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Surgical implications of anatomical variations in hepatic arteries

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Abstract

Modal arterial vascularization of the liver is ensured by the common hepatic artery, branch of the celiac trunk. Anatomical variations are explained by the persistence or regression of primitive segmental arterial branches in the embryo. The aim of our work is to review the anatomy of the HA and the surgical implications arising from its variations, through a few observations. These variations have an impact primarily on hepatobiliary and pancreatic surgery, liver transplantation, as well while performing gastrectomy or interventional radiology procedures.

Ignorance of these variants can lead to errors in surgical technique, often resulting in serious complications, dominated by intraoperative hemorrhage and ischemia or postoperative biliodigestive anastomosis leakage and biliary necrosis.

Preoperative arterial CT-scan is the method of choice for mapping hepatic arterial anatomy and its variations.

Keywords: Hepatic Arteries; Variations; Surgery; Liver; Pancreas.

1. Introduction

The hepatic artery vascularizes the liver, bile ducts and pancreas. Its anatomical variations have always aroused the interest of many authors, and occupy a special place in their work. Perfect knowledge of these variants is particularly crucial in the planning and performance hepato-biliary, pancreatic and gastric of surgery. Hepatic arterial vascularization, known as modal vascularization, is present in approximately 55 to 65% of the general population [1]). For the remaining 35%, multiple variations in number, course, origin and termination have been described by anatomists and surgeons. Preoperative CT-scan in the arterial phase is the benchmark examination, providing an exhaustive map of vascular variants and thus guiding the surgeon in his choice of approach and enabling him to adapt the surgical technique to each variant, with the aim of avoiding iatrogenic surgical complications (haemorrhage, ischemia).

2. Method

Our work is an analytical study based on 5 observations of patients operated for hepatobiliary, pancreatic and gastric pathology , all patients have preoperative angioscan, which revealed the existence of anatomical variations of the HA. These variations may concern the number, origin, route and distribution. Several authors have tried to group these variations for didactic or practical surgical purposes. For example, Adachi (1928)[2], Michels (1966) [1], Hiatt (1994)[3] and Abdullah (2006)[4]) each proposed a classification based on variations in HA origin and number. Our study is based on the Michels classification (table 1) [1], as it is the most widely used and anatomically more complete, since it distinguishes between a replaced artery and an accessory artery.

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To simplify the nomenclature, the proper HA arising from the celiac trunk is called the middle HA (MHA), which, in the modal arrangement, bifurcates into the right and left branches. A right HA (RHA) or left HA (LHA) is said to be accessory when it coexists with the MHA; it is said to be replacement when the MHA does not exist. This classification describes 10 types of hepatic arterial variations, from type I for modal anatomy and from II to X for the variants. (Figure 1)

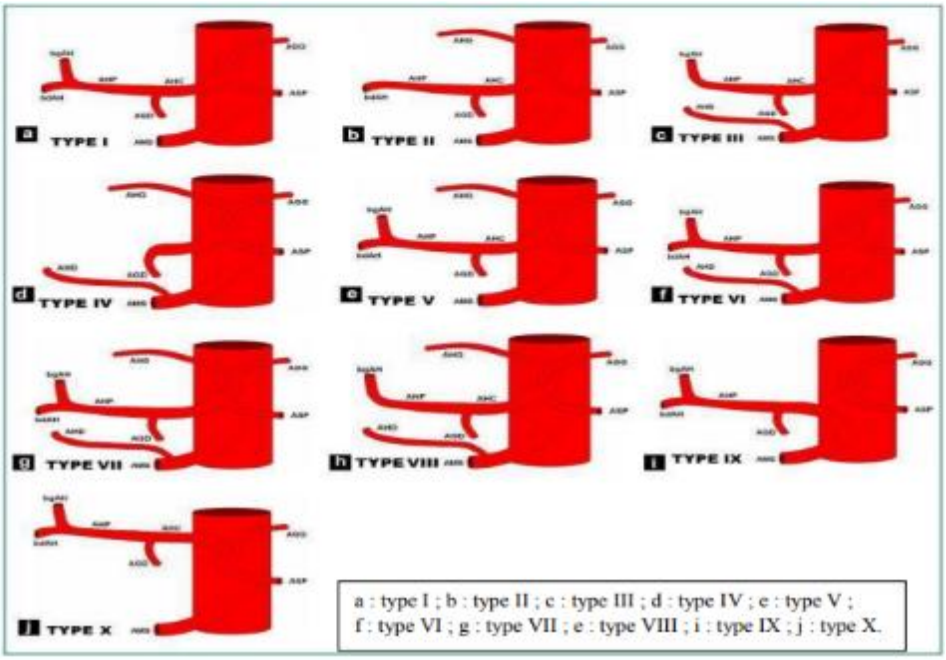

Figure 1 Variations in hepatic arterial supply, Michels classification [1]

Table 1 Michels classification and incidence of anatomical variations

	Type	Description	Incidence
	I	Modal vascularization	55%
Arteries replaced	**II**	Left hepatic artery replaced origin of left gastric artery	10%
	III	Right hepatic artery replaced originating from the superior mesenteric artery	11%
	IV	Left hepatic artery and right hepatic artery replaced	1%
Accessory artery	**V**	Left hepatic artery accessory to the left gastric artery	8%
	VI	Accessory right hepatic artery originating from the superior mesenteric artery	7%
	VII	Accessory left and right hepatic arteries	1%
	VIII	Replaced right hepatic artery and accessory left hepatic artery or accessory right hepatic artery and replaced left hepatic artery	4%
	IX	Common hepatic artery originating from the superior mesenteric artery	2.5%
	X	Common hepatic artery originating from the left gastric artery	0.5%

Objective

The aim of our work is to highlight the anatomical variations of the HA and to emphasize the implications of this variations during hepatopancreatic or gastric surgery.

3. Results

All patients underwent angio-CT, which revealed arterial variations (table 2).

Table 2 Anatomical arrangements of HA found in our patients

Patient	Vascular variations	Michels classification	Gesture
1	right hepatic artery arising from the SMA; the MHA was destined only for the left liver (figure 2)	III	Right hepatectomy
2	right hepatic artery irrigating the entire liver, with absence of the MHA (figure 3)	IV	Whipple procedure
3	Right hepatic artery associated with an MHA (figure 4)	VI	Whipple procedure
4	coexistence of an RHA originating from the SMA and an LHA originating from the LGA in addition to a middle hepatic artery (figure 5)	VIII	Whipple procedure
5	Modal vascularization RHA associated with donor MHA	I VI	Liver transplantation
6	MHA, which arises separately from the aorta, with a posterior retropancreatic and retroportal course, bypasses the left edge of the hepatic pedicle to join the liver hilum and divide into its two right and left branches.	not described	Whipple procedure

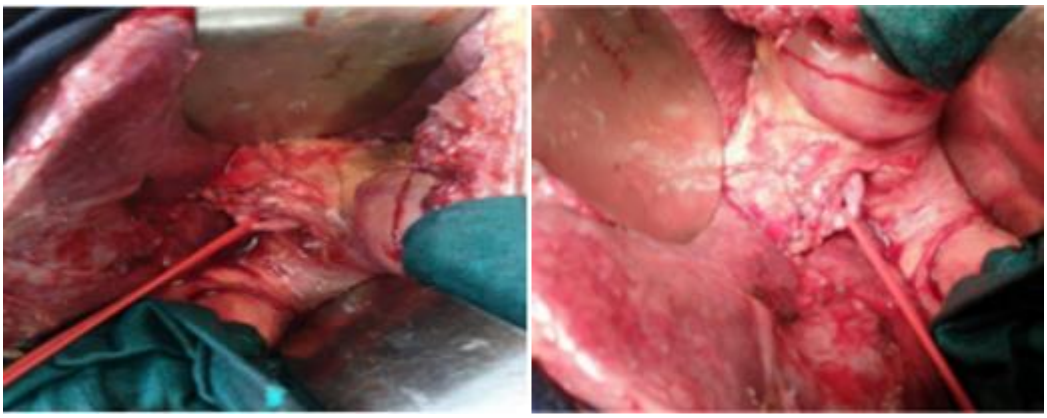

Figure 2 Control of the RHA which arises from the SMA

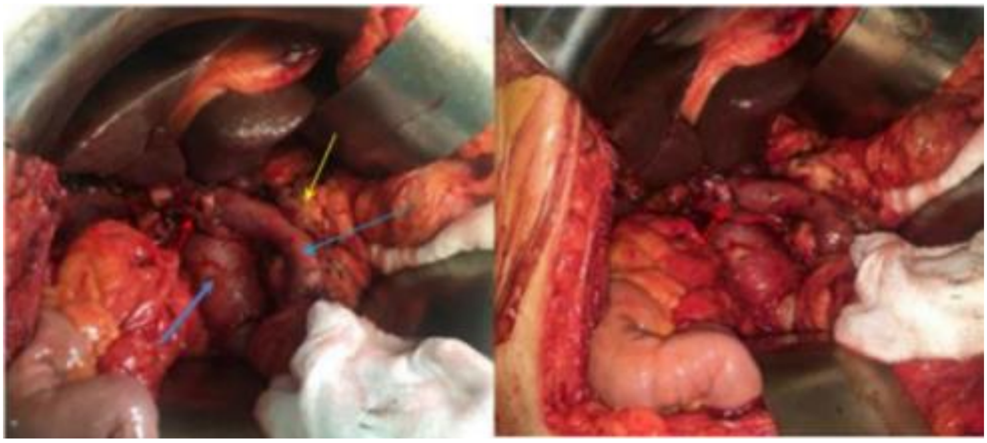

Figure 3 Intraoperative view of RHA intended for the entire liver, branch of the SMA

Figure 4 Operative view showing the coexistence of an RHA (red lake) and an MHA (blue lake) with its right and left branches

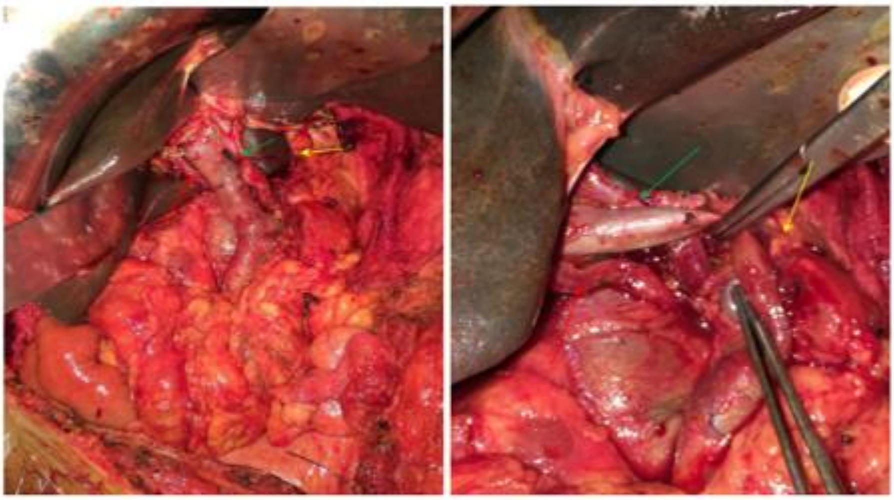

Figure 5 Operative views showing the coexistence of 3 hepatic arteries; an RHA (red arrow) from the SMA, an MHA (green arrow) and LHA (yellow) from the left gastric artery.

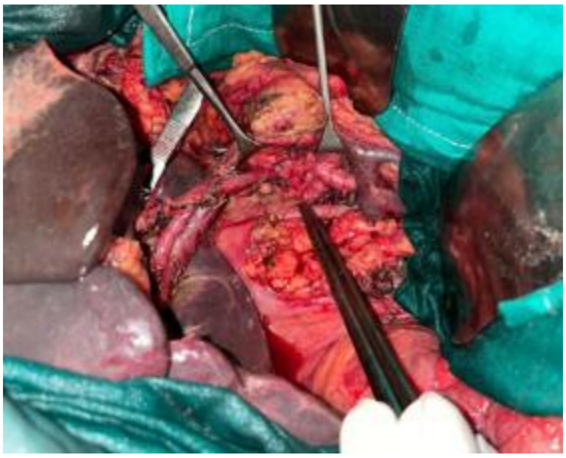

Figure 6 MHA, which arises separately from the aorta, with a posterior retropancreatic and retroportal course, bypasses the left edge of the hepatic pedicle to join the liver hilum and divide into its two right and left branches

4. Discussion

The vascular anatomy of the hepatic arteries is important to know, as variations are frequent and therefore have a major implication during hepatobiliary, pancreatic and gastric surgery. Their preoperative recognition is essential to avoid complications such as hemorrhage or ischemia.

Hepatic arterial vascularization is of the terminal type, which in the event of surgical trauma, thrombosis or ligation of one of the HAs, leads to ischemia of the corresponding territory, all the more so as collateral circulation and interterritorial anastomosis routes are poorly developed.

Suppletive arterial collaterals can develop in the event of HA obstruction from the contralateral artery (right and left branches of the MHA, RHA and LHA) through the hilar plate (communicating arch) and via the marginal arteries derived mainly from the posterosuperior pancreatic artery, itself a branch of the GDA (figure 6) and via the epicholedocian network (figure 7) [5][6]. The liver can also recruit arterial supplementation via the coronary and triangular ligaments from the phrenic, intercostal and internal mammary arteries[7]. In the event of occlusion of the common AH, the GDA constitutes a very important bypass route, bringing blood back to the liver in countercurrent from the SMA.

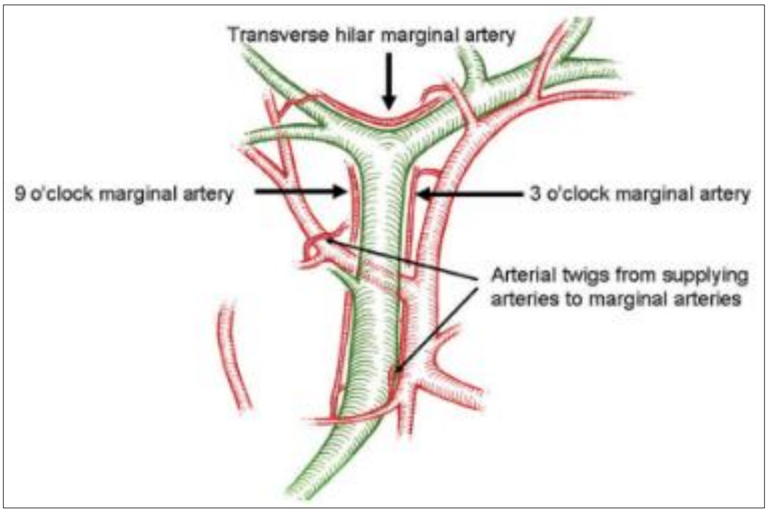

Figure 7 The marginal arteries [6]

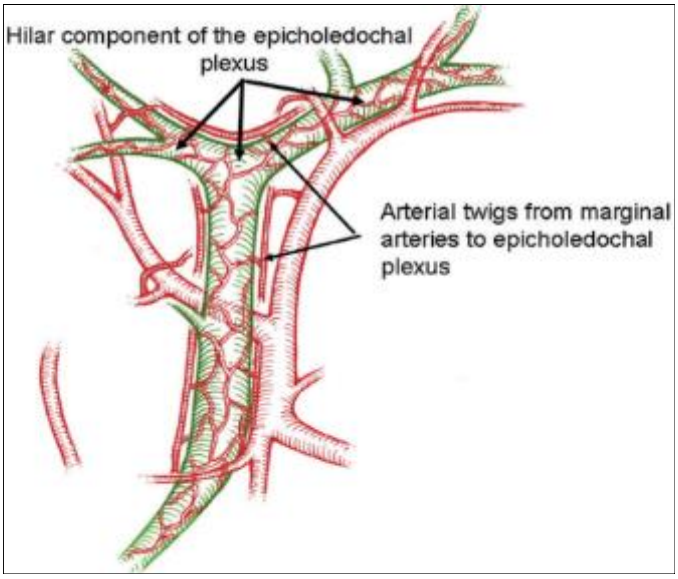

Figure 8 The epicholedochal plexus [6]

Several imaging techniques are used to map hepatic arterial anatomy in search of possible variants, as well as possible truncal arterial stenoses and associated bypass networks. Thanks to its isotropic spatial resolution and extremely rapid data acquisition, angiography-CT is the reference non-invasive imaging method for establishing the anatomy and pathology of vascular structures, as well as for planning surgical treatment. The acquisition protocol must be exhaustive in order to obtain lesion characterization elements, a resectability assessment (particularly in terms of arterial invasion) and precise vascular mapping. Typically, the various elements to be evaluated for vascular assessment are:

- Vessel permeability: atheroma, thrombosis, cavernoma;
- Study of the portal trunk: vascularization, caliber;
- Anatomical variants, espacially of the HA, but also of the portal system, hepatic veins (accessory vein, inferior hepatic vein, common ostium) and inferior vena cava.
- In the case of duodenopancreatic tumours and cholangiocarcinoma, imaging must be used to assess resectability, in particular by identifying arterial and venous invasion of the region, and also to describe all vessels to the right of the SMA.

The GDA is of particular interest during supra-mesocolic surgery, and the radiologist must specify its origin, course, caliber and functionality. Thus, the GDA - which becomes large-calibre - provides countercurrent shunting from the SMA to the hepatic artery in the case of CT or CHA stenosis; or in the direction of blood flow from the CHA to the SMA in the case of ostial stenosis of the latter. At the end of this workup, the radiologist must specify the arterial variations observed, in particular the most frequent ones:

- an arched ligament causing stenosis of the celiac trunk (detected on multiplanar frontal reconstructions); this anomaly is seen in 5 to 10% of the population and requires preservation of the GDA, which ensures flow into the MHA [8]);
- LHA is seen in 6.6% to 32% of patients [9]), and may represent the only blood supply to the liver in less than 1% of cases. ([9]). It arises from the right lateral surface of the left gastric artery, without joining the hepatic pedicle. It crosses the lesser omentum to reach the hepatic hilum. It may vascularize the left lobe, the left liver or, exceptionally, the entire liver.
- RHA is found in 13 to 26% of cases [10]. It stands alone in 3% of patients. It arises from the SMA and has a sub- and retroportal course in the hepatic pedicle. It vascularizes the right liver. There are a few cases where the RHA arises directly from the aorta (0.6 to 1.7% of cases) [11]), often just below the emergence of the CT (this variant is not mentioned in Michels' classification).
- The simultaneous presence of all 3 arteries (MHA, LHA and RHA) is observed in around 2% of patients.
- The common coeliomesenteric trunk (Michels type 9) arises from the anterior aspect of the aorta and groups together the CT and SMA, which separate after 2-3 cm. The left gastric artery then often arises from the aorta, just prior to the emergence of the common trunk. (Figure 9)

- The level of bifurcation of the right and left branches of the MHA varies considerably over the height of the hepatic pedicle. In the most common arrangement, this bifurcation occurs anterior to the portal bifurcation, below the superior biliary convergence, with the right branch of the HA passing posterior to the common hepatic duct. This bifurcation may also occur lower down, or even at the same level as the emergence of the AGD, the latter sometimes originating from the right branch of the HA. Rarely, the right branch of the AH may cross the bile duct from the front.

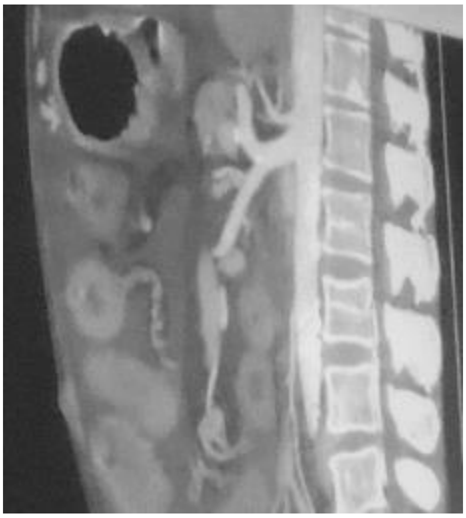

Figure 9 Angio-CT image showing a coeliomentric trunk, noting the departure of the AGG just upstream.

4.1. Surgical implications of anatomical variations in the hepatic artery

The coeliomesenteric region and the hepatic pedicle are frequently used as a crossroads for supramesocolic surgery. The variations in HA described above have direct implications for hepatobiliary and pancreatic surgery, in endoarterial approaches and also in gastric surgery.

4.2. During hepatectomy

During hepatectomies, dissection of the hepatic pedicle (PH) will always look for a variation in the number of HA, mainly a RHA that runs up the postero-right edge of the HP in its usual form, or more rarely, may see an anterior position. The level of division of the HA is also highly variable; usually, this division takes place at the level of the liver hilum, below the biliary convergence, with the right branch of the HA passing posterior to the hepatic bile duct. However, this division may take place lower down the whole height or even at the foot of the PH, giving a trifurcation (GDA, right branch of the HA and left branch of the HA). The absence of an MHA should prompt the surgeon to look for replacement arteries on imaging and intraoperatively, i.e. the coexistence of a RHA and a LHA, or the presence of a single accessory trunk for hepatic vascularization (RHA or LHA - total liver). For example, in the case of right hepatectomy, ligation of a RHA vascularizing the entire liver compromises the arterial vascularization of the left liver, leading to its necrosis and major postoperative morbidity and mortality. The presence of a RHA makes it possible to perform continuous clamping combined with selective clamping of the right portal branch to perform a right hepatectomy without having to make a wide dissection of the hepatic hilum. Left hepatectomy is facilitated by the presence of a LHA, which simply needs to be controlled in the lesser omentum and combined with hilar control of the left portal branch to ensure continuous clamping of the blood supply to the liver to be resected. In the case of tumoral pathology (hilar cholangiocarcinoma, etc.) with arterial invasion, the presence of a right or left HA extends the indications for resectability, on condition that it lies on the side of the remaining liver and feeds a sufficiently large hepatic territory. This can be confirmed intraoperatively by Doppler analysis of the intrahepatic branches.

4.3. During liver transplantation

During liver transplantation from a brain-death donor, arterial reconstruction is an important step. The presence of an anatomical variation in the graft's hepatic artery requires adaptation of the arterial reconstruction technique to obtain optimal perfusion of all liver territories. In the presence of a RHA branch of the SMA, organ harvesting must necessarily include the celiac trunk and the SMA. In our transplant patient, we re-implanted the graft RHA into the ostium of the GDA, and we performed then anastomosis of the native and graft CHA. In all cases, both the middle and right hepatic arteries must be included in the hepatic perfusion scheme.

In the presence of a RHA branch of the SMA associated with an LHA branch of the left gastric artery, the harvest must also include the celiac trunk. Reconstruction involves an anastomosis between the graft CT and the native CHA. In the case of LHA, anastomosis of the donor celiac trunk with the recipient hepatic artery has been proposed to preserve the LHA and avoid arterial reconstruction.

For partial liver transplants and living-donor transplants, the use of the LHA is recommended by some authors [9]. Because of its length (42 mm versus 9 mm for the left branch of the MHA) and diameter (2.5 mm versus 2 mm), this artery is less prone to thrombosis (3.2% versus 11.4%). Thus, if a LHA is present, it can be tied off in the event of reflux, with the presence of the left branch of the HA; or, on the contrary, used for vascular reconstruction if its caliber is sufficient, or if it constitutes the only arterial tributary of the transplanted left liver. A donor RHA for the right liver will also facilitate harvesting, respecting the MHA, and implantation, with anastomosis of the graft RHA with the native MHA. A real challenge to transplantation from the living donor is the segment IV arterial branch arising from the right branch of the HA, present in 27.5% to 50% of the population [12]). This variation limits graft possibilities to the left lobe of the liver.

4.4. During whipple procedure (cephalic duodenopancreatectomy)

The common, middle and right hepatic arteries are particularly vulnerable during dissection of the head and isthmus of the pancreas, when approaching the retroportal lamina, and also during hepatic and celiac lymphadenectomy. In the presence of the replaced LHA, the only arterial supply to the left liver, it is exposed when the lesser omentum is slit to approach the celiac region and, above all, when the right edge of the CT is approched. At this level, the dissection of the LGA must be carefully identified and preserved to avoid ischemia of the left liver.

The variable pathway of the RHA has important consequences during Whipple procedure. Three different anatomical pathways of the RHA have been described in the literature [13] :

- In the 1st configuration, the RHA is posterior to the head of the pancreas. In this situation, it is possible to preserve the RHA, which can be dissected from the pancreatic parenchyma without any involvement of the aberrant RHA.
- In the 2nd variant, the RHA may present an intra-parenchymal pathway that implies its monobloc resection with the head of the pancreas and reimplantation at the ostium of the GDA. This arterial resection and reconstruction increase operative morbidity ([14].
- In other cases, an anterior path of the RHA is described, necessitating its release and a decrease in relation to the duodenopancreas.

Thus, complete duodenopancreatic detachment using the Kocher maneuver, with the first centimeters of the SMA approached, should precede pancreatic sectioning, in order to anticipate the presence of an RHA and assess tumor resectability. Regardless of the methods used, it is recommended to preserve the aberrant RHA if it does not show tumor invasion.

During cephalic pancreatectomy, accidental ligation of the replaced CHA from the SMA through a common trunk called the hepato-mesenteric trunk, is associated with ischemia of the bilio-digestive anastomosis and biliary leakage with sepsis and risk of death due to complete devascularization of the liver and extra-hepatic biliary tree; in this case, Shukla reports a high postoperative hemorrhagic risk after arterial reconstruction ([15]

Intraoperatively, a replaced CHA is usually recognized visually or by palpation near the epiploic foramen. The surgeon may clamp the artery and check pulse and hepatic blood flow using Doppler ultrasound. In suspected cases, the key to surgical technique is to identify the origin of the SMA by dissecting all soft tissues and lymph nodes located in the retro-pancreatic plane, allowing safe exposure of a replaced artery originating from the SMA or the aorta (figure 6), and thus reducing the risk of bleeding due to its trauma.

The configuration in which the RHA comes from GDA is a delicate situation, since the standard ligation of GDA leads to devascularization of the right liver (at least) and the bile ducts. This situation must absolutely be recognized on the preoperative CT scan; the GDA must then be dissected on the anterior surface of the pancreas, tied and sectioned after the RHA has departed. Accidental sacrifice of this vessel during the Whipple procedure can be devastating, particularly for biliary anastomosis tightness, which depends on arterial flow. Lack of visualization of a replaced RHA from the SMA on imaging should not lead the surgeon to wrongly conclude that ligation of the GDA to the usual site is insignificant.

The right and/or left accessory arteries associated with the presence of a MHA with its two right and left branches (16% of cases) should be preserved as far as possible, because even if the hepatic parenchymal and biliary vascularization is generally not susceptible to the interruption of one of the accessory trunks, it is difficult to predict the hepatic territory that depends on it.

4.5. During gastrectomy

HAs are involved in gastric surgery due to their anatomical proximity, in particular with LGA, and the lymphatic extension of gastric cancers along the arterial axes (celiac (lymphatic station 9,) common hepatic (lymphatic station 8), gastric (lymphatic station 7) and the hepatic pedicle (lymphatic station 12), which imposes a lymphadenectomy with sub-adventitial dissection of the corresponding arteries. Aberrant LHA from the LGA accounts for 25% of hepatic artery variants, of which 55% and 45% correspond to the replaced LHA and accessory LHA respectively [16]. It goes transversely through the pars condensa of the lesser omentum to the hilum and usually enters the left hepatic lobe via the umbilical fissure. It irrigates a variable territory of the parenchyma which may correspond to the left lobe in the majority of cases or to a single segment of the left lobe; however, the possibility of a LHA- total liver is not ruled out and has been reported in 0.3% to 1% of cases [9]). Aberrant LHA is easily recognized, it can be injured either by direct ligation at the opening of the small omentum, or by inadvertent spreading of the left lobe.

In the case of gastrectomy for cancer, it is routine to tie the LGA to its origin in order to perform the group 7 lymph node resection. In this case, a LHA can only be sacrificed after clamping test to verify the persistence of the pulse in the hepatic pedicle, and after hepatic Doppler showing the persistence of good intra-hepatic arterial flow. If the left hepatic branch of the AH is replaced by the LHA (Michels 2 and 4), the LHA should be preserved, and ablation of group 7 should be performed by sub-adventitial dissection and "peeling" of the LGA, which will be tied downstream of the departure of the LHA.

Dissection of the hepatic pedicle and/or clamping of the LHA will eliminate the possibility of total liver-LGA. Preservation of the LHA is indicated in the absence of CHA, in which case the LHA is voluminous. It must also be preserved in patients with chronic liver disease and impaired liver function; those patients are particularly vulnerable to ischemia caused by aberrant LHA ligation.

5. Conclusion

Knowledge of the modal anatomy of the HA and its course, origin and number variants is essential because of the clinical implications and especially for the hepatobiliary and pancreatic surgery, and liver transplantation where arterial reconstruction is a crucial step. Cooperation between radiologist and surgeon is essential. in order to plan the surgical procedure: angio CT-scan and determine the cartography of the hepatic arterial blood supply, and look for a HA invasion in neoplastic pathology. During surgery, the surgeon will sometimes have to modify the surgical technique and approach, and differentiate between an accessory hepatic artery or one replaced by the techniques of clamping and using peroperative arterial doppler, as well as the adaptation of the arterial reconstruction technique in the liver transplantation in order to obtain optimal perfusion of all the territories of the liver graft and to avoid complications dominated by hepatic artery thrombosis and biliary ischemia. The various surgical techniques that are readily available in the conventional surgery can be a real challenge when it comes to the laparoscopy.

There are several classifications of HA variations, including the above based on the dissection of 200 cadavers, but remain insufficient, due to the existence of unclassifiable anatomical variants

Compliance with ethical standards

Disclosure of conflict of interest

The authors declares that they have no conflict of interest.

Statement of informed consent

Patients consented to the submission of their case reports and the use of their personal pictures to this submission.

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