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Variations in the Ventral Branches of Abdominal Aorta and its Alinical Importance - Case Series

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ABSTRACT
Introduction: the derivatives of abdominal part of foregut, midgut and hindgut are supplied by the ventral branches of the abdominal aorta. Celiac trunk is artery of foregut, superior mesenteric artery is artery of midgut and inferior mesenteric artery is artery of hindgut.
Materials and Methods: this study was carried out in JSS medical college during routine abdomen dissection for under graduate students. Multiple variations in the ventral branches of abdominal aorta in three cadavers were observed. First variation, Right hepatic artery was taking origin from the gastroduodenal artery, 1 cm below the bifurcation of the common hepatic artery. Proper hepatic artery continued as left hepatic artery. Second variation, CHA trifurcated into RHA, LHA and GDA and RHA gave two cystic arteries to gall bladder in the Calot's triangle. Third variation, Hepato-splenic trunk, splenic artery was unusually long and had a looped course along the superior border of pancreas. Fourth variation, A common trunk from the superior mesenteric artery (SMA) dividing into right colic artery (RCA) and middle colic artery (MCA). A separate branch arising proximal to the middle colic artery from the common trunk of SMA - accessory middle colic artery (AMCA) was anastomosing with left colic artery. Fifth variation, the left colic, sigmoidal and superior rectal arteries from inferior mesenteric artery (IMA) arising from common point. Preoperative radiological evaluation of variations in the branching pattern of CT SMA and IMA, their importance are essential in minimising intraoperative bleeding during various surgeries and intervention of abdomen.
Keywords: Right hepatic artery; Gastroduodenal artery; Double cystic arteries; Middle colic artery; Marginal artery; Left colic Artery; Arc of Riolan.

Introduction

The left gastric, splenic and common hepatic arteries of celiac trunk supplies abdominal part of foregut derivatives namely the abdominal oesophagus, stomach, duodenum till the opening of bile duct, liver, spleen, and pancreas. Inferior pancreaticoduodenal, jejunal, ileal, ileocolic, right colic and middle colic arteries of superior mesenteric artery supplies midgut derivatives namely the duodenum below the opening of bile duct, jejunum, ileum, caecum, appendix, ascending colon, hepatic flexure and right 2/3^{rds} of transverse colon. Inferior mesenteric artery supplies hindgut derivatives through left colic and sigmoidal arteries and continues as superior rectal artery. The derivates of hind gut includes the left 1/3rd of transverse colon, splenic flexure, descending colon, sigmoid colon, rectum and anal canal till pectinate line. The arterial supply of the bowel is highly complicated and with numerous interconnecting anastomoses, which provides rich arterial supply to the bowel to help the process of digestion, absorption and also protect from ischemia or infarction. Anastomoses between superior and inferior pancreaticoduodenal arteries, marginal artery are the two main links between celiac trunk, superior and inferior mesenteric arteries. Sometimes additional connection like Arc of Riolan (AOR) may be present which connects SMA and IMA. The marginal artery (MA) of Drummond, is one artery of special interest to surgeons and radiologists because of its formation by anastomosing with branches of SMA and IMA to supply the major portion of large intestine and provide collateral circulation during colorectal procedures and surgeries[1]. MA is an arterial arch extending from ileocolic junction to sigmoid colon, formed by the colic arteries and their arterial arcades arising from the ileocolic, right colic, middle colic, left colic arteries. It's formation is clear and evident in the ascending, transverse and descending colon but poorly developed in sigmoid colon[2]. Many authors believe that MA is present in all [3] but its absence from arterial supply to large intestine has been reported in some cases. Most common point of MA variation is Griffith's point at the splenic flexure which is a major watershed area of the middle colic and left colic branches of SMA and IMA respectively[4]. Absence of adequate anastomosis at Griffith's point can make the affected person prone for decreased perfusion and ischemic colitis. A thorough knowledge of arterial supply including normal, variations and additional anastomosis, is required for the proper assessment

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during surgery and treatment of the various diseases which affects the arterial supply of the gastrointestinal tract[5].

We are reporting a case series of multiple variations in the ventral branches of abdominal aorta in three cadavers. This study was carried out in JSS medical college during routine abdomen dissection for under graduate students. Twenty embalmed cadavers were dissected following the Cunningham's dissection manual. Celiac trunk, superior mesenteric and inferior mesenteric arteries with their branches were traced, variations noted and photographed (JSS/IEC/18122023/26 NCT/2023-24).

Case 1 – First Variation:

Common hepatic artery (CHA) was dividing into proper hepatic artery (PHA) and gastroduodenal artery (GDA). The right hepatic artery (RHA) was arising from GDA, 1 cm below the bifurcation of the common hepatic artery. It was running posterior to the common bile duct and entered the Calot's triangle. In the Calot's triangle it gave cystic artery to gall bladder and supplied the right lobe of liver. Proper hepatic artery (PHA) continued as left hepatic artery (LHA) and entered the liver through the fissure for ligamentum venosum. (Fig 1 and 2)

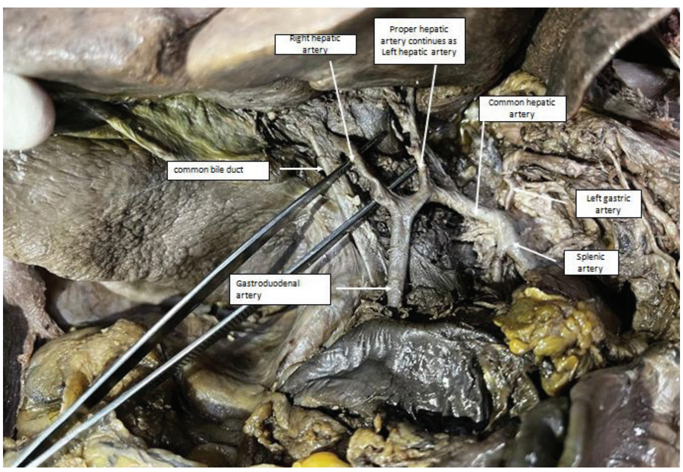


Figure 1. The right hepatic artery taking origin form the gastroduodenal artery, 1 cm below the bifurcation of the common hepatic artery.

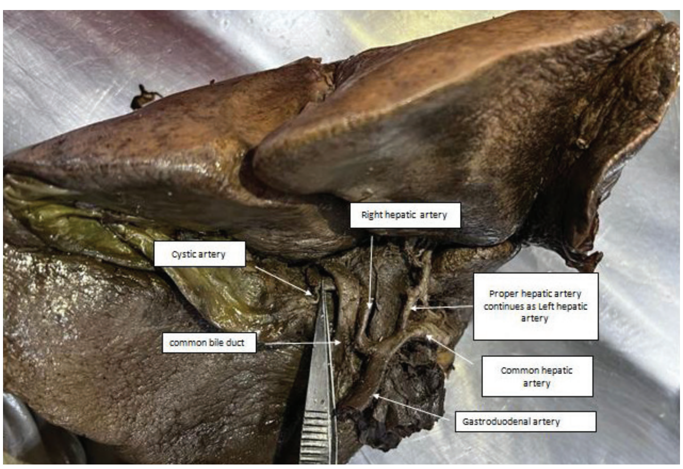


Figure 2. Right hepatic artery in Calot's triangle and giving cystic artery.

Case 2 – Second Variation:

Trifurcation of CHA into right and left hepatic arteries, gastroduodenal artery. Proper hepatic artery was absent, RHA was running behind the common bile duct and later in the Calot's triangle. RHA gave a small branch before it entered Calot's triangle which was supplying the quadrate lobe of the liver. In the Calot's triangle it presented the Moynihan's hump/caterpillar hump and gave two cystic arteries to gall bladder – Double cystic arteries. One branch was running in the peritoneal fold which was suspending the gall bladder in the fossa for gall bladder, another branch was running along the inferior surface of the gall bladder. (Fig 3 and 4)

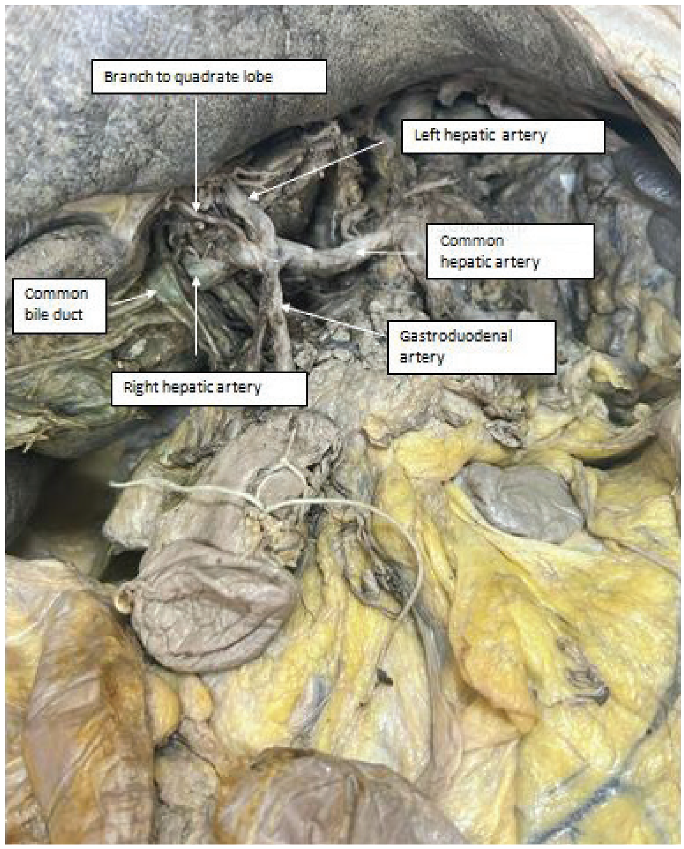


Figure 3. CHA trifurcation – Right and left hepatic arteries, gastroduodenal artery. Proper hepatic artery was absent.

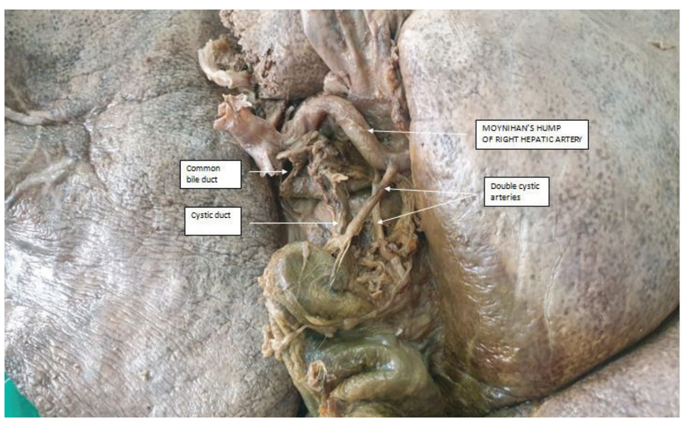
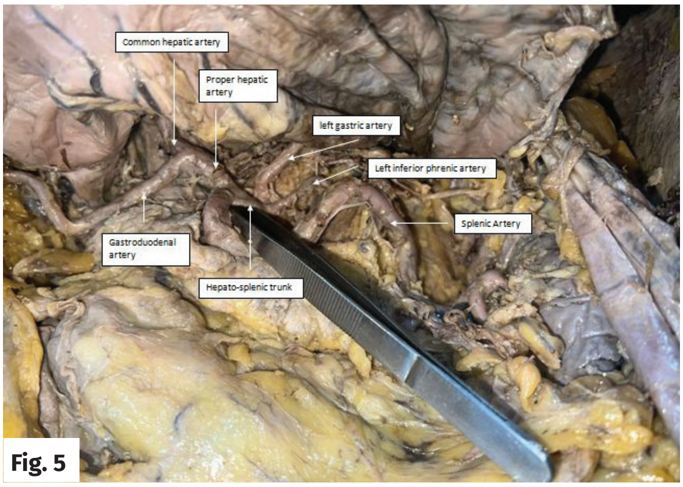


Figure 4. Right hepatic artery presenting Moynihan's hump running proximal and parallel to the cystic duct and gave two cystic arteries to gall bladder – Double cystic arteries.

Case 3 – Third Variation:

Celiac trunk giving left gastric, left inferior phrenic artery, hepato-splenic trunk. Splenic artery was unusually long and had looped course along the superior border of the pancreas. Common hepatic artery divided into PHA and GDA. (Fig 5 and 6)



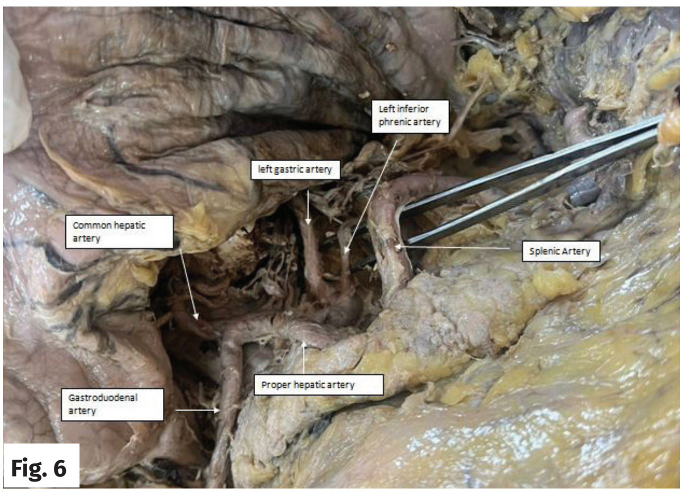


Figure 5 and Figure 6. Celiac trunk giving left gastric, left inferior phrenic artery, hepato-splenic trunk. Splenic artery was unusually long and had looped course along the superior border of the pancreas.

Case 4 – Fourth Variation:

This variation was seen in the same cadaver along with first variation. A common trunk from the superior mesenteric artery (SMA) divided into right colic artery (RCA) and middle colic artery (MCA). The right branch of MCA supplied right $2/3^{rds}$ of transverse colon whereas left $1/3^{rd}$ of transverse colon was supplied by a separate branch arising proximal to the middle colic artery from the common trunk of SMA - accessory middle colic artery (AMCA) which was anastomosing with the left branch of MCA and ascending branch of the left colic from inferior mesenteric artery. This variation in the formation of Marginal artery of Drummond has been reported by some authors in their angiographic studies but cadaveric report was not found in the literature. Thus altering the arterial supply to left $1/3^{rd}$ of the transverse colon, splenic flexure and proximal part of ascending colon. (Fig 7 and 8)

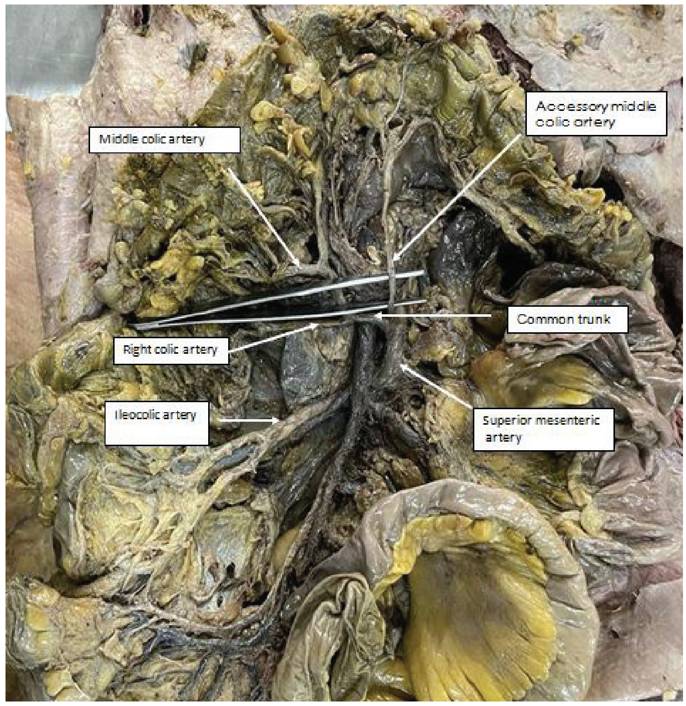


Figure 7. Superior mesenteric artery gave a common trunk which divided into right colic artery (RCA) and middle colic artery (MCA).

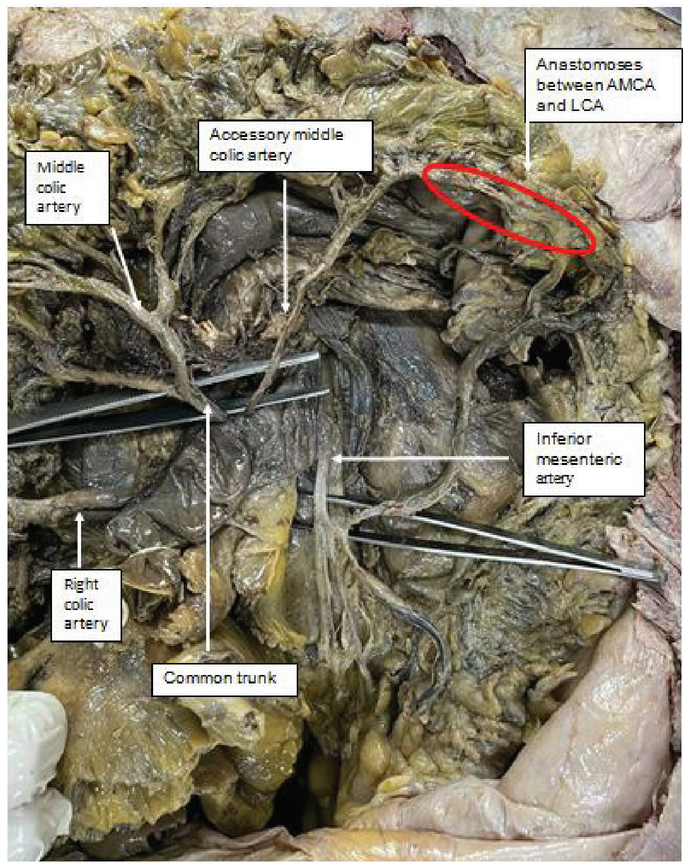


Figure 8: Accessory middle colic artery anastomosing with middle colic artery and ascending branch of the left colic from inferior mesenteric artery.

Case 5 - Fifth Variation:

This variation was also seen in the same cadaver along with first and fourth variations. Inferior mesenteric artery branches, left colic, sigmoidal and superior rectal arteries all were arising from same point. LCA, ascending branch was forming marginal artery with the left branch of AMCA from the common trunk of the SMA. The ascending branch of the LCA turned towards left side at the hilum of kidney in relation to the splenic flexure, dividing into two branches and terminated into a small "V" shape bifurcation representing a physiological and anatomic arterial arch that completed the marginal artery. (Fig 9)

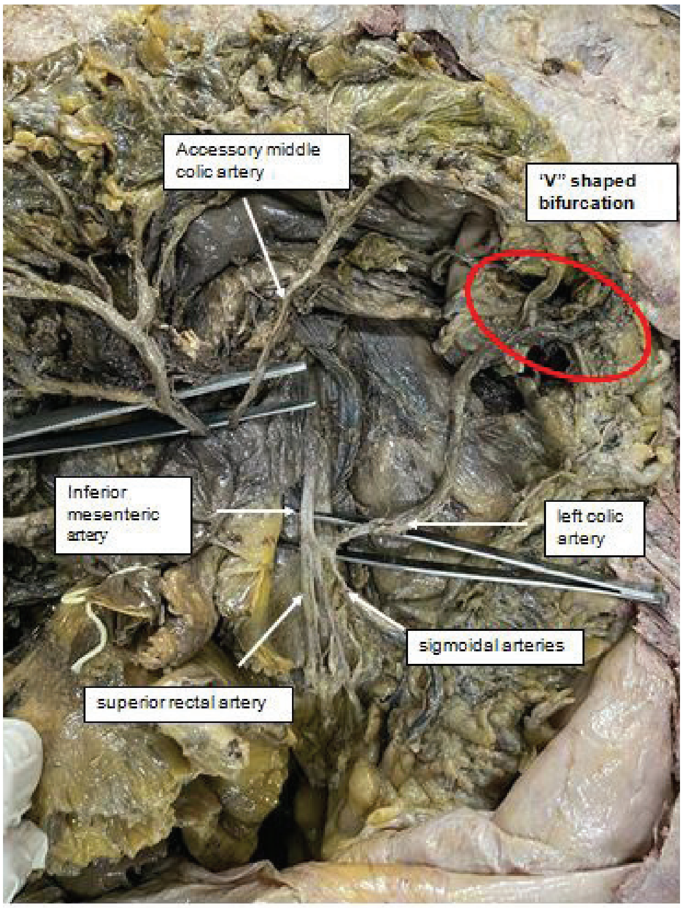


Figure 9. Inferior mesenteric artery branches left colic artery, sigmoidal and superior rectal arteries coming from same point. LCA, ascending branch forming marginal artery with AMCA.

Discussion

Celiac trunk (CT) is the artery of foregut from the abdominal aorta just as it enters the abdomen at the level of the T12 vertebra. It runs horizontally forwards towards the right side superior to the body of pancreas and splenic vein, dividing into three classical branches: left gastric, common hepatic and splenic arteries[2]. Many authors have reported various branching pattern of the celiac trunk by dissection using cadavers and angiographic methods. Chen H *et al.*, reported that normal branching pattern of CT was seen in 89.8% of cases and hepato-splenic trunk in 4.4% of cases in their cadaveric study[6]. Another study by Macro-Clement I *et al*, mentioned complete CT was seen in 90.5% and hepato-splenic trunk in 4.5% of cases which included 43 cadavers and 596 MDCT angiography examinations[7].

The normal hepatic artery anatomy with the left and right hepatic artery arising from the common hepatic artery after giving of the gastroduodenal artery is present in up to 55% of the population[8]. But according to Noussios G *et al.*, normal hepatic artery anatomy is seen in approximately 80% of cases, in the remaining 20% of cases multiple variations have been described[9]. According to Yong Yan *et al.*, the standard text book description of hepatic artery has been reported in 55% to 70% of cases in literature with different detection methods[10], while several variations in hepatic arterial anatomy are seen in around one-third of the population[11]. Studies regarding the hepatic artery variations are plenty in the literature. Most common variations reported in the hepatic arterial branching pattern include replaced RHA ranging from 11-21% of cases and replaced LHA ranging from 3.8-10% of cases[12]. Replaced right hepatic artery (Michel's type III) is the most commonest variation seen in 3.7% of cases and it is the main artery which supplies the bile duct[10] as reported by Yong Yan. When replaced RHA is present it usually arises from SMA in 12.9% of cases or from celiac trunk in 0.24% of cases or from abdominal aorta in 0.15% of cases or CHA in 0.09% of cases[13]. In the present case, replaced RHA was arising from the GDA, although very few cases of replaced RHA from the GDA with less than 0.1% incidence has been reported by Yong Yan *et al* [10]. Winston CB *et al.*, reported 5 cases in 371 patients (1.3%), Gruttadauria S *et al.*, reported 1 in 687 patients (0.14%), Imam A *et al.*, reported 1 in 241 patients (1.2%) in their angiographic studies[14,15,8]. Our case report is cadaveric report of RHA from GDA. The precise knowledge about the variations in the hepatic artery origin, course allows the surgeons to preserve these variations, to avoid injuries to the harvested donor liver that might result in recipient unhealthy state or even death[15].

The two main arteries supplying the common bile duct are RHA and posterior branch of superior pancreaticoduodenal artery[16] and damage to RHA during surgeries like cholecystectomy, pancreatoduodenectomy, liver transplant etc leads to hepatic and biliary ischemia and possible liver failure [17] and during pancreatoduodenectomy, adequate arterial supply to the common bile duct has to be maintained, as obstruction of the arterial supply results the biliary fistula. The gastroduodenal artery is usually cut and removed during pancreatoduodenectomy surgery, as a result bile duct completely depends on RHA for its arterial supply [18]. The presence of replaced hepatic artery itself is demanding for surgeons to maintain the arterial supply during the surgery[19]. When the RHA arises from the GDA, surgery becomes extremely dangerous and can confuse the surgeon to ligate the RHA instead of the GDA. Hence, knowledge of normal vascular anatomy and also of rare variations like RHA arising from GDA is of utmost importance to avoid damage to the right hepatic lobe arterial supply.

Therefore, careful dissection of the arteries within the hepatoduodenal part of the lesser omentum is necessary for complete recognition of arteries before any critical structure is cut resulting in haemorrhage and ischemia[20]. Damage to replaced hepatic artery can result in severe complications such as liver necrosis and liver failure in liver transplantation, so the replaced hepatic artery should be reconstructed[21]. If this variation is recognized before surgery, the GDA should be tied distal to the origin of replaced RHA to avoid arterial injury and preserving sufficient blood flow to the right lobe of liver[22]. The aberrant hepatic arteries, especially RHA and its reconstruction, is clinically important in living donor liver transplantation, as proper arterial supply to the graft is essential for its survival[23,24].

Although many reports have been published on variations in the origin, branching pattern of CHA, trifurcation of CHA reported in the literature are very few[25]. There was no proper hepatic artery in this case. LHA was short and straight entered the left lobe of liver, RHA was slightly tortuous and was running posterior to common bile duct entered the Calot's triangle and supplied the right lobe of liver. Before Calot's triangle it gave a small branch to quadrate lobe of liver. In the Calot's triangle it gave two cystic arteries – double cystic arteries to gall bladder. Moynihan's hump or caterpillar hump, is seen when the right hepatic artery forms a tortuous course occupying the major part of Calot's triangle and is more prone to damage during cholecystectomy[26]. It usually lies very close to the gall bladder neck. RHA usually gives single cystic artery in 75-80% of reported cases, passing through Calot's triangle[27]. But according to Sarkar *et al.*, the cystic artery can arise from right hepatic artery in 63.9% of cases or from common hepatic artery in 26.9% of cases or from left hepatic artery in 5.5% of cases or from gastroduodenal artery 2.6% of cases or from superior pancreaticoduodenal artery in 0.3% of cases or from right gastric artery in 0.1% of cases or from celiac trunk in 0.3% of cases and from superior mesenteric artery in 0.8% of cases respectively[28]. The incidence of double cystic artery varies from 12 - 25% of cases[29]. The cystic artery was taking origin within the Calot's triangle in 62.2% of cases and in 37.8% of cases origin was outside respectively. The cystic artery passing anterior to common bile duct in 26.8% of cases while 6.1% of cases passing posterior to bile duct[30]. In our case, the double cystic arteries were taking origin in the Calot's triangle and were passing behind the common bile duct which is rare.

Splenic artery arising from hepato-splenic trunk was seen in only one specimen out of 50 specimens as reported by Nagajyothi D *et al.*, in a cadaveric study and its considered as Type 2 variety according to Lipshutz classification[31]. But according to Araujo Neto SA *et al.*, reported in their angiographic study that hepato-splenic trunk was found in 8.3% of patients[32].

Covantsev S *et al.*, described four types of course for the splenic artery: straight, tortuous, serpentine and alternating[33]. The tortuous splenic artery is not a typical feature in new born and in children. The splenic artery becomes tortuous because of the increasing difference between the distance of its origin till the hilum of spleen with the length of the splenic artery. The tortuous course is made more prominent by the main branches direction which runs perpendicular to the course of the splenic artery[34]. Splenic artery is more tortuous in the proximal end where big branches like dorsal pancreatic artery are given off to the pancreas and splenic artery is more or less straight in the distal end where small numerous branches arises to supply the pancreas which tend to fix the artery[35,36].

Normally, CT trifurcates into three arteries: the left gastric, splenic, and common hepatic arteries. Most commonly, the initial branch of the celiac trunk is the left gastric artery, followed by a division into the splenic and the common hepatic arteries; this pattern is seen in 65 to 75% of individuals, whereas a true trifurcation is seen in only 25% of cases[5]. Most common variations of CT includes either the inferior phrenic arteries (35% incidence) or the dorsal pancreatic artery (22% incidence) taking origin from the CT[35,36,37,14].

When there are multiple variations, as in this case reported, the chances of vascular damage is very high which might lead to severe postoperative morbidities, bilomas, hematomas, sepsis or even mortality[38]. Knowledge of these anomalies is especially important in hepatobiliary and pancreatic surgery in order to avoid unnecessary complications[39].

SMA is the artery of midgut, arises as a second ventral branch from the abdominal aorta, 1 cm inferior to the celiac trunk, behind the body of pancreas and splenic vein, enters the root of the mesentry[2]. Inferior pancretico-duodenal, jejunal, ileal, ileocolic, right colic and middle colic arteries are the branches of SMA. Together with the IMA and celiac trunk, SMA contributes to the complicated and interconnecting anastomotic arterial supply of the gastrointestinal tract[40].

Variations in the origin, branching pattern and distribution of SMA has been reported in the literature. Such variations and their relationship with the surrounding structures are, therefore, important from a clinical and surgical perspective[41].

According to Gamo E *et al*, who proposed a new classification of SMA into four patterns, after studying SMA and its colic branches in cadavers and in CT angiogram[42].

Pattern I as the separate origin of the three colic branches of the SMA, Pattern IIa, common trunk from SMA giving rise to RCA and MCA, Pattern IIb, common trunk giving rise to RCA and ICA, Pattern IIc, common trunk from SMA for all the three colic branches, Pattern III, absence of RCA and Pattern IV, based on presence of accessory arteries[42]. Although most literature describe the separate origin of the three colic arteries from SMA, the right colic artery is responsible for major variation. In our present case, its Pattern IIa type of Gamo E *et al.*, where a common trunk from SMA gave rise to RCA and MCA and also Pattern IV since the common trunk gave an additional branch – AMCA. Splenic flexure cancer is rare, representing less than 8% of all colorectal cancers[43]. Compared to other colon cancers, splenic flexure cancer has a poor prediction due to risk of obstruction and more advanced stage at the time of detection and lower cure rate than other types of left colon cancers[44]. The splenic flexure is typically supplied by branches of the superior and inferior mesenteric arteries, an accessory middle colic artery (AMCA) often arising from SMA and passing along the inferior border of the body of the pancreas to supply the splenic flexure has been identified in 6.6 % to 36.4% of cases[43]. In the absence of left colic artery, AMCA may become an important feeder artery to splenic flexure cancer[45].

Variations regarding the SMA branching pattern is essential for clinicians, especially for surgeons who perform colorectal surgeries, because tying of the inferior mesenteric artery during surgery might result in ischemic colitis, since inferior mesenteric is the only artery responsible for the arterial supply to the structures derived from the hind gut[46].

Tanaka *et al.*, recently proposed a classification of the arterial vascularization of the left colonic angle into four types based on preoperative imaging. The arterial supply to the splenic flexure was divided into four types: type I, the left branch of the middle colic artery (MCA) and the left colic artery (LCA), type II, the left branch of the MCA with independent origin arising from SMA and the LCA, type III, the accessory MCA (AMCA) and the LCA and type IV the LCA alone[47].

In a recent study, Iguchi *et al.*, classified 5 types of arterial supply to the splenic flexure based on 3D-CT images. They are type 1A, the left branch of middle colic artery (L-MCA) anastomosing with left colic artery (LCA), Type 2A, the accessory middle colic artery (AMCA) from SMA with LCA, Type 3A, the L-MCA independently branch off from the SMA and LCA, TYPE 4A, the L-MCA and AMCA independently branching off from the SMA and LCA, Type5A, only the AMCA from SMA and LCA, L-MCA is absent[48]. Our variation is little different from this classification, since MCA was arising from a common trunk along with RCA and AMCA also from this common trunk and not from SMA.

All of these classifications, various studies highlight the variations in the branching pattern and the concealed role of the MCA in the arterial supply of splenic flexure, which could have an impact on the surgical planning to be implemented for splenic flexure cancers[43].

The SMA and IMA are linked through the marginal artery of Drummond and may also be connected through the arc of Riolan. IMA gives left colic artery which divides into an ascending branch and a descending branch shortly after its origin. Ascending branch anastomose with the left branch of the MCA to form the MA supplying the left 1/3rd of transverse colon, splenic flexure and proximal part of descending colon. The dominant arterial supply to splenic flexure is LCA but sometimes left branch of MCA can also supply[45]. Apart from this, arterial supply to splenic flexure region may be additionally supplied by an inner arterial - arc of Riolan which runs in the mesentry of colon between the main trunk of the MCA and ascending branch of LCA. The arc of Riolan is situated medial to the mesenteric border of the colon, that provides collateral mesenteric circulation in 10% of individuals[49].

There are so many types of classification of the anatomical variations of the IMA and its branches, but Yada *et al.* classification is presently accepted by most scholars. Type I LCA originates from IMA separately, Type II LCA and SA from common trunk, Type III all three from same point, Type IV LCA is absent[50].

The anatomy of the IMA and its branches is extremely important in the anastomosis it forms with the MCA, therefore affecting the choice of surgical approach (level of IMA ligation).

There was no anastomotic leakage, when IMA was ligated high in type III patients with an arc of Riolan, whereas patients with a type III IMA had anastomotic leakage with absence of arc of Riolan. In patients with an absence of arc of Riolan, left hemicolectomy is dependent on the IMA for blood supply, and ligating IMA high approach can possibly cause ischemic changes. Therefore, IMA should be ligated at a low level, that preserves the LCA in order to maintain blood supply is suggested. Since left hemicolectomy depends on the IMA for blood supply in cases of absence of arc of Riolan, the high ligation approach leads to ischemic changes, thereby increasing the risk of postoperative anastomotic leakage[50].

Moreover, the descending colon has a longer segment of the large intestine and lacks a direct blood supply. Therefore, patients with colorectal cancer with type III, should undergo radical colorectal cancer surgery with preservation of the LCA because high ligation of the IMA during radical resection will block LCA blood flow and may lead to inadequate blood supply to the descending colon and distal anastomosis, thus increasing the risk of anastomotic leakage[51].

As reported by Bruzzi m *et al.*, three branching patterns of the ascending branch of the LCA: L1 (10.5%), L2 (13.9%), and L3 (24.3%) has been reported. In L1, the ascending branch of the LCA travels to the medial side of the left kidney hilum and reaches the left 1/3 mesocolon of the transverse colon directly, without branches to descending colon. In L2, the ascending branch of the LCA divides into two branches (left and right) and terminates into a V shape at the level of the renal hilum; one branch travels upward to the transverse colon, and the other branch extends to the upper part of the descending colon. In L3, the ascending branch of the LCA turns left at the renal hilum toward the splenic flexure, then divides into two branches and terminates into a small V shape[52].

In the present case, there was modified marginal artery in the region of transverse colon, splenic flexure and proximal descending colon regions since this part of the MA was replaced by AMCA. This type was arterial supply to splenic flexure was reported by Tanaka *et al*., as type III where the AMCA and LCA forms the marginal artery and by Iguchi *et al*., as Type5A, where the AMCA from SMA and LCA forming marginal artery, L-MCA is absent. Both reports are based on angiographic studies. But in our case report, AMCA was taking origin from common trunk of SMA and not from SMA directly and it's cadaveric report.

In conclusion, the origin, course and branching pattern of hepatic arteries, SMA and IMA in each patient should be thoroughly investigated and recognized in planning and performing surgeries like liver transplantation, hepatobiliary, Pancreatoduodenectomy, gastrojejunostomies, hemicolectomy to avoid vascular complications and injuries and successful outcomes. Contrast-enhanced CT is an important method to find and identify variations of arterial branching pattern. Reconstruction images of contrast-enhanced CT are helpful to visualize the arterial variations and its spatial relation with adjacent structures and facilitate surgical planning.

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