64 Slice CT Evaluation of Anatomical Variations of Main Arteries Arising from the Abdominal Aorta and their Branching Pattern

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Abstract
Aim: To determine the comprehensive spectrum of celiac axis including SMA, IMA, hepatic and renal artery variations with the use of multi-detector computed tomography (MDCT).

Material and Methods: This retrospective and prospective study was conducted in the Department of Radio diagnosis, Dr. S.N. Medical College and Associated Group of Hospitals, Jodhpur in 500 patients subjected to MDCT abdomen for various indications. Patients with a history of prior major upper abdominal surgery and patients with occlusion of celiac, hepatic, SMA and renal arteries were excluded.

Results: Seven types of celiac axis anatomic variations were identified in our study (including SMA). Anatomic variations in celiac axis were seen in 9% of patients with ambiguous celiac axis anatomy in 2% of the patients. IMA origin was normal in all patients. CHA originated from celiac axis in 95.20% of the patients. Variations in anatomic origin of CHA were seen in 2.8% patients. Normal origin of RHA from HAP and CHA was seen in 77.75% patients. LHA originated from HAP and CHA in 77.75% patients. MHA originated from RHA in 48% patients, LHA in 12% and from CHA in 12% cases. Origin of MHA could not be defined in 28% of patients. GDA originated from CHA in 95% of patients. Single renal artery was seen in 53% patients. 49% patient have variation in the form of early branching and additional renal arteries.

Conclusion: Variations in the celiac trunk, SMA, hepatic artery and renal artery are common, and their detection is important prior to any interventions or abdominal surgeries.

Keywords: SMA/IMA-superior/inferior mesenteric artery; CHA- common hepatic artery; HAP-hepatic artery proper; RHA/LHA/MHA- right/left/middle hepatic artery; GDA-gastro duodenal artery.

Introduction
Evaluation of arteries branching from the abdominal aorta (the level of their divergence, presence of atypical variants of a common origin of arteries or presence of additional arteries) plays an important role in the surgical planning. Due to short time of the examination, the Multi detector Computed Tomography (MDCT) proves to be useful in emergency cases as well as in a quick assessment of the vascular axis and for the purposes of immediate surgeries or endovascular interventions.[1]

In 1955, Michel described the classification scheme for describing anatomic variation in the hepatic arterial blood supply based on the results of dissecting 200 cadavers [Table 1].[2] In 1994,
Hiatt described surgical anatomy of the hepatic arteries in 1000 cases. In 1969, Vandamme et al., did extensive research on hepatic artery anomalies on 156 cadavers. Then, in 1971, Suzuki et al., published their series on 200 patients based on angiography study and highlighted the importance of hepatic artery variations. In 2010, Song et al., published the largest series of their work in celiac axis and hepatic artery variations in 5002 patients. Anatomical variations of the celiac axis and hepatic artery are described primarily according to Song’s nomenclature and compared according to Uflacker’s system for celiac axis and Michel and Hiatt classification for hepatic arteries.

Recently, with the advent of newer interventional and surgical options for patients with primary and metastatic hepatic malignancies, partial hepatectomy for liver transplantation and laparoscopic cholecystectomy, surgeons and interventional radiologists are now relying on accurate imaging and assessment of the hepatic arterial supply. A road map of the arterial vascularity of the donor and recipient is a prerequisite for transplant surgery. Detailed hepatic arterial anatomy and its variations has its significance in liver surgeries and interventional hepatic procedures, relative to the hepatic lobe involved. The RHA, being an end artery is important in hepatobiliary surgery. It is to be preserved as injury to it cause necrosis of right lobe of the liver. Presence of accessory hepatic arteries have significance in liver transplant recipient patients, these patients often have small caliber CHA which increases risk of post-transplantation hepatic artery complications like stenosis and thrombosis. "

Renal artery variations are not uncommon either and give rise to several problems that are encountered by clinicians. Kidneys with large number of renal arteries are reported to have a higher rate of transplantation failure than those with a single renal artery. The risk represented by these vascular variations is not, however, limited to renal transplantations and to the surgical treatment of renovascular hypertension. Variations in the origin, course and branching pattern of the renal artery occur frequently and are of special interest to the urologists, nephrologists, surgeons and radiologists, with respect to the diseases associated with it.

Knowledge of distance of branching of renal artery from aorta is important. The one ostium usually can be obtained during laparoscopic donor nephrectomy if the early branches are beyond 10 mm from the origin of the main renal artery. Otherwise, the renal arteries have to be reconstructed on the back table or separate renal artery anastomosis to the recipient has to be performed. An accessory artery in the inferior renal pole crosses the ureter obliquely from its anterior aspect, and may lead to hydronephrosis by compressing the ureter. Around 70% of individuals the kidney is supplied by single renal artery arising from abdominal aorta. However, renal artery variations are very common regarding their origin and number that have been reported by many researchers. The renal arteries may vary in their level of origin, caliber, obliquity, number and precise relation. The frequencies of renal artery variations showed social, ethnic and racial differences for example variations in renal artery and its branching pattern are more common in Africans and less common in Indians.
Table 1: Hepatic artery variations: Michel’s and Hiatt’s classifications. [2,3]

| Michel’s classification | Hiatt classification |
|-------------------------|----------------------|
| **Type**                | **Frequency (%)**    | **Description**                  | **Type** |
| I                       | 55                   | Hepatic artery originates from the CHA and bifurcates into the RHA and LHA | I         |
| II                      | 10                   | Replaced LHA arising from the LGA | II        |
| III                     | 11                   | Replaced RHA arising from the SMA | III       |
| IV                      | 1                    | Replaced RHA and LHA             | IV        |
| V                       | 8                    | Accessory LHA arising from LGA   | II        |
| VI                      | 7                    | Accessory RHA arising from SMA   | III       |
| VII                     | 1                    | Accessory RHA and LHA            | IV        |
| VIII                    | 4                    | Replaced RHA and accessory LHA or replaced LHA and accessory RHA | IV        |
| IX                      | 4.5                  | Entire hepatic trunk arises from the SMA | V         |
| X                       | 0.5                  | Entire hepatic trunk arises from the LGA | NOD       |
| NOD                     | 1                    | Common hepatic artery directly originating from the aorta | Type VI   |

Table 2: Celiac axis variations according to Song’s classification [6] scheme

| Description                                                  | Song’s classification scheme (including celiac trunk and SMA) |
|--------------------------------------------------------------|---------------------------------------------------------------|
| The CHA, SpA and LGA originating from the celiac trunk       | Normal anatomy                                                |
| The CHA, SpA and LGA have a common point of origin from the celiac trunk | HGSp+SM                                                        |
| CHA and SpA have a common point of origin with the LGA demonstrates variable points of origin |                                                              |
| CHA and SA have common trunk with the LGA arises separately from aorta | HSp trunk + LG + SM                                             |
| CHA and LGA have common trunk with the SpA and SMA arises separately from the aorta | HG trunk + Sp + SM                                               |
| CHA, SA and SMA have common trunk with the LGA arises separately from the aorta | HSpM trunk + LG                                                   |
| LGA and SA have a common trunk with the CHA and SMA arises separately from the aorta or common SMA and CHA trunk from aorta | CH + GSp trunk + SM                                          |
| Celiac and SMA have a common trunk                           | CM trunk                                                       |
| The middle colic artery and the celiac have the same trunk   | Not classified                                                  |
| No celiac trunk with the CHA, SpA, LG and LGA arises directly from the aorta | CH + LG + Sp + SM                                               |
| CHA and SMA have a common trunk with SpA and LGA arise separately from the aorta | HM trunk + LG + Sp                                              |
| CHA and LGA have a common trunk similarly SMA and SpA arise as common trunk from the aorta | HG trunk + SpM trunk                                           |
| LGA, SpA and SMA have a common trunk with CHA arise separately from the aorta | CH + GSpM trunk                                                  |
| SpA and SMA have a common trunk with CHA and LGA arise separately from the aorta | CH + LG + SpM trunk                                             |
| CHA and SpA have a common trunk similarly LGA and SMA arise as common trunk from the aorta | HSp trunk + GM trunk                                           |
| CHA, LGA and SMA have a common trunk with SpA arise separately from the aorta | HGM trunk + Sp                                                  |
| LGA and SMA have a common trunk with CHA and SpA arise separately from the aorta | CH + GM trunk + Sp                                              |
| Absent CHAorVariant CHAs with an unclear origin due to the presence of a persistent anastomotic channel | Ambiguous anatomy                                              |

Material and Methods
Source of Data
This retrospective and prospective hospital based study was conducted in the Department of Radio diagnosis, Dr. S. N. Medical College and Associated Group of Hospitals, Jodhpur. The necessary permission and approval from Ethics Committee and authority prior to initiation of the...
study was taken. The study population included CT images of 500 patients who underwent MDCT abdomen in our hospital for various indications between January 2017 to November 2017. The celiac trunk, SMA, IMA, hepatic and renal arterial system were individually assessed, and variations were noted.

**Method of Collection of Data**

The examinations were carried out with PHILIPS 64 slice CT SCANNER with Philips windows workstation and software. The examined area was stretched from the diaphragm domes to the pubic bone. Contrast agent bolus was administrated using an automatic injector. The volume of the non-ionic iodinated contrast agent ranged from 80 to 130 ml, depending on the patient’s body mass. The rate of the contrast agent administration was 3.0–5.5 ml/s. Contrast medium administration was followed by injection of 40 ml of a normal saline (wash out bolus). CT examinations was performed according to two protocols: a regular CTA (one-phase examination) or an abdominal CT (multi-phase examination), depending on indications. The multi-phase examinations were evaluated in the early arterial phase only.

**Image Interpretation**

The obtained scans were analyzed using Philips windows workstation and Philips IntelliSpace portal software. Image post processing techniques involved isotropic multiplanar two- and three-dimensional reconstructions (Maximum Intensity Projection MIP; Volume Rendering VR). Only those images that were free from artefacts i.e. where the arterial phase was appropriately visualized and an adequate and comprehensive evaluation of the aortic branches were possible – were used for the analysis. The images were analyzed independently by three radiologists Radiologist 1 (A.S.C) with 1.5 years, Radiologist 2 (R.G.) with 25 years and Radiologist 3 (K.R.C) with 20 years of experience.

**Interpretation of variation in origin of LG, SpA, SMA and origin/course of CHA**

To describe the results of systematic analysis of the celiac axis including SMA and the hepatic anatomy comprehensively, we used nomenclature system described by Song et al (Table 2–4).[^6] The abbreviations and terms used in this system are listed in Tables 2-5. By integrating the data obtained from the analysis of the CT images, we classified the variations of the celiac axis and the CHA and compared them with those seen in song et al[^6], sureka et al[^17], Osman et al[^18] and other studies. Variations in LG, SpA, CHA and SMA were also compared with study done by Ulfacker et al.[^7]

**Interpretation of variation in origin and course of RHA, LHA, MHA and GDA**

After assessing the celiac axis anatomy, we evaluated the CHA anatomy, including its origin site, anatomic course, and relationship to surrounding structures (portal vein or superior mesenteric vein, pancreas head or uncinate process). Next, we evaluated the branching patterns of the downstream hepatic arteries—specifically, the proper, right, left, and middle hepatic arteries—and the gastroduodenal artery in the patients with celiac axis and CHA variations. Variation in origin and course of RHA, LHA, MHA and GDA were described according to Michel’s classification [Table 1], Songs classification scheme and Sureka et al. Results were also compared with other studies[^2,3,19,20,21,22].

**IMA Variants**

In literature, IMA has little variation in terms of position and origin.[^23]

**Renal Arteries Variations**

Renal artery variations were divided into two groups as **early branching (EB)** into segmental arteries and additional renal artery.

**Early branching** was defined as branching of the main renal arteries into segmental branches at a more proximal level than the renal hilum or at less than 2cm distance from their aortic origin.[^24]
Additional renal artery was more than one main renal artery usually arising from aorta supplying kidney[25]. It was also divided into two types-

1. **Aberrant renal artery** means additional renal artery entering through hilum of kidney.

2. **Accessory renal artery** means additional renal artery entering kidneys directly piercing poles (inferior/superior) of kidney.

**Interpretation of renal artery variation**
First word denotes total number of renal arteries, second one denotes type of additional artery (AC or AB), next is hyphen with further next origin artery of additional artery.

Example- if one kidney was supplied by single renal artery entering through hilum and giving segmental branches at more than 2cm distance from their aortic origin, was marked as 1.If one kidney was supplied by single renal artery entering through hilum and giving segmental branches at less than 2cm distance from their aortic origin or before renal hilum, was marked as 1E. If one kidney was supplied by main and accessory artery, marked as 2, AC-AORTA. If one kidney was supplied by main and aberrant superior polar artery, marked as 2, AB (SP) - AORTA. If two accessory arteries were present, it was marked as 3, AC-AORTA

**Table 3. Abbreviation**

| Abbreviation | Description |
|--------------|-------------|
| Ao           | Aorta       |
| CA           | Celiac axis ( hepatogastroplenic trunk) or its equivalent |
| CH/CHA       | Common hepatic artery, an arterial trunk containing at least one segmental hepatic artery and the gastroduodenal artery, regardless of its origin site or anatomic course |
| CM trunk     | Celiacomesenteric trunk |
| GDA          | Gastroduodenal artery |
| GM trunk     | Gastromesenteric trunk |
| GSpM trunk   | Gastroesplomesenteric trunk |
| HG trunk     | Hepatogastric trunk |
| HGM trunk    | Hepatogastromesenteric trunk |
| HGSp trunk   | Hepatogastroplenic trunk, normal celiac axis |
| HM trunk     | Hepatomesenteric trunk |
| HSp trunk    | Hepatosplenic trunk |
| HSpM trunk   | Hepatosplomesenteric trunk |
| LG           | Left gastric artery |
| LH/LHA       | Left hepatic artery, which is equivalent to S2/3/4 |
| HAP          | Proper hepatic artery, which is an arterial trunk before branching into the right and left hepatic arteries, regardless of its origin site or anatomic course |
| RH/RHA       | Right hepatic artery, which is equivalent to S5/6/7/8 |
| SM/SMA       | Superior mesenteric artery |
| SpM trunk    | Splenomesenteric trunk |
| Sp/SpA/SA    | Splenic artery |
### Results and Comparison to Other Studies

#### Table 4 - Celiac axis variations - comparison

| Ulfacker’s classification \nonly celiac trunk | Osman et al\(^7\) \nN=1000 | Song’s classification scheme \nincluding celiac trunk and SMA | Our study \nn=500 (%) | Song’s et \nal\(^6\) \nN=5002 | Sureka et \nal\(^17\) \nN=600 |
|------------------|-------------|---------------------------------|-------------|-------------|-------------|
| **Type** | | | | | |
| I | Trifurcation | 905 (90.5) | Normal anatomy | 455 (91) | 4457 (89.1) | 546 (91) |
| | Classic pattern | 638 (63.8) | HGSp+SM | 152 (30.4) | | |
| | Non-classic pattern | 267 (26.7) | HSp trunk + LG + SM | 285 (57) | | |
| | Quadrifurcation | - | HSp trunk + LG + SM | 18 (3.6) | | |
| II | Hepato-splenic trunk | 28 (2.8) | HGSp trunk + LG + SM | 17 (3.4) | 221 (4.42) | 17 (2.83) |
| III | Hepato-gastric trunk | 6 (0.6) | HG Sp trunk + Sp + SM | 0 | 1 (0.02) | |
| IV | Hepatopsoeno-mesenteric \ntrunk | 0 | HSpM trunk + LG | 3.6 (0.6) | 34 (0.68) | 1 (0.16) |
| V | Gastro-splenic trunk | 43 (4.3) | CH + GSp trunk + LG | 5 (1) | 11 (0.22) | 5 (0.83) |
| | | | HM trunk + GSp trunk | 5 (1) | 132 (2.64) | 4 (0.66) |
| VI | Celiacomesenteric trunk | 6 (0.6) | CM trunk | 1 (0.2) | 53 (1.06) | 4 (0.66) |
| VII | Celiaco-colic trunk | 0 | Not classified | - | - | - |
| VIII | No celiac trunk | 10 (1) | CH + LG + Sp + SM | 1 (0.2) | 5 (0.10) | 0 |
| | | | HM trunk + LG + Sp | 2 (0.4) | 12 (0.24) | 2 (0.33) |
| | | | HGSp trunk + SpM trunk | 1 (0.2) | 8 (0.16) | 0 |
| | | | CH + GSpM trunk | 0 | 3 (0.06) | 0 |
| | | | CH + LG + SpM trunk | 0 | 1 (0.02) | 0 |
| | | | HSp trunk + GM trunk | 0 | 1 (0.02) | 0 |
| | | | HGM trunk + Sp | 0 | 0 | 0 |
| | | | CH + GM trunk + Sp | 0 | 0 | 0 |
| | | | 2 (0.2) | 10 (2) | 63 (1.26) | 21 (3.5) |

#### Table 5 CHA Anatomy variations - comparison

| Anatomic Course and Specific Variation | Our study \nn=500 | Songs et al N=4939 | Sureka et al \nN=600 |
|--------------------------------------|-------------|-----------------|-------------|
| A. Originating from celiac axis or \nis equivalent | 476 (95.2) | 4763 (96.44) | 575 (95.83) |
| Suprapancreatic preportal course | 474 (94.8) | 4756 (96.29) | 576 (98.12) Total* |
| | HGSp trunk | 453 (90.6) | 4,443 (89.96) | 576 (98.12) Total* |
| | HSp trunk | 17 (3.4) | 222 (4.49) | |
| | CM trunk | 0 | 49 (1) | |
| | HSpM trunk | 3 (0.6) | 34 (0.7) | |
| Originating from left gastric artery | HG trunk | 1 (0.2) | 8 (0.16) | |
| Suprapancreatic retroportal course | HGSp trunk | 2 (0.4) | 6 (0.12) | 7 (1.19) Total* |
| Transpancreatic pre SMV course | 0 | 1 | |
| B. Originating from SMA | 8 (1.6) | 148 (3.00) | 6 (1) |
| Suprapancreatic preportal course | 5 (1) | 39 (0.8) | |
| | HM trunk | 4 (0.8) | 38 (0.8) | |
| | CM trunk | 1 (0.2) | 1 | |
| Suprapancreatic retroportal course | 3 (0.6) | 85 (1.72) | |
| | HM trunk | 3 (0.6) | 83 (1.7) | |
| | CM trunk | 0 | 2 | |
| C. Originating from aorta: suprapancreatic preportal course | 6 (1.2) | 20 (0.40) | 2 (0.33) |
| D. Ambiguous dual pathway: HM trunk | 1 (0.2) | 1 | 4 (0.66) |
| E. Absent | 9 (1.8) | 63 (1) | |
| F. Not determined | 0 | - | 13 (2.16) |

*over all course of CHA, Ligamentum venosum 2 (0.34), Tp-retroportal 1 (0.17), Ip-preportal 1 (0.17) course were also reported in Sureka et al.
Table 6 RHA, LHA, GDA, and MHA origins variations and comparison

| RHA, LHA, GDA and MHA origins | Our study (N=500) (%) | Sureka et al. N=600 |
|-------------------------------|----------------------|---------------------|
| **RHA origin**                |                      |                     |
| A. HAP/CHA                    | 392 (78.4)           | 478 (79.6)          |
| B. Replaced                   | 97 (19.4)            | 91 (15.16)          |
| SMA                           | 69 (13.8)            | 81                  |
| Celiac axis                   | 26 (5.2)             | 8                   |
| Aorta                         | 2 (0.4)              | 2                   |
| C. Accessory                  | 11 (2.2)             | 31 (5.16)           |
| SMA                           | 11 (2.2)             | 21                  |
| Celiac axis                   | 0                    | 6                   |
| Aorta                         | 0                    | 4                   |
| **LHA origins**               |                      |                     |
| A. HAP                        | 386 (77.2)           | 489 (81.5)          |
| B. Replaced                   | 30 (6)               | 65 (10.8)           |
| LGA                           | 29 ((5.8)            | 63                  |
| Aorta                         | 0                    | 2                   |
| CA                            | 1 (0.2)              | 0                   |
| C. Accessory                  | LGA 84 (16.8)        | 46 (7.6)            |
| **GDA origin**                |                      |                     |
| A. CHA                         | 474 (94.8)           | 586 (97.6)          |
| B. Celiac axis                | 9 (1.8)              | 10 (1.6)            |
| C. RHA                        | 13 (2.6)             | 2 (0.33)            |
| D. LHA                        | 4 (0.8)              | 0                   |
| E. Not defined                 | 0                    | 2 (0.33)            |
| **MHA origin**                |                      |                     |
| A. RHA                        | 195 (39)             | 248 (41.33)         |
| B. LHA                        | 60 (12)              | 167 (27.83)         |
| C. CHA                         | 54 (10.8)            | 27 (4.5)            |
| D. Not defined                 | 191 (38.2)           | 158 (26.3)          |

Table 7 hepatic artery variations in our study- according to Michel’s classification

| Michels’s | Frequency in our study |
|-----------|------------------------|
| Type      |                        |
| no 500 (%)|                        |
| I         | 272 (54.4%)            |
| II        | 29 (5.8%)              |
| III       | 69 (13.8%)             |
| IV        | 5 (1%)                 |
| V         | 84 (16.8%)             |
| VI        | 11 (2.2%)              |
| VII       | 4 (0.8%)               |
| VIII      | 27+1 (5.6%)            |
| IX        | 8 (1.6%)               |
| X         | 1 (0.2%)               |
| NOD       | 6 (1.2%)               |
Table 8 Renal artery variation in our study

|                  | RIGHT KIDNEY (n=498) | LEFT KIDNEY (n=497) | Both side (n=500) |
|------------------|-----------------------|---------------------|-------------------|
| A. Single renal  | 428 (85.94)           | 402                 | 359               |
| artery           |                       |                     |                   |
| a. Early branching| 53                    | 63                  | 21                |
| B. Double renal  | 64                    | 89                  | 20                |
| arteries         |                       |                     |                   |
| a. Accessory     | 53                    | 76                  | 17                |
| b. Aberrant SP+IP| 8+3=11 (16.3%)        | 10+3=13             | 0                 |
| C. Three renal   | 5                     | 5                   | 0                 |
| arteries         |                       |                     |                   |
| D. Four renal    | 0                     | 1                   | 0                 |
| arteries         |                       |                     |                   |
| E. Horseshow     | 2, each had three     | 2                   | 0                 |
| kidneys          | arteries              |                     |                   |
| F. Unilateral    | 2, each with single   | 1, accessory artery |                   |
| kidneys          | artery                | supplying hilum     |                   |
| G. Two renal     | 2                     | 0                   | 0                 |
| arteries on the   |                        |                     |                   |
| right and three   |                        |                     |                   |
| renal arteries   |                        |                     |                   |
| on the left      |                        |                     |                   |
| H. Two renal     | 2                     | 0                   | 0                 |
| arteries on the   |                        |                     |                   |
| the left and three |                    |                     |                   |
| renal arteries   |                        |                     |                   |
| on the right     | 4                     | 0                   | 0                 |
| I. Two renal     | 1                     | 0                   | 0                 |
| arteries on the   |                        |                     |                   |
| right and four    |                        |                     |                   |
| renal arteries   |                        |                     |                   |
| on the left      | 1                     | 0                   | 0                 |

Table 9 Prevalence of bilateral anomalies of renal arteries in the literature

| Study                        | Rate of bilateral anomalies |
|------------------------------|----------------------------|
| Our study                    | 27/500 (5.4%)              |
| Note- if include early       | 48/500 (9.6%)              |
| branching                    |                            |
| Saldarriaga et al. [26]      | 6/194 (3.1%)               |
| Kurcz et al. [27]            | 7/216 (3.2%)               |
| Sampaio et al. [28]          | 6/70 (8.57%)               |
| Tarzammi et al. [29]         | 11/117 (9.4%)              |
| Spring et al. [30]           | 53/444 (12%)               |
| Kornafel et al [1]           | 20/201 (10%)               |
| Ugurel et al [7]             | 7/100 (7%)                 |
| Bastiram et al [31]          | 21/200 (10.5%)             |

Range of bilateral extra renal arteries 3.1-12%. Variation in our study stands at 5.4%

Table 10. Renal artery variations- comparison

|                  | RIGHT KIDNEY | LEFT KIDNEY | Both side (detail on next table) |
|------------------|--------------|-------------|----------------------------------|
|                  | A (n=498) (%)| B (%)       | C D N=200 (%)                     | A (n=497) | B (%) | C | D N=200 (%) | A (n=500) | C |
| A. Single renal  | 428 (85.94)  | 713 (83)    | - 153 (76.5)                     | 402 (80.88) | 736 (86) | 139 (69.5) | 359 | 62 |
| artery           | a. Early branching | 53 (10.64) | - 5 15 (7.5) | 63 (12.67) | - 7 12 (6) | 50 (25) | 20 | 11 |
| B. Double renal  | 64 (12.8)    | 126 (15)    | 10 32 (16)                      | 89 (17.9)  | 105 (12) | 50 (25)  | 20 | 11 |
| arteries         | a. Accessory | 53 (10.64) | - 13 (6.5) | 76 (15.29) | - 15 (7.5) | 17 |     |
| B. Aberrant SP+IP| 8+3=11 (2.2) | 6+13=19 (9.5) | 10+3=13 (2.6) | 13+22=25 | 0 |     |     |
| C. Three renal   | 5 (1)        | 9 (1%)      | 3 1 (0.5)                      | 5 (1)      | 6 (0.7) | 2 0 | 0 | 1 |
| arteries         | D. Four renal | 0 (0)      | 0 (0%)                         | 0 (0.2)    | 2 (0.2%) | 0 |     |     |
| arteries         | E. None (no renal | 1 (0.2) | 7 (0.8%) | 0 | 2 (0.4) | 6 (0.7%) |     |     |

Note – A. Our study, B. Özkan et al. [32], C. Kumaresan et al. [33], D. Kornafel et al.
Fig 1 3D VR images showing a. classical b. non-classical form of normal celiac axis (HGSp trunk + LG) and c. quadfurcation of celiac axis. d. HSp trunk with separate origin of LG and SM from aorta.
Fig 2B-D VR images showing some of the observed celiac axis variations

Fig 3A and 3B VR images showing ambiguous celiac axis due to absent CHA and ambiguous dual pathway

Fig 4 VR image showing replaced origin of CHA from aorta

Fig 5 MIP showing suprapancreatic retroportal course of CHA originating from SMA
Fig 6A VR
Fig 6 VR images showing A. replaced LHA from LG and B. replaced RHA from SMA

Fig 7 MIP image of showing ligamentum venosum course of LHA

Fig 8 3D VR
Fig 8 3D MIP
Fig 8 VR and MIP images showing aberrant superior polar renal artery on right side directly entering kidney by piercing renal capsule

**Conclusion**
This study is the first of its kind which comprehensively describes variations of celiac axis, hepatic artery branches and renal arteries. Developmental anomalies of the main arteries branching from the abdominal aorta were frequently seen in our study – in 255/500 (51%) of patients. They were mostly concerning renal arteries and revealing a great variability of variants, with the most common one being the presence of an additional hilar artery. The study showed a statistically significantly higher number...
of vasculature anomalies of the left kidney in comparison to the right kidney. In our study group, renal vasculature anomalies were clearly more frequent in men, but the difference was not statistically significant. No statistically significant association was seen between celiac axis/hepatic artery and renal artery variations.

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