celiac Trunk and Renal Arteries

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ABSTRACT

Background: The abdominal aorta and its main branches, such as the celiac trunk and the renal arteries are manipulated during various radiologic, surgical, and oncologic procedures. This study aimed at evaluating the anatomical pattern of these vessels to assist surgeons and radiologists reduce the risk of intra- as well as postoperative complications.

Methods: A retrospective analysis of 536 Computed Tomography Angiography (CTA) studies of living potential kidney donors was conducted from January 2012 to December 2018.

Results: The anatomical variations of the celiac trunk was found in 9.5% of the cases. Among these cases, the most frequent variation was the Left Gastric Artery (LGA) as the first branch of the celiac trunk (80.4% of the cases). Gender was not overall significantly associated with the variations of the celiac trunk (P=0.670); however, there was a significant correlation between male gender and the most prevalent form of the celiac trunk variation (P=0.004). Variations of the renal artery occurred in 22.94% of the cases, with the left accessory renal artery being the most common variant (28.45% of the cases). Gender and the involved side (right / left) were not significantly related to the renal artery variations (P=1.000 & P=0.546, respectively). No concomitant variation of the celiac trunk and the renal artery was detected in our study.

Conclusion: The anatomical variations of the celiac trunk and the renal arteries occur commonly; thus, the branching pattern of these arteries should be assessed prior to any procedure concerning them.

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1. Introduction

Evaluating the anatomical pattern of vessels using modalities, such as conventional angiography, Computed Tomography Angiography (CTA), or Magnetic Resonance Arteriography (MRA) prior to particular procedures has become an intimate element of medical care. Besides, they have implications for a broad spectrum of physicians, such as transplantation surgeons, oncological surgeons, radiologists, and oncologists [1]. The rationale behind this is to reduce, and ideally eliminate, potential complications prompted by the unrecognized anatomical variations of vessels; thus, prevent catastrophic events. The abdominal aorta and its main branches, such as the celiac trunk and the renal arteries are manipulated in a multitude of diagnostic and therapeutic procedures; therefore, we have conducted this study using CTA to appraise the anatomical variations of these vessels, as well as their frequencies.

The celiac arterial trunk is an anterior branch of the abdominal aorta with a relatively large diameter; approximately 2.25 cm in length. It is normally bifurcated into 3 branches of the common hepatic, the left gastric, and the splenic artery. The Common Hepatic Artery (CHA) generates a gastroduodenal artery and a proper hepatic artery. This normal pattern is sometimes referred to as tripus Halleri [2]. The concept of anatomical variations of the celiac trunk has been first proposed by Haller, in 1756 [1]. Since then, various classifications of the celiac trunk variations have been introduced; the more recent of which is the one employed by Panagouli et al. [2] in 2013. This was achieved after conducting a systematic review of cadavers and imaging studies. The same classification was used in our study to report the anatomical variations of the celiac trunk.

The other variations assessed in our study are those occurring to the renal arteries. The renal arteries are among the main branches of the abdominal aorta, branching off it inferiorly to the Superior Mesenteric Artery (SMA) [3-5]. The healthy pattern of the renal artery is a single artery originating from the abdominal aorta, which enters the renal hilum. It is at this point, or somewhere near this point, where the renal arteries give rise to anterior and posterior branches. At further points, lobar, interlobar, and arcuate arteries branch off. To evaluate the anatomical variations of the renal arteries, we implemented the classification proposed by Merklin and Michels, in 1958 [6].

2. Materials and Methods

A CTA database of the abdominal aorta and its branches conducted on living potential kidney donors in our imaging center between January 2012 and December 2018 was included in this study.The study exclusion criteria were as follows: technically inadequate CT scans, CT scans with inadequate demographic data, duplicated CT scans, CT scans with inadequate arterial phases, patients with pathologies possibly influencing the healthy vascular anatomy of the abdominal aorta, CT scans performed at other centers, and a history of abdominal surgeries, such as the liver and gastric operations, or nephrectomies.

A 64-detector scanner (Brilliance, 64 Multislice CT System, Philips Medical Systems, Best, the Netherlands) was used to perform multidetector CT angiography studies. Iodinated non-ionic contrast medium (iodixanol 320 mgI/mL, Visipaque; Oslo, Norway) was injected into the brachial vein via an 18-20-gauge angiocath needle using an automatic injector. The Field of View (FOV) was the area from the lower sections of the thoracic spine to the level of the symphysis pubis, with a supine position of the patient. Accordingly, 1.4-mm images were obtained with an increment of -0.7 mm, collimation of 64×0.625, and 120 kV.

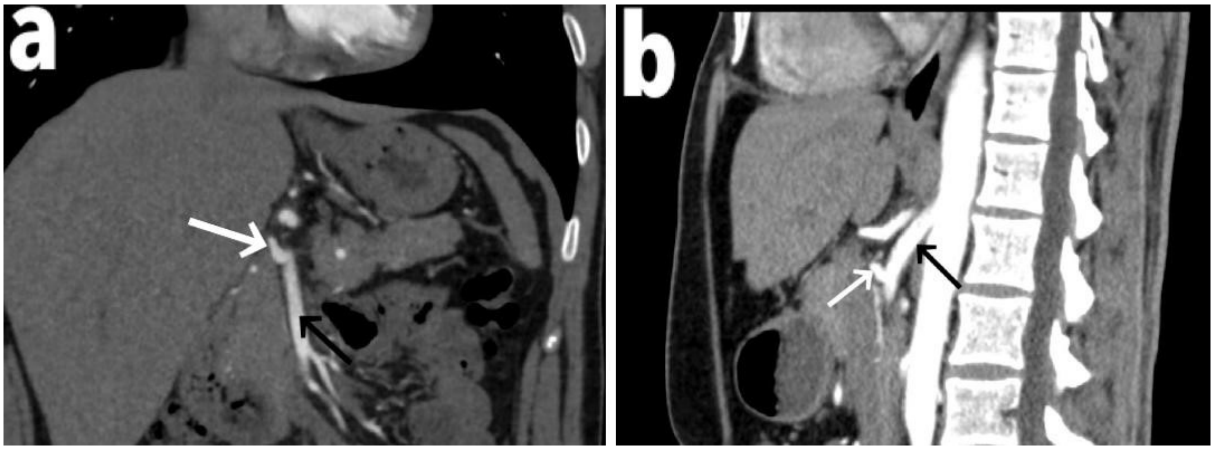
To analyze the images, they were transferred to a workstation, and a Three-Dimensional (3D) volume rendering technique (3D VRT), Multiplanar Reconstruction (MPR), and Maximum Intensity Projection (MIP) were used for assessing relevant cases. Two board-certified radiologists independently studied the data provided to determine the vascular pattern of the celiac trunk; superior and inferior mesenteric arteries according to Panagouli's classification [2] (Table 1), and the renal arteries based on Merklin and Michel's [6] classification. According to Merklin and Michel's [6] classification, the accessory renal arteries are categorized based on their origin and entry into the kidney; I) from the abdominal aorta, II) from the main renal artery, and III) from other origins. Ethical approval was granted from our institutional review board. Besides, an informed written consent form was obtained from all the participants to access their CTA images and publish this paper and any accompanying images.

Quantitative data were reported as Mean±SD. Furthermore, qualitative data were presented as frequencies and percentages. The Chi-squared test, Fischer's Exact test, and Independent Samples t-test were used to compare vascular characteristics based on the variables. $P<0.05$ was considered statistically significant.

3. Results

From January 2012 to December 2018, 735 CTA studies were performed in our imaging center. After considering the study exclusion criteria, a total of 536 cases were enrolled in this research. Among these cases, 51 (9.5%) patients presented anatomical variations of the celiac trunk according to Panagouli's classification [2] (Figure 1). Besides, 123 (22.94%) patients demonstrated renal arteries variations according to Merklin and Michel's classification [6]. Table 2 lists the frequency distribution of each group, as well as gender and age regarding the celiac trunk variations recorded in our study.

Of the total 51 cases with anatomical variations of the celiac trunk, 37 (72.5%) patients were males. The patients' age in this group varied between 20 and 39 years, with the Mean±SD age of 29.62±5.27 years. The most frequent anatomical variation of the celiac trunk was the type I, form 2a (Figure 2) with a prevalence of 80.4%, followed by type II, form 1 with a frequency of 9.8%. The group-wise frequency of different forms based on Panagouli's classification [2] is detailed in Table 3.



International Journal of
Medical Toxicology & Forensic Medicine

Figure 1. An example of an anatomical variation of the celiac trunk on a. coronal; and b. sagittal MIP reconstructed CTA, showing replaced Right Hepatic Artery (RHA) (white arrow) originating from SMA (black arrow)

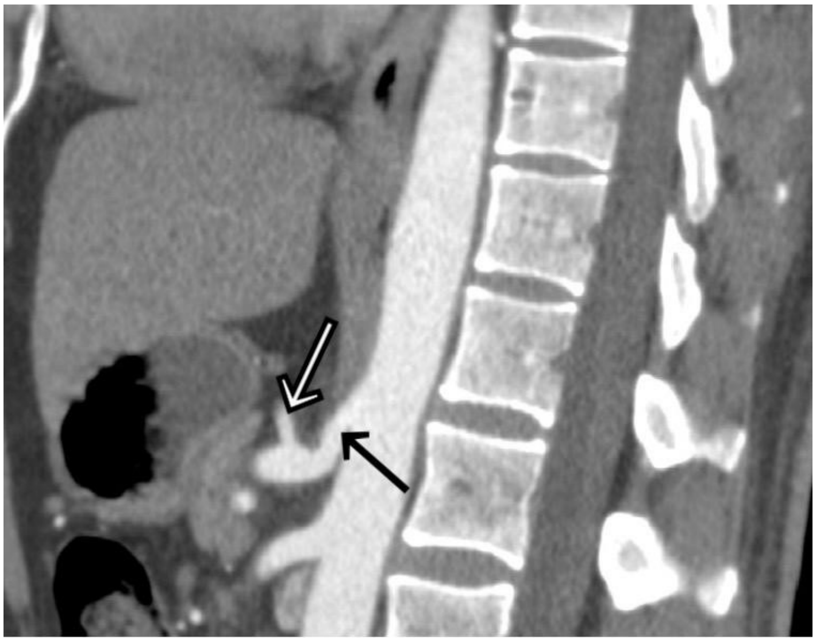


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Figure 2. Sagittal MIP reconstructed CTA, reflecting LGA (white arrow) as the first branch of the celiac trunk (black arrow), Panagouli type I, form 2a

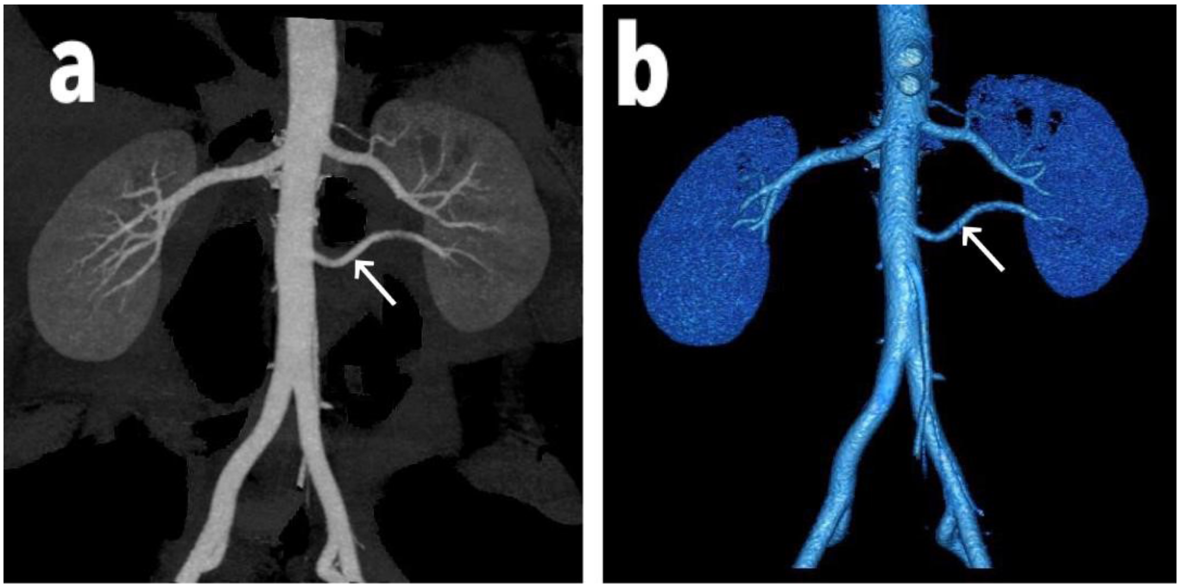

Figure 3. Coronal a. MIP reconstructed CTA, and b. 3D VR reconstructed CTA, demonstrating left accessory renal artery (arrows)

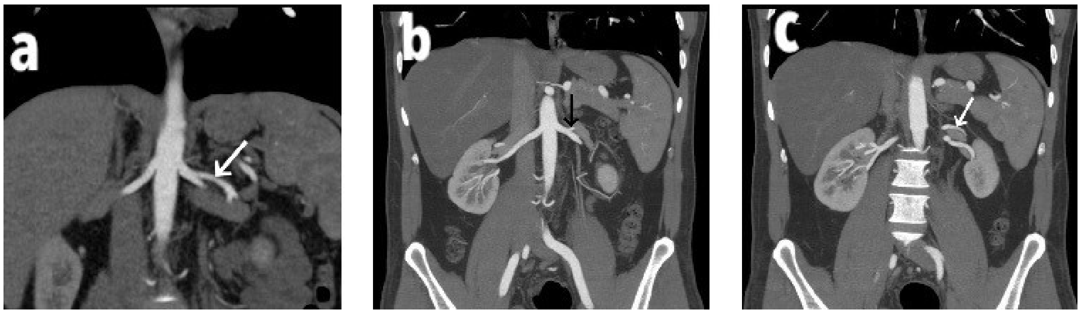

Figure 4. a, b, and c Coronal MIP reconstructed CTA, indicating left HUP variant of the renal artery (arrows)

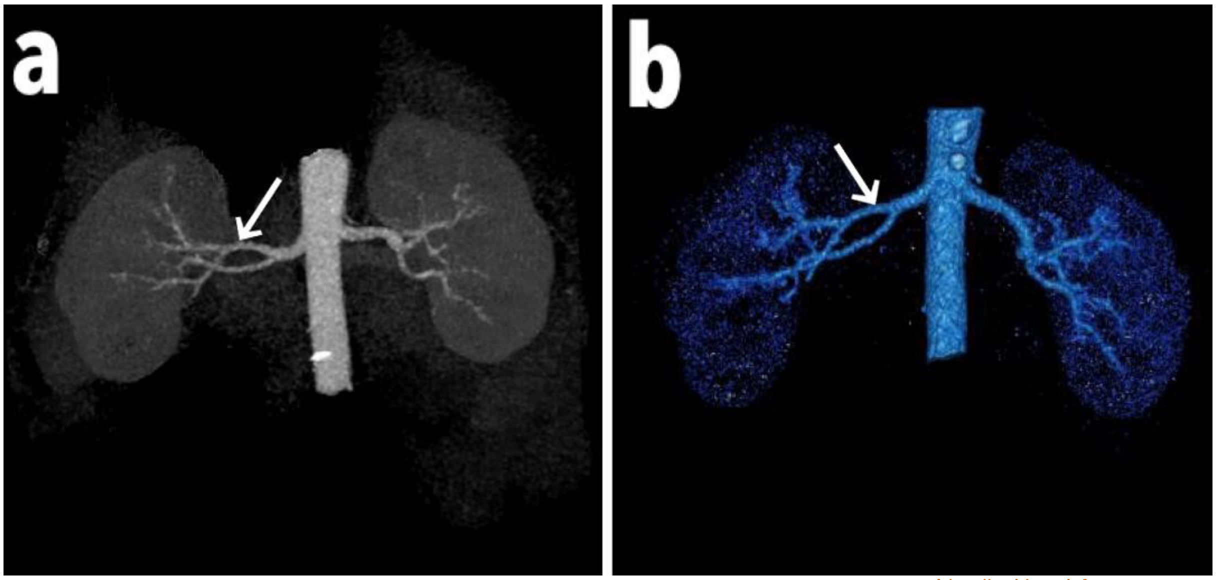

Figure 5. Coronal (a) MIP reconstructed CTA, and (b) 3D VR reconstructed CTA, presenting the right HUP variant of the renal artery (arrows)

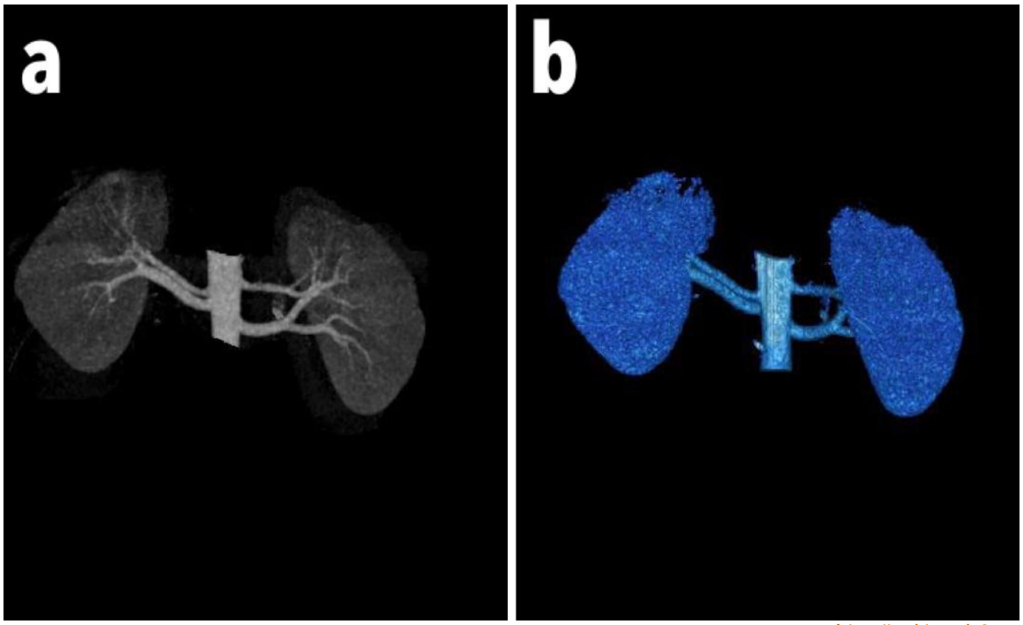

Figure 6. Coronal a. MIP reconstructed CTA; b. 3D VR reconstructed CTA, showing bilateral accessory renal arteries

Overall, there was no significant association between gender and anatomical variations of the celiac trunk (P=0.670); however, the male gender was significantly correlated with the type I-2a variant (P=0.004).

Of the total 123 cases of anatomical variations of the renal arteries, 104 (84.6%) were males. The Mean±SD age of the patients in this group was 28.60 (5.63) (age range: 17-42 years). The most prevalent renal artery anatomical variation was the accessory renal artery, with a prevalence of 53.7%; this rate was followed by the variant which originates from the main hilar artery and goes to the hilar upper polar(HUP) (HUP) (27.6%). Using the Chi-squared test, the affected side of the body (right/left) was neither significantly associated with the two most frequent variations of the renal artery (accessory artery and HUP) (P=0.161) nor with classifications II and III (P=0.546). The association between gender and anatomical variations of the renal artery was also insignificant (P=1.000). Table 4 demonstrates the details of anatomical variations of the renal artery found in our study. None of our patients presented variations of the celiac trunk and the renal artery, concomitantly.

4. Discussion

Being aware of the pattern of the celiac trunk's branching has several implications for radiologists and surgeons. It can aid radiologists in the process of therapeutic or diagnostic angiographies. Moreover, it is beneficial when celiac trunk catheterization is required during embolization indicated in active upper gastrointestinal bleeding or pseudoaneurysms. It also significantly impacts oncologic disorders; a desirable representative would be Hepatocellular Carcinoma (HCC). This is because the origin as well as the course of the hepatic artery must be determined before initiating transarterial hepatic artery chemoembolization [2].

For liver transplantation surgeons, it is of prime importance to not compromise the celiac trunk, as well as proper hepatic artery and CHA, during the operation procedure. Thus, preoperative evaluation of the celiac trunk and its potential anatomical variations is necessary. The same scenario also applies to pancreatic and hepatobiliary surgeries, gastrectomies, and esophagogastric resections. Even lymph node dissections involving the aforementioned areas necessitate the vascular anatomy to be elucidated before any procedure; any insult may result in hemorrhage, ischemia, or the necrosis of the affected organ.

In vascular surgery, like aneurysm repairs conducted in the thoracoabdominal region, or the treatment of the celiac trunk compression syndrome, the pre-evaluation of the anatomy of the celiac trunk is required. This is because particular types of celiac trunk, like prevalent trunks with the SMA may increase the risk for postoperative complications. The significance of such evaluations may be further highlighted when there is suboptimal visualization of the surgical field. For example, when the patient is obese, or in cases of inflammation or hepatobiliary neoplasms with prior surgeries [2, 7, 8].

Table 1. Panagouli's classification of the celiac trunk anatomical variations

Type	Description
I	The trifurcation of the celiac trunk (CHA, LGA, & SA)
Form 1	The common origin of CHA, LGA, and SA (True Tripod)
Form 2	The division into two branches with the third branch arising earlier along the celiac trunk (false tripod)
Form 2a	LGA being the first branch
Form 2b	CHA being the first branch
Form 2c	SA being the first branch
II	The bifurcation of the celiac trunk
Form 1	Hepatosplenic trunk with LGA originating from the AA
Form 2	Hepatosplenic trunk without normal LGA
Form 3	Hepatosplenic trunk and gastroenteric trunk
Form 4	Splenogastric trunk with CHA originating from the AA
Form 5	Splenogastric trunk with CHA originating from the SMA
Form 6	Splenogastric trunk and hepatomesenteric trunk
Form 7	Hepatogastric trunk with SA originating from the AA
Form 8	Hepatogastric trunk with SA originating from the SMA
Form 9	Hepatogastric trunk and splenomesenteric trunk
III	Additional branches
IV	Celiacomesenteric trunk
V	The variations of the origin of the CHA
VI	Hepatosplenomesenteric trunk with LGA arising as a branch of the others or independently
VII	The absence of the celiac trunk
VIII	Splenogastromesenteric trunk with CHA arising as a branch of the others or independently
IX	Splenogastric trunk as the origin of a common inferior phrenic trunk
X	Celiac-bimesenteric trunk

International Journal of Medical Toxicology & Forensic Medicine

CHA: Common Hepatic Artery, LGA: Left Gastric Artery, SA: Splenic Artery, AA: Abdominal Aorta, SMA: Superior Mesenteric Artery.

The reason for anatomical variations detected in the celiac trunk may be found in abnormal regression or the persistence of the primitive splanchnic arteries [9] during vascular evolution. Such incidences occur throughout the embryonic, and later, the fetal life, when the viscera begin to descend into the abdomen, and the arterial origins move likewise [10].

There is a data inconsistency regarding the frequency of anatomical variations of the celiac trunk. In our study, the anatomical variations of the celiac trunk occurred in 9.5% of the cases. Furthermore, LGA as the first branch of the celiac trunk (Panagouli type I, form 2-a) was found to be the most frequent form of these variants with a frequency of 80.4%. Panagouli et al. [2] performed a systematic review of 7 imaging studies, as well as 25 cadaveric materials.

Table 2. The frequency of the detected anatomical variations of the celiac trunk based on Panagouli's classification

Type-Form	No. (%)	Gender, No. (%)		Mean±SD
		Male	Female	Age (y)
I-2a	41 (80.4)	30 (72.2)	11 (26.5)	30.21±5.07
I-2b	1 (2)	1 (100)	0 (0)	21
II-1	5 (9.8)	2 (40)	3 (60)	28±7.51
II-4	2 (3.9)	2 (100)	0 (0)	28±4.24
II-9	1 (2)	1 (100)	0 (0)	27
III	1 (2)	1 (100)	0 (0)	28

International Journal of
Medical Toxicology & Forensic Medicine

They identified bifurcated celiac trunk as the most frequent variation with a frequency of 7.40%. Additionally, 0.38% of the cases had no celiac trunk. Besides, a hepatosplenomesenteric trunk was observed in 0.40% of them. Celiacomesenteric trunk had an incidence of 0.76%. Their study also revealed that the anatomic variation of the celiac trunk occurred in 10.5% of the imaging series, and 14.9% of cadaveric ones.

Winston et al. [8] used CTA for evaluating the anatomical variations of the celiac trunk in 371 patients; among whom, 44% presented a single arterial variant, and in 6% of the cases, more than one arterial variations were detected. They reported a replaced RHA arising from the SMA as the most common variation with a frequency of 15%. This rate was followed by a replaced left hepatic artery arising from the LGA with a frequency of 8%. Araujo Neto et al. [11] explored 60 multidetector CT scans. They concluded that hepatosplenic trunk was the most prevalent anatomical variation of the celiac trunk with a prevalence of 8.3%.

Brasil et al. [12] evaluated the celiac trunk variations in 100 cases using the same imaging modality. They observed a normal celiac trunk in <50 (43%) patients. The classification employed in their study was introduced by Sureka et al. [13], and not Panagouli's classification [2]; according to which, our findings were stratified.

The other investigated anatomical variation concerned the renal artery. The number of renal arteries, as well as the anatomical location, may vary in individuals. The kidneys are supplied by various arteries as they form in the pelvis, and during ascend to the abdomen to be located in their final position. Initially, they form the common iliac arteries, then form the distal aorta, and finally form the renal arteries; they arise from the abdominal aortic artery [14]. Accessory renal arteries may enter the kidneys directly from the inferior or superior renal poles; thus, the ligation of these arteries during surgical procedures may lead to the necrosis of the supplied segment [15].

Renal transplantation could be the most evident indication for the preoperative evaluation of the anatomical pattern of the renal arteries. However, several other pro-

Table 3. The group-wise frequency of various forms of anatomical variations of the celiac trunk according to Panagouli's classification

Group		No. (%)
I	I-2a	41 (97.8)
	I-2b	1 (2.4)
II	II-1	5 (62.5)
	II-4	2 (25)
	II-9	1 (12.5)
III	-	1 (100)

International Journal of
Medical Toxicology & Forensic Medicine

Table 4. The characteristics of the anatomical variations of the renal artery observed in our study

Group-Form	No. (%)	Gender, No. (%)		Mean±SD	Involved Kidney, No. (%)	
		Male	Female	Age (y)	Left	Right
Accessory (Figure 3)	66 (53.7)	55 (83.3)	11 (16.7)	29.31±6.20	35 (53)	4 (31)
HUP (Figures 4, 5)	34 (27.6)	30 (88.2)	4 (11.8)	27.05±5.11	13 (38.2)	21 (61.8)
HLP	6 (4.9)	4 (66.7)	2 (40)	27±2.96	6 (100)	0 (0)
HUP + Accessory	7 (5.7)	6 (85.7)	1 (14.3)	28.14±3.33	3 (42.9)	4 (57.1)
Accessory + Accessory (Figure 6)	4 (3.3)	4 (100)	0 (0)	29±4.83	3 (75)	1 (25)
HLP + Accessory	6 (4.9)	5 (83.3)	1 (16.7)	31.50±5.24	4 (66.7)	2 (33.3)

HUP: originates from the main hilar artery and goes to the upper renal pole

HLP: originates from the main hilar artery and goes to the lower renal pole

cedures, such as graft deployment during the repair process of an endovascular aneurysm; nephrectomy; open aneurysmorrhaphy [16]; abdominal vascular surgeries, particularly severe renal artery stenosis; renal trauma, and urologic and radiologic evaluations could benefit from this assessment. Studies suggested that in cases of multiple renal arteries, the odds of failure of the transplantation could be higher than that of the cases with a single renal artery [17, 18].

The importance of performing a preoperative evaluation of renal vascular structure may be better highlighted by a case presented by Buisman et al. [19]. They conducted a right laparoscopic nephrectomy on a patient due to post-traumatic renal function deterioration. They overlooked a preoperative renal evaluation, which resulted in the ischemia of the left kidney. This incidence occurred due to an undetected common trunk right renal artery, supplying a precaval left renal artery.

Costa et al. [20] conducted a retrospective study on 302 living kidney donor candidates who underwent preoperative radiologic assessment using MRI or CTA. Accordingly, they reported that 58.9% of the cases had at least one anatomical variations or acquired abnormalities. Sarsengaliyev et al. [21] preoperatively explored the CTAs of 32 living donor candidates. Additional renal arteries were observed in 32.3% of the cases, with >50 (54.5%) of them being females. Our study, however, failed to demonstrate any significant association between gender and the variations of the renal artery (P=1.000).

Yang et al. [22] determined indications for right nephrectomies. Subsequently, they argued that 89.3% of these cases were due to multiple or proximal bifurcating left renal arteries. Low et al. [23] evaluated 22 potential kidney donors. Of the total 44 native kidneys, 9 and 5 had accessory renal arteries and early arterial branches, respectively.

Johnson et al. [16] assessed 302 CT scans,; 36.1% of the cases were found to have accessory renal arteries. In the majority of the cases, the accessory renal arteries arose from the abdominal aorta. Kornafel et al. [24] evaluated 201 cases of CTAs and reported the frequency of variations as 43.8%. In their study, anatomic variation was more frequent in the renal arteries, compared to the celiac trunk and the SMA. Our study supported this finding.

Satyapal et al. [25] documented significant differences in the additional first renal arteries incidence based on the patient's gender and race. They reported the frequency of the first and second additional arteries to be 23.2% and 4.5%, respectively. The prevalence of renal artery variations was equal to 22.94% in our study. Besides, the left accessory renal artery was the most common variant, without any significant association with the patient's gender (P=1.000).

A large body of literature indicates that the variants of the renal artery significantly occurred on the left side. This finding was, however, disapproved by our study; we found no significant association between the side of involvement (right/left) and the variations of the renal artery (P=0.546) [14, 25].

Previous studies also reported cases with concomitant vascular anatomic variations. Ugurel et al. [15] found a significant association between renal artery variations and celiac trunk-hepatic arterial system variation. Arifuzzaman et al. [26] conducted a retrospective cross-sectional study on 110 patients undergoing multidetector CTA of the abdominal aortic artery. They concluded that 8.2% of them had a celiac trunk with a gastrosplenic trunk variant. Moreover, 15.5% of the patients had renal arterial system variations, with two renal arteries on the left side and two on the right as the most frequent ones. There is also a report on the heptafurcation of the celiac trunk and double renal arteries on both sides by Rusu and Manta [27]. Our study, however, does not support the co-occurrence of these variations.

One of the strengths of our study was using CTA to assess the variations. CTA is increasingly used in imaging centers for some reasons. First, it has an accuracy of 97%-98% in detecting arterial anatomic variations [28, 29]. The minimally invasive nature of CTA also makes it preferred over invasive modalities, like conventional angiography. The third reason is the ability of this modality to visualize smaller arterial structures, which makes it even more reliable.

This study considered 536 cases; therefore, it involved a relatively larger population, compared to the majority of previous studies. It has also assessed the odds of finding concomitant anatomical variations (the celiac trunk and renal arteries); however, most of the prior studies have solely focused on the variations of either the celiac trunk or the renal arteries. We have also evaluated the prevalence rate of the renal artery variations on each side (right / left).

This study also had some limitations; one of which is that we disregarded evaluating the impact of anatomical variations on future treatment planning. However, there seems to be adequate data regarding this matter. The other research limitation was assessing neither the length nor the diameter of the detected anatomical variations.

5. Conclusion

The obtained data indicated that 9.5% and 22.94% of the patients may be expected to have variants of the celiac trunk and the renal artery, respectively. There was no significant association neither between gender and these anatomical variations nor between the side of involvement (right/left) and the variations of the renal artery. There is a relatively high frequency of anatomical variations of the celiac trunk. The renal artery entails an assessment of the structure of these vessels that must be considered before any procedures.

Ethical Considerations

Compliance with ethical guidelines

Institutional Review Board approval was obtained for the study and Informed consent was obtained from all individual participants included in the study.

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Author's contributions

Project development: Sara Besharat; Manuscript writing and editing, interpretation of the data: Parima Safe; Project development: Nasser Malekpour Alamdari; Data analysis: Sara Besharat, Parima Safe, Husain Karrabi; Data collection: Sara Besharat, Parima Safe, Husain Karrabi; Final version approve: All authors.

Conflict of interest

The authors declared no conflicts of interest.

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