Hepatic Artery Variations Analyzed in 1141 Patients Undergoing Digital Subtraction Angiography

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Research

Keywords: Digital subtraction angiography, Hepatic artery, Anatomical variation, Liver tumor

Posted Date: February 19th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-218499/v1>

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Abstract

Background: The hepatic artery has several variations that can be observed by digital subtraction angiography (DSA). In recent years, clinical studies have continued to explore its diversity, leading to the discovery of rare variations and the development of new classifications.

Methods: Institutional Review Board approval was attained. This retrospective study was based on analysis of DSA images in 1141 patients who were pathologically or clinically diagnosed with liver tumor from May 2015 to December 2019. All patients involved in this study had undergone hepatic arteriography at our hospital. The study aimed to complete angiographic assessments of the left gastric artery (LGA), superior mesenteric artery (SMA) and HA, which supply the liver parenchyma.

Results: It was worth mentioning that we found five new cases of hepatic artery variations. The four major types of hepatic artery anatomy were identified. Normal hepatic artery anatomy was pointed in 871 (76.3%) of 1141 patients, and the incidence of hepatic artery variation was 270 (23.7%) cases. Variation in hepatic artery origin was identified in 240 (21.1%) cases. Variation in bifurcation was identified in 18 (1.6%) cases. Three (0.5%) cases had synchronized bifurcate and variation of origin, which has not been reported previously.

Conclusion: Hepatic artery variation have diversity and complexity. The known and newly is covered variations were thoroughly analyzed in detail, which has important clinical significance for hepatobiliary surgeries and interventional operations.

Introduction

The anatomical variations of the hepatic artery are highly variable, and their incidence is generally from 19.7–49% [1–4]. Michels [3] proposed an internationally recognized classification of hepatic artery abnormalities in 1966, which was based on the results of 200 autopsies to describe the anatomical variations in the hepatic artery blood supply. In 1994, Hiatt [5] analyzed the hepatic arteries of 1000 patients accepted liver transplantation and modified the Michels classification.

Nowadays, DSA characterized by accurate imaging and evaluation of the blood supply of hepatic arteries is playing a crucial role in the treatment of liver tumor [6]. For liver tumor resection, liver transplantation, and even pancreatoduodenal surgery [7–9], angiography is a critical part of preoperative assessment in order to reduce or even avoid unnecessary intraoperative vascular damage. Full familiarity with these variations can also help us to avoid complications. Interventional radiologists who perform hepatic artery embolization operation must be acquainted with common and rare hepatic artery variations; If radiologist failure to recognize the presence of abnormal blood vessels can lead to incomplete hepatic tumor embolization [10].

The aim of this study was to describe and evaluate the incidence and types of hepatic artery variations using DSA method in patients with liver tumor. The procedure paid much attention to rare variations

which were previously unreported.

Material And Methods

Patients

From May 2015 to December 2019, a retrospective analysis was conducted in 1141 liver tumor patients who were clinically or pathologically diagnosed. Besides, all of them had at least accepted one DSA examination. The only inclusion criteria were DSA images, including angiography of all normal branches of the celiac axis (CA) and the superior mesenteric artery (SMA).

During the study period, we eliminated 15 patients due to incomplete data format and inability to provide images, and excluded 29 patients with surgical resection of the liver or gastroduodenal arteries. Duplicate data for individual patients, such as those receiving repeated interventional embolization, were not included. The study included 928 men and 213 women patients, aging from 28 to 86 years. The diagnosis included 1073 cases of primary liver cancer, 38 of metastatic liver cancer (from stomach cancer, colorectal cancer, pancreatic cancer) and 10 of hepatic hemangioma.

DSA examination

All patients were examined by DSA (Artis Zee Floor, Siemens, Germany). Patients accepted successful puncture using the Seldinger technique under local anesthesia. Then, through a 5F catheter (Cobra or Simmons, Boston Scientific, Natick, MA, USA), primary angiography was performed on the CA and SMA using a nonionic contrast agent (iodoxanol; Jiangsu Hengrui Medicine Co. Ltd., Jiangsu, China). The location and distribution of the main blood vessels and hepatic artery were revealed. If necessary, a microcatheter (Progreat, 2.7/2.8F, Terumo, Tokyo, Japan) was inserted into the specific vessels which supply the liver. DSA was performed by three interventional radiologists who had 5–20 years of experience in the angiography field. Regardless of their origin, we always attempted a complete angiographic evaluation of the left gastric artery (LGA), SMA, and all hepatic artery that supply the liver parenchyma.

Assessment of outcomes

All data were recorded in standard form immediately after angiography, and the procedure was recorded by one of the operators. The origin, shape and distribution of the hepatic arteries were recorded. Hepatic artery variations were recorded and a CD-ROM was made. The CD-ROM was reread and systematic analysis of the hepatic artery variations was done by us.

Results

In the study of 1141 patients with DSA images, 871 (76.3%) were proved to have normal hepatic artery anatomy (Fig. 1), however 270 (23.7%) had hepatic artery variation, including 62 cases could not fit into the Michels classification. The new classification (Table 1) revealed all 10 types of hepatic artery

variation in the Michels classification, unclassified variations, as well as 5 new variations which were unreported before.

Table 1
Type of hepatic artery variations in 1141 Patients compared to Michels

New classification	Current study (n = 1141) DSA	Michels' study (n = 200) autopsies
I: Normal anatomy	871(76.3)	110(55)
II: Variation in origin ^a	240(21.1)	90(45)
a. Replaced or accessory LHA	73(6.4)	36(18)
b. Replaced or accessory RHA	108(9.5)	36(18)
c. Replaced or accessory RHA and LHA	15(1.3)	8(4)
d. Replaced CHA from CA, AA, SMA or LGA	27(2.4)	10(5)
e. Replaced PHA from AA or SMA	2(0.2)	NA
III: Variation in bifurcation	18(1.6)	0
a. CHA trifurcation	15(1.3)	NA
b. CHA quadrifurcation	3(0.3)	NA
c. CHA penta-furcation	0	NA
IV: Bifurcation and variation of origin ^b	3(0.3)	0
CHA trifurcation and replaced LHA	1(0.1)	NA
CHA trifurcation and accessory LHA	1(0.1)	NA
CHA trifurcation and replaced CHA from SMA	1(0.1)	NA
Other		
Anastomotic channel between CHA and SMA	8(0.7)	NA
Double hepatic artery ^c	15(1.3)	NA
SIT	1(0.1)	NA
Notes: Numbers in parentheses are percentages. NA= not applicable. ^a Two unreported variations: LHA arose from GDA and RHA arose from SMA; LHA and RHA separately originated from SMA. ^b Bifurcation and variation of origin have not been reported. ^c DHA belongs to the special type of variation in HA origin, which was analyzed separately.		

Variation in the origin of left hepatic artery (LHA) was confirmed in 73 patients (6.4%); the most common being a replaced or accessory LHA originating from the LGA in 71 patients. In one patient, the rare replaced LHA arose from the gastroduodenal artery (GDA) (Fig. 2a), and in another rare case, a replaced LHA arose from the SMA (Fig. 2b, c). There were 108 patients (9.5%) with variation in the origin of right hepatic artery (RHA). Replaced RHA stemming from the SMA was the most common variation in 81 patients, followed by accessory RHA stemming from the SMA in 16 patients. In an unusual case, an accessory RHA arose from the CA (Fig. 3a). In three patients, accessory RHA originated from the GDA (Fig. 3b, c). In one rare case, a replaced RHA originated from the SMA and an accessory RHA originated from the GDA (Fig. 3d, e). Simultaneous variations in the origin of the RHA and LHA were pointed in 15 patients (1.3%), and the most common was LHA arising from the LGA, with the RHA originated from the SMA concurrently in five cases. There was an uncommon case in which the accessory LHA originated from the LGA and the accessory RHA originated from the SMA (Fig. 4), which belongs to the Michels type VII. It is worth mentioning that two cases of hepatic artery variation have not reported in the literature. In a very rare case, the LHA arose from the first branch of the GDA and the RHA arose from the SMA (Fig. 5a-c). In another case, the LHA and RHA respectively originated from the SMA (Fig. 5d-f).

Variations in the origin of the common hepatic artery (CHA) were identified in 27 cases (2.4%), and the most common was CHA originating from the SMA in 24 cases. There was one case of CHA arising from the abdominal aorta (AA) and one case of Michels type X in which the CHA originated from the LGA (Fig. 6), which is the first case reported by DSA. In another case, the CHA arose from the SMA, and simultaneously, an accessory LHA originated from the LGA (Fig. 7). The PHA arose from the first branch of the SMA or AA in two cases (0.2%), which was considered as a scarce variation. Double hepatic artery (DHA) was proved in 15 cases (1.3%), which referred to the situation where one or both hepatic arteries originated directly from the CA or AA (Fig. 8). These were considered to be a special type of variation in hepatic artery origin, and were analyzed separately.

Bifurcation variation of the CHA were observed in 18 cases (1.6%) without proper hepatic artery (PHA), including 15 cases of trifurcation (1.3%) and three of quadrifurcation (0.3%) (Fig. 9a, b). Bifurcation and variation in origin occurred simultaneously in three cases (0.3%), which has not been reported in the literature previously. In one case, the first branch of SMA was the CHA, which trifurcated into the LHA, RHA and GDA (Fig. 10a, d). The second case that the trifurcation of CHA and the accessory LHA originated from the LGA (Fig. 10b, e). The third case that the CHA forked into RHA, GDA and RGA, while LHA originated from the LGA (Fig. 10c, f).

We observed stenosis or occlusion of the CHA, even at the root of the CA. Tortuous arterial perfusion in the CHA formed by collateral branches of the SMA was found in eight cases (0.7%). A persistent anastomotic channel was formed between the CHA and SMA (Fig. 11), which resulted from stenosis or occlusion at the root of the CA and was difficult to classify into any type. The primary liver cancer with situs inversus totalis (SIT) was found in only one case (0.1%) (Fig. 12).

Discussion

In the normal anatomy of the hepatic artery, the CA divides into three branches [10]. The first branch is the LGA, followed by the SA and the CHA, which divides into the GDA and PHA, while the PHA divides into the LHA and RHA. According to autopsy and early DSA report [2, 10–12], some papers even reported the sensitivity of computed tomography (CT) and magnetic resonance (MRI) angiography to describe hepatic artery variation [13–17]. Hepatic artery variation has been found to be diverse and complex. In general, the description of hepatic artery variation has been enriched and the classification has been improved [11–13, 15]. Although DSA is an invasive examination, it is an important method for vascular examination and a means of treatment. Moreover, in this study, we reported some rare variations and deficiency of the complement type. Through retrospective analysis of the origin, shape and branches of the hepatic artery by DSA, we concluded that the incidence of hepatic artery variation rate in 1141 patients with hepatic tumor was 23.7%, which was lower compared with previous reports [1–3]. First of all, our study was performed retrospectively and was based on analysis of DSA images. Moreover, regional differences, ethnic differences, and differences in selected investigation populations who all had liver tumor were considered.

The most common variation is the RHA originating from the SMA, then LHA from LGA, and CHA from SMA. Extensive MEDLINE search showed that the presence or absence of middle hepatic artery which is considered normal is independent from this [10]. It has been reported that both the LHA and RHA can originate from the CA, AA, LGA, GDA, SMA, SA and even right renal artery [18–21]. The CHA may arise from the CA, AA, SMA and LGA [11]. The PHA can arise from the CA, AA and SMA [10]. Compared with the Michels [3] and Hiatt [5] classifications, which were confined to origin of the hepatic artery from the LGA and SMA. We found five new variations and proposed a new classification. The first type is normal hepatic artery anatomy.

The second type is variation in origin which is considered to be the primary type of variation, including variation in origin of the LHA, RHA, PHA and CHA. DHA belongs to a special type of variation in origin, which was analyzed separately. Fasel et al [22] proposed that DHA refers to the situation in which one or two hepatic arteries directly originate from the CA or AA. It is an uncommon but important variant, in which there is no CHA and the GDA may originate from either hepatic artery. As far as we know, many case reports have been made about rare variations in the literature [23–28]. In our study, we discovered uncommon cases arising from the SMA, such as LHA originating from the SMA [23], PHA from SMA [10], LHA and RHA both originating from SMA, which has not been reported before. There are rare cases of the hepatic artery originating from the LGA, including CHA originating from the LGA [3, 11]. In addition to replaced or accessory LHA and RHA from vessels other than the SMA or LGA, there are infrequent cases of GDA origin. In this study, we observed that rarely, the LHA arose from the GDA [24, 25], and the accessory RHA arose from the GDA [26]. In rare cases of AA origin, including the CHA originated from the AA alone [11], and the PHA originated from the AA [10]. Some of the original variants even have double replaced or accessory systems, including: RHA arising from the SMA and accessory RHA arising from the GDA [26]; accessory LHA derived from the LGA and accessory RHA derived from the SMA [3, 27]; CHA arising from the SMA and accessory LHA arising from the LGA [28]; and LHA arising from the GDA and

RHA from the SMA, which has never been reported before. Thus, variation in origin is variable, while rare variations also play an important role in understanding tumor blood supply.

The third type is variation in bifurcation [11], including trifurcation, quadrifurcation and pentafurcation of the CHA. Németh et al [25] referred to one case of pentafurcation that underwent 3D volumetric CT reconstruction. However, it was not observed in this study, and trifurcations accounted for 1.4%, which was less than the 2.0% of patients in the study by Vandamme et al [29]. Quadrifurcation is a peculiar variation, and we only discovered three cases (0.3%). Covey et al¹⁰ also described this category.

The fourth type is bifurcation and variation of origin, which has not been reported by DSA examination. We refer to the situation where the CHA bifurcated directly as having any variation of hepatic artery origin. We found 3 new cases that the incidence rate of this specific situation was only 0.3%. Although only a few authors detect and consider bifurcation to be a variant condition [11, 29], it does have critical surgical implications. Especially for transcatheter arterial chemoembolization (TACE), the catheter should be superselected into the liver parenchyma for injection. Obviously, practice has proved that this variation proposed was reasonable, feasible as well as necessary.

Besides, we discovered eight cases of stenosis or occlusion in the CHA, even at the root of the CA [11, 30], with multiple tortuous collateral vessels, forming a continuous anastomotic channel between the CHA and SMA, which only accounted for 0.7%. This variation was not common, and could not be classified as a specific type. Song et al. [11] reported the ambiguous CA anatomy and the prevalence of this persistent anastomotic channel was 0.2%. It can be seen that in the treatment of such patients with TACE, and it needs to be performed by SMA uplink superselection. The more tortuous the anastomotic channel is, the more difficult the operation.

Moreover, we found one case of liver cancer with SIT. SIT is a rare congenital disease with an incidence rate of 1:500–1:20 000 [31], in which the abdominal and thoracic viscera are all mirror image shifted. The etiology of visceral transposition is unknown and does not affect normal health or life expectancy, but has important surgical significance. To our knowledge, hepatocellular carcinoma (HCC) with SIT is extremely rare, and only 10 cases have been reported in Pubmed [31–35]. The condition was first described by Kanematsu et al [32] in 1983. Later Tao Li et al [35] reported a case of HCC with SIT by writing to the editor in 2007, which was treated by TACE. We also successfully treated such a patient who is still alive, and it was the second report by DSA.

We know that CHA can be divided into four types, arising from the CA, AA, SMA and LGA, and has been analyzed by CT and DSA. All forms were found in our study, including rare CHA separately originating from the AA or LGA. In previous studies the incidence of the latter was 0.4–0.5% [11, 36, 37], with a total of 15 cases. Michels [3] and Uva [36] respectively reported a case, which was found at autopsy. Two cases were found by Gruttadauria [38] during hepatic surgery and Waki [37] during pancreatic surgery. The remaining 11 cases, which were detected by CT angiography and 3D reconstruction, were reported by

Okada [39] and Song [11]. However, it is the first case of the CHA arising from the LGA with liver tumor treatment reported by DSA image in the world.

Conclusions

We systematically classified complex hepatic artery variations, including several rare and unreported variations, enriching the data for hepatic artery variation. For many hepatobiliary and interventional surgeries, hepatic angiography is a central part of preoperative evaluation. Surgeons should be familiar with common and rare hepatic artery variations, because knowledge of the patients' vascular conditions can save operation time, achieve ideal effects of embolization, and reduce or avoid unnecessary vascular injury.

Abbreviations

AA: abdominal aorta; CA: celiac axis; CHA: common hepatic artery; DHA: double hepatic artery; DSA: digital subtraction angiography; GDA: gastroduodenal artery; LHA: left hepatic artery; LGA: left gastric artery; PHA: proper hepatic artery; RHA: right hepatic artery; SA: splenic artery; SMA: superior mesenteric artery; SIT: situs inversus totalis; TACE: transcatheter arterial chemoembolization; HCC: hepatocellular carcinoma.

Declarations

Acknowledgements

We thank all patients for participating in this study and the radiologists who generously participated in this study.

Authors' contributions

DD designed the study, analyzed the data, and drafted the work. XW and MM performed the radiotherapy and interpreted the data. YW and RG collected the data and participated in the investigation. JG and ZR participated in conception and revising the work. ZZ performed the operation, interpreted the data, revised the work, and participated in project supervision. All authors read and approved the final manuscript.

Funding

This study was supported by an unrestricted grant from the [National Natural Science Foundation of China](#) (Grant No. 81870205).

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The institutional review board (NO. 2019-211) approved the study design. Written informed consent was waived due to the retrospective design and the absence of any intervention.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

Figure 1

Normal hepatic artery anatomy. The CA divides into the LGA, SA and CHA (straight black arrow). After the GDA (straight white arrow), the CHA becomes the PHA (short arrow). The PHA bifurcates into the RHA (curved white arrow) and LHA (curved black arrow).

Figure 2

Variation in origin of LHA (straight arrow). a): Angiogram of the CHA dividing into the RHA and GDA, and the first branch of the GDA was the LGA. b): Angiogram of the CA demonstrates the CHA dividing into the RHA, middle HA and GDA, and no LHA was visualized. c): LHA originated from the SMA.

Figure 3

DSA image shows accessory RHA (curved arrow). a): Angiogram of the CA demonstrates the CHA dividing into the RHA (straight arrow), LHA and GDA. In addition, an accessory RHA arose from the CA. b): Angiogram of CA and (c) accessory RHA arising from GDA. (d) and (e): Angiogram of accessory RHA arose from the GDA and RHA arose from the SMA (short arrow).

Figure 4

DSA image shows the double accessory variations of RHA and LHA. a): Angiogram of the CA demonstrates the CHA dividing into the RHA, LHA and GDA. Accessory LHA (curved arrow) arose from the LGA, and (b) accessory RHA (straight arrow) arose from the SMA.

Figure 5

DSA image shows the double replaced variations of RHA (straight arrow) and LHA (curved arrow). a-c): Angiogram of the first branch of the GDA was the LHA and the RHA arose from the first branch of the SMA. d-f): the RHA and LHA were separately from the SMA.

Figure 6

DSA image shows CHA (curved arrow) arising from LGA (short arrow), which belongs to Michels type X. a): Angiogram of the CA, showing division into the LGA and SA, and no CHA emergence. b): Angiogram of LGA region shows a replaced CHA as the first branch of the LGA.

Figure 7

DSA image shows two variations of replaced CHA (straight arrow) and accessory LHA (curved arrow). a): Angiogram of the CA divided into LGA and SA, and accessory LHA was the first branch of the LGA. No

CHA was visualized. b): Angiogram of the SMA shows a replaced CHA as the first branch of the SMA.

Figure 8

DSA image shows a DHA. There was no CHA and the GDA (straight white arrow) originated from either HA. a): RHA (straight black arrow) and LHA (curved arrow) arose from the CA. The GDA arose from the LHA. b): The GDA arose from the RHA.

Figure 9

DSA image shows bifurcation variation of the CHA. a): Trifurcation of the CHA dividing into the LHA (curved arrow), RHA (straight black arrow) and GDA (straight white arrow). b): Quadrifurcation of the CHA dividing into the LHA, RHA, RGA (short arrow) and GDA.

Figure 10

DSA image shows bifurcation and variation in origin without PHA in 3 cases. a) and d): The first branch of SMA (straight white arrow) is the CHA, which trifurcates into the LHA, RHA and GDA. b) and e): Trifurcation of the CHA divided into the LHA, RHA and GDA. Accessory LHA (curved arrow) was the first branch of the LGA. c) and f): Trifurcation of the CHA divided into the RHA, RGA and GDA, and a replaced CHA (straight arrow) was the first branch of the LGA.

Figure 11

DSA image shows a persistent anastomotic channel (straight arrow) between CHA and SMA. a): The root of the CA was blocked, and tortuous arterial perfusion in the CHA was formed by collateral branches of the SMA. b): Angiogram of the CA region showings SA and LGA which divided into the LHA, and the CHA was blocked. c): Anastomotic channel between CHA and SMA.

Figure 12

DSA image shows liver cancer with SIT. Angiogram of the CA shows the intact SA, LGA and CHA (straight arrow), but the abdominal vessels are all mirror image shifted. The incidence of this type of variation is extremely low.