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CASE REPORT

Accessory Hepatic Arteries with a Duplicated Inferior Vena Cava: Anatomical and Surgical Significance

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Abstract

Hepatic artery variations are relatively common findings in many patients. These variations have been categorized and quantified using Michels classification system. Findings of accessory right and left hepatic arteries were found in a 69-year-old White female donor with a duplicated inferior vena cava during routine anatomical dissection (Michels type 7 variation). Research supports that the hepatic artery variations can be due to either failure of regression of ventral anastomosis between the dual aortas or failed regression of fetal hepatic blood flow. Given the concurrent development of the inferior vena cava and aortic branches during the fourth to seventh week of gestation, this patient's duplicated inferior vena cava and abnormal celiac trunk and superior mesenteric artery anatomy may be related to a failure of fetal vasculature regression. There are no known associated comorbidities with this vascular variation; however, it is clinically significant when undergoing any hepatobiliary surgical procedures and suggests an increased risk for hepatic ischemic events.

Key Words: *Accessory hepatic artery; Duplicated inferior vena cava; Embryologic development; Anatomical variation*

Introduction

The study of anatomical variation has a significant impact on appropriate clinical practice and surgical procedures. These variations are relatively common findings found throughout the body, often incidentally found during imaging, surgical procedures, or cadaveric dissections. The celiac trunk (CT) and superior mesenteric artery (SMA) are two anterior branches of the aorta with close anatomical and functional relationships, supplying blood to the foregut and midgut organs, respectively [1]. Their proximity and synchronous embryologic development yield common vascular variations that have been widely studied. These variations were studied and classified into categories within the Adachi, Hiatt and Michels models

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[2]. The Michels model is the newest and most widely used by surgeons today to categorize the types of hepatic artery variations. We present a case report of a 69-year-old White female with an accessory left hepatic artery (aLHA) and a right hepatic artery (aRHA) found upon cadaveric dissection. This patient was also found to have a duplicated inferior vena cava (IVC), which was described in detail in a previously published report [3]. In addition to highlighting the anatomical variations found in this patient, a secondary aim of this case report is to discuss the epidemiology, embryological origin, as well as the clinical significance of varied hepatic artery anatomy.

Case Description

During routine anatomical dissection of human donors during the 2021 first-year medical gross anatomy course at the Uniformed Services University of the Health Sciences, an aLHA and an aRHA were observed in a 69-year-old White female donor with a listed cause of death of corticobasilar degeneration (neurodegenerative disease) Figures 1 and 2. Both the CT and SMA demonstrated anatomic variations, along with a duplicated IVC Figure 3. This patient had a typical branching pattern for their splenic and common hepatic arteries off the CT, but the third branch was an aLHA feeding into the left side of the liver. The left gastric artery (LGA) branched off the aLHA 3 cm from the base of the CT. The common hepatic artery (CHA) then followed the expected vascular anatomy branching into the proper hepatic artery (PHA), bifurcating into its left hepatic artery (LHA) and right hepatic artery (RHA) 1.5 cm after the CHA transitioned into the PHA. Typically, the cystic artery (CA) branches from the RHA to provide blood supply to the gallbladder. However, this patient's RHA did not have a branching CA. Dissection of the SMA revealed an aRHA feeding into the liver that was 5.5 cm in length and 1.1 cm in diameter. This aRHA traveled toward the liver, giving off the CA that is 1.7 cm in length and 0.6 cm in diameter. Ultimately, blood supply to the liver in this patient was provided by three separate branches (CHA with RHA and LHA branches, as well as an aRHA and an aLHA). Gallbladder blood supply was derived solely from the accessory branch off the SMA.

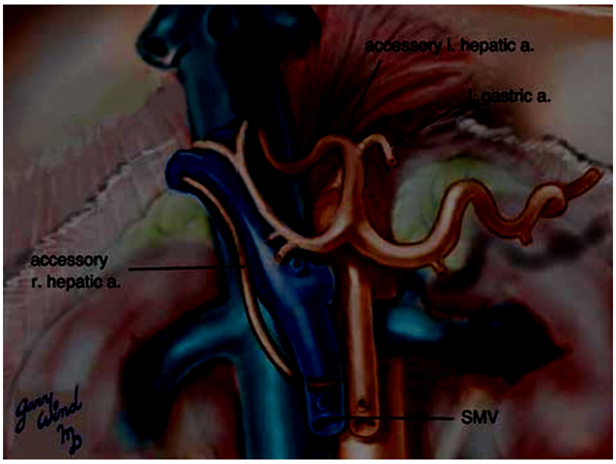

Figure 1) *Illustration of the CT with the aRHA coursing off the main trunk as well as the aLHA branching from the SMA indicating Michel Type 7 variant.*
SMV: Superior Mesenteric Vein.

Figure 2) *An anterior view of the Celiac Trunk (CT) and its subsequent branches. The CT has three main branches: Common Hepatic Artery (CHA), Splenic Artery (SA), and an accessory Left Hepatic Artery (aLHA) that gives off the Left Gastric Artery (LGA). The CHA then follows an expected anatomical path into the Proper Hepatic Artery (PHA), which bifurcates into the Right and Left Hepatic Arteries (RHA, LHA). The gallbladder is supplied by the Cystic Artery (CA) branching off the accessory Right Hepatic Artery (aRHA), which is seen diving posterolaterally to the Common Bile Duct (CBD). The aRHA originates from the superior mesenteric artery (not pictured).*

Figure 3) *Anterior caudal view of the hepatobiliary tree and vasculature. The accessory Right Hepatic Artery (aRHA) is branching off the Superior Mesenteric Artery (SMA), supplying blood to the right side of the liver. The aRHA runs laterally to the Portal Vein (PV) as it enters into the liver. The Cystic Artery (CA) is branching off the aRHA, supplying blood to the gallbladder. Of note, the anterior communicating connection between the duplicated Inferior Vena Cava (IVC) can be visualized in this image just below the SMA.*

Discussion

Anatomical variants of the hepatic artery have been widely studied due to their relevance in common general surgery procedures and importance in more complex hepatobiliary surgical procedures [4]. The replaced right hepatic artery and replaced left hepatic artery are the most common vascular variations of hepatic blood flow occurring in about 11% and 10% of the population respectively followed by accessory left and right hepatic arteries (8% and 7% respectively) as seen in this patient [2]. In 1955, Michels created his classification of hepatic artery variants as seen in Table 1 that is commonly used by surgeons today [2]. In our case, this patient had Michels variation type 7 consisting of an aRHA and an aLHA which is reported to happen in only about 1% of the population [2].

TABLE 1

Michels classification of variant hepatic artery anatomy found in a review of cases. This patient is variation type 7 consisting of an accessory left and right hepatic artery (CHA=Common Hepatic Artery; LGA=Left Gastric Artery; LHA=Left Hepatic Artery; RHA=Right Hepatic Artery; SMA=Superior Mesenteric Artery).

Type	Description	%
1	Normal	55
2	Replaced LHA from LGA	10
3	Replaced RHA from SMA	11
4	Replaced RHA and LHA	1
5	Accessory LHA	8
6	Accessory RHA	7
7	Accessory RHA and LHA	1
8	Replaced RHA and accessory LHA or replaced RHA and accessory RHA	4
9	CHA from SMA	2.5
10	CHA from LGA	0.5

Accessory right and left hepatic arteries

Accessory and replaced hepatic arteries are thoroughly discussed in literature with the most commonly known variation being a replaced right hepatic artery (RRHA) [4]. Replaced hepatic arteries refer to arteries having an aberrant or anomalous origin, whereas accessory hepatic arteries have abnormal origins and supply a section of the liver along with another artery [4]. Given that this patient has a normal PHA with its own respective RHA and LHA, the additional right and left hepatic arteries would be classified as “accessory” and not “replaced.” Replaced and accessory right hepatic arteries deliver blood to the right lobe of the liver and derive their blood supply from the SMA, rather than the CT through the CHA. The aLHA is also a common variant of CT vasculature. Typically, an aLHA branches off either the LGA or directly from the CT, supplying blood to the left side of the liver. Dominant and accessory blood supply to the liver can be assumed by the diameter of the feeding arteries in the cadaveric dissection. Based on the diameter of the aRHA, measured as greater than 80% larger than the RHA, we presume the aRHA served as the primary blood supply for the right hepatic lobe as well as the primary blood supply to the gallbladder. However, in vivo vascular imaging would more accurately confirm the blood flow distribution of the four hepatic arteries. The similar size of the RHA compared to the LHA and aLHA suggests it was still an important inflow source to the liver and vessel compromise could result in infarct.

Embryologic development

A review of the literature suggests that there are two leading theories behind the embryological origin of replaced or accessory right and left hepatic arteries [5-7]. Ultimately, failure of regression of fetal vasculature during development renders accessory vessels. In one theory, fetal anatomy consists of two aortas and failure of regression of ventral anastomoses leads to abnormal vasculature, as depicted in Figure 4. The other theory pertains to hepatic blood flow, as a fetus initially requires three arteries for liver perfusion, two of which regress throughout development. The CT and SMA have a close anatomic and functional relationship, contributing to significant vascular variations arising in utero.

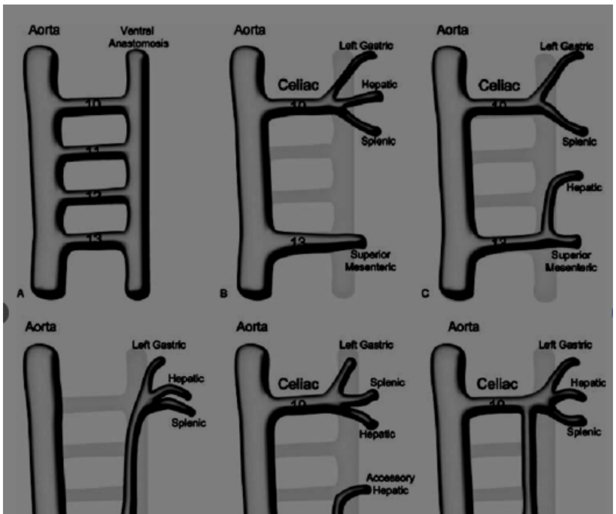

Figure 4) *Ventral anastomosis in utero. This shows variants that develop after the ventral anastomosis of the aorta regresses and leaves the relevant vasculature. (A) Normal fetal vascular anatomy with ventral anastomosis. (B) Normal CT and SMA anatomy. (C, D, E, F) Vascular variations due to failure of regression.*

During fetal development, the abdominal viscera has dual blood supply from dorsal and ventral aortas that anastomose through a series of communicating arteries [5]. Three of these vitelline arteries persist during development (10^{th}, 13^{th}, 21^{st}) to form the CT, SMA, and the inferior mesenteric artery, respectively [5]. Vascular abnormalities occur when either vitelline arteries or parts of the ventral anastomosis fail to regress [5]. As seen in Figure 4, there are a myriad of anatomical variations that have been reported due to failure of ventral regression. This figure demonstrates how this patient may have developed an accessory hepatic artery branching from the SMA; however, this theory does not explain the aLHA from the CT, which may be better explained by the fetal hepatic blood flow theory.

The other previously mentioned embryological theory behind accessory right and left hepatic arteries suggests that three hepatic arteries are present during development, with persistence of a single artery [6,7]. There are numerous reports that there are three hepatic arteries in utero that consist of the right hepatic artery that arises from the SMA, the middle hepatic artery from the CT, and the LHA from the LGA supplying the respective regions of the liver [6,7]. Throughout fetal development the right and left hepatic arteries regress, leaving only the middle hepatic artery [6,7]. This middle hepatic artery then becomes the PHA, giving off its own LHA and RHA. When the embryonic right and left hepatic arteries remain, accessory right and left hepatic arteries are present, branching from the SMA and CT or LGA, respectively, as present in this patient.

Given the concurrent development of the IVC and aortic branches during the fourth to seventh week of gestation, this patient's duplicated IVC and abnormal CT and SMA anatomy are likely related, both a result of failure of regression of fetal vasculature [8]. While accessory hepatic arteries likely result from failure of regression of either aortic anastomoses or fetal hepatic vessels as previously discussed, the persistence of both supracardinal veins in the suprarenal tract result in a duplicated IVC [9].

Clinical and surgical significance

Laparoscopic cholecystectomy is the standard of treatment for cholecystitis, symptomatic cholelithiasis, and gallbladder polyps >10 mm or with risk factors for malignancy. Management for gallstone pancreatitis and choledocholithiasis also includes cholecystectomy, often within the same hospitalization. During a cholecystectomy, obtaining the critical view of safety is essential before removing the gallbladder. The critical view of safety is achieved when the hepatocystic triangle is clear of fibrofatty tissue, the lower third of the gallbladder is dissected from the liver to expose the cystic plate, and there are only two visible tubular structures entering the gallbladder - the cystic duct (CD) and the CA. The hepatocystic triangle is bordered by the inferior edge of the liver, the CD, and the common hepatic duct and typically the CA is visible within this triangle. When removing the gallbladder, the CD and CA are clipped both distally and proximally and divided between the applied clips. Blood vessel injuries during laparoscopic cholecystectomy result in conversion to open surgery in up to 1.9% of cases and mortality increases up to nearly 15% with an intraoperative vascular injury [10]. Vascular variations increase the risk of bleeding during a routine procedure. In this case, the CA branches from the aRHA that branches from the SMA. During dissection of the hepatocystic triangle the CA may be difficult to visualize prior to clipping and dividing, increasing the risk of iatrogenic clipping and dividing of the aRHA, and therefore compromising blood flow to the right lobe of the liver. Overall, this vascular variation significantly increases the risk of iatrogenic injury, thus increasing the risk of bleeding and mortality in a common general surgery procedure.

The SMA has a higher risk for atherosclerosis due to its acute angle branching off the aorta, increasing turbulent flow and contributing to vessel wall stress. SMA occlusion, either thrombotic or embolic, results in cessation of blood flow to the midgut - the majority of the small bowel, as well as the ascending colon. Acute mesenteric ischemia has a high mortality rate of greater than 60% [11]. Significant hepatic and cystic blood flow derived from the superior mesenteric artery may result in ischemia if compromise of the SMA occurs, as in this patient. The CA is the exclusive blood supply to the gallbladder, which, therefore, would have an increased ischemic risk in a patient with the CA existing as a branch of the aRHA from the SMA. In general, the liver is resistant to ischemic injury given the dual blood supply via the hepatic arteries and portal venous system [12]. However, there has been a reported case of a patient with extensive arterial disease involving the CT and SMA with normal portal venous flow that was found to have hepatic infarctions in multiple lobes of the liver [12]. Despite the dual blood supply liver infarctions are a possible complication of abnormal hepatic vasculature as seen in this patient.

Accessory hepatic arteries may also have surgical significance in major hepatobiliary operations, including liver resections or pancreatic procedures. Such complex operations depend upon accurate identification of the vascular anatomy to determine appropriate resection margins. Liver resections are highly dependent on the supporting vasculature and knowledge of a patient's specific anatomy. It is not uncommon to map out the vasculature of the region in preparation for these procedures to evaluate the internal segmental anatomy of the liver with its corresponding blood supply. Anatomic vascular mapping helps determine functional segments of the liver through both the arterial and venous input and major resections of the liver are completed after adequate understanding of internal segmental anatomy [13]. In patients with abnormal CT and SMA vasculature can significantly alter the operative plan. Intraoperatively during liver resections, ultrasound is routinely used to identify metastatic lesions as well as visualizing the relationship of the tumor to vascular structures and guide the surgeon's approach to the resection [13]. Additionally, there is evidence of increased incidence of hepatic artery stenosis and thrombosis in liver transplant recipients with an aberrant right hepatic artery [6]. Overall, this abnormal vasculature can not only make routine general surgery procedures more difficult and increase the risk of iatrogenic injury, but they can also increase the risk for long term complications, as well as significantly alter operative plans for more complicated hepatobiliary procedures.

Conclusion

With better imaging modalities and contribution to research with case reports of cadaveric dissections, a larger database of CT and SMA vascular abnormalities is being developed. With this larger pool of research, it is now evident that these abnormalities are common within the population and suggest that surgeons should be aware of and expect to see such vascular variations, even while performing common general surgery procedures. Additionally, the high prevalence of CT and SMA vascular abnormalities suggests that preoperative vascular mapping is crucial prior to complicated abdominal surgeries or operations involving the liver. Mapping of these abnormalities will likely reduce operative complications and iatrogenic injury as well as improve overall patient outcomes.

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