The arterial blood supply of the extrahepatic biliary tract – surgical aspects

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Knowledge of the arterial blood supply of the extrahepatic biliary tract is very important for a surgeon. This knowledge is essential during all surgical procedures in the biliary tract, from the easiest, such as cholecystectomy, to the most complicated, such as the reconstruction of the biliary iatrogenic injuries, as well as during operations on the liver, the stomach, and the pancreas. It is important to recall the arterial blood supply of the biliary tract in the biliary anastomoses, as many complications are caused by a lack of knowledge on the subject. A frequent cause of postoperative biliary strictures is ischaemia in the anastomosis. Hence, it is vitally important to anastomose well-vascularised segments to guarantee proper healing.

Knowledge of the arterial blood supply of the biliary tract is important in hepatic transplantation, liver resection, reconstructive surgery of the biliary tract, and pancreatoduodenectomy (1).

The arterial blood supply of the extrahepatic biliary tract is based on the following topographical division (2):
- the gall-bladder and the cystic duct,
- the right and the left hepatic ducts, or the hilar portion,
- the common hepatic duct and the common biliary duct (CBD) (in its supra- and retro-duodenal portion), or the supra- and retro-duodenal portion,
- the common biliary duct (in its pancreatic portion).

The gall-bladder and the cystic duct are supplied with arterial blood by the cystic artery. The arterial vascularization of other parts of the biliary tract is different: very rich in the hilar and pancreatic portions and very poor in the supraduodenal segment (2, 3).

The cystic artery usually arises as a single branch from the right hepatic artery (the right branch of the proper hepatic artery) within the hepatocystic triangle (4-12). The hepatocystic triangle is formed by the common hepatic duct (medially), the cystic duct (laterally), and the inferior margin of the right lobe of the liver (superiorly). This description of the hepatocytic triangle differs from Calot’s original definition. In 1891, Calot defined a triangle-shaped anatomic area formed by the common hepatic duct medially, the cystic duct laterally, and the cystic artery superiorly (13).

The primary definition (described by Calot in “De la Cholecystectomy”, vol. 2) and Calot’s triangle differ in only one landmark, the superior boundary. It is thus proposed to reserve the name “hepatocystic triangle” for the primary definition. The actual definition of the hepatocystic triangle (with the upper boundary within the inferior margin of the right lobe of the liver) is more significant for a surgeon. In some cases, the accessory bile ducts draining into the cystic duct or the common hepatic duct, run within this triangle. The accessory or replaced hepatic artery originating from the superior mesenteric artery usually courses through the medial part of the triangle. Therefore, visualization of this area and proper identification of all structures is very important during cholecystectomy (4, 5, 9, 14, 15).
In approximately 80% of cases, the cystic artery arises from the right hepatic artery within the hepatocystic triangle. In other cases, it may arise from the left hepatic artery (5.9%), the proper hepatic artery (11.5%), the common hepatic artery (3.8%), the gastroduodenal artery (2.5%), the superior pancreatoduodenal artery (0.15%), the superior mesenteric artery (0.9%), or the celiac trunk (0.3%) (5, 9, 13). The cystic artery may arise from the proximal right hepatic artery or from the common hepatic artery and may run proximal to the hepatic duct, which may be injured when the artery is ligated (4, 5). Within the hepatocystic triangle, the cystic artery supplies the cystic duct with one or more small arterial branches. Near the gall-bladder, the cystic artery usually divides into a superficial branch and a deep branch. The superficial branch of the cystic artery courses along the anterior surface of the gall-bladder, and the deep branch passes between the gall-bladder and liver within the cystic fossa (4, 5, 7, 8, 17).

Anatomic variations of the hepatic and cystic arteries are described in approximately 50% of cases. Aleksandrowicz (18), Nowak (16, 19), Kędzior and Kuś (17), and Benson and Page (20) described essential variations of the extrahepatic biliary tract vessels for a surgeon.

An accessory or double cystic artery occurs in 15-20% of cases (6, 20). These arteries usually arise from the right hepatic artery within the hepatocystic triangle. During dissection of the hepatocystic triangle, it is important to be mindful of the possibility of the presence of an accessory cystic artery. If it is present, the vessel should be ligated in order to avoid bleeding. A triple cystic artery occurs very rarely (0.3% of cases) (6). The cystic artery may course anteriorly to the common bile duct or the common hepatic duct. In this location, the cystic artery is the first structure encountered during dissection within the low margin of the hepatocystic triangle. Such an artery should be ligated and divided in the early phase of dissection during cholecystectomy in order to properly visualise the cystic duct (5). In 5-15% of cases, the right hepatic artery courses through the hepatocystic triangle in close proximity to the cystic duct before turning upward to enter the hilum of the liver. In such situations, the cystic artery arises from the convex aspect of the angled or humped portion of the hepatic artery. This “caterpillar hump” right hepatic artery may be easily mistaken for the cystic artery and divided during cholecystectomy. The cystic artery arising from such a hepatic artery may be easily avulsed from the hepatic artery during excessive traction of the gall-bladder (4, 5).

The hilar portion of the biliary tract has a very rich arterial blood supply from the right and left hepatic arteries. In 85% of cases, the right hepatic artery passes posteriorly to the common hepatic duct, and in the remaining 15% of cases, it courses anteriorly to the common hepatic duct (4, 5). The accessory or replaced (aberrant) right hepatic artery originates from the superior mesenteric artery and courses through the hepatocystic triangle. The aberrant hepatic artery supplies the liver instead of the proper hepatic artery. The accessory hepatic artery supplies a liver segment independently of the proper hepatic artery. The aberrant replaced hepatic artery is the sole blood supply of a liver lacking the proper hepatic artery. Aberrant hepatic arteries are recognized in 12-26% of cases. In 75-85% of cases, the aberrant right hepatic artery is a replaced vessel in which accidental ligation could cause segmental liver necrosis. The aberrant right hepatic artery usually arises from the superior mesenteric artery, although it may also arise from the celiac trunk, aorta, the gastroduodenal artery and left hepatic artery. The aberrant left hepatic artery usually originates from the left gastric, rarely from the gastroduodenal or the common hepatic artery. It passes through the hepatoduodenal ligament and supplies the left lobe of the liver (4, 6, 19, 21, 22, 23).

Vellar has described an arterial plexus between the branches of the left and right hepatic arteries, which was found on the inferior surface of the “hilar plate”. The hilar plate is a condensation of connective tissue lining the hilum of the liver that forms a roof over the contents of the hilum, separating these structures from the liver parenchyma. The hilar plexus is formed by collateral vessels bridging between the right and left hepatic arteries. The hilar arterial plexus plays a role in arterial supply of the hepatic ducts confluence, and is an important place of collateral circulation between branches of the right and the left hepatic arteries. Branches originating from the hilar plexus also supply the caudate lobe and process of the liver. The majority of the branches
to the hilar plexus originate from the right and left hepatic arteries, and ascend posteriorly to the right and left hepatic ducts (1, 24).

The pancreatic part of the CBD also has a very rich arterial blood supply. It is primarily supplied with the arterial blood by the posterior superior pancreatic artery (PSPD a.), as well as the supra- and retroduodenal arteries (5, 25). The PSPD a. usually arises from the gastroduodenal artery 1-2 cm below its origin from the common hepatic artery at the level of the superior margin of the first part of the duodenum. Less frequently, the PSPD a. may arise from the superior pancreaticoduodenal artery (as its posterior branch), the common hepatic artery, the proper hepatic artery, the left hepatic artery, the replaced or accessory right hepatic artery, the superior mesenteric artery, the dorsal pancreatic artery or the splenic artery. The course of the PSPD a. is descending. At the beginning it runs transversally to the right, anteriorly crossing the space between the common bile duct and the portal vein at the level of the superior margin of the pancreatic head and the lowest portion of the pancreatic part of the common bile duct. Next, the PSPD a. turns around the right side of the common bile duct, reaching the posterior surface of the pancreas, between the gland and the Treitz’ layer. From this location it runs to the left, posteriorly crossing the intrapancreatic portion of the common bile duct. The posterior superior pancreaticoduodenal artery (PSPD a.) has a very characteristic course in relation to the CBD, surrounding it spirally. This spiral and descending course Peri (26) called the “vascular arch of Gregoire”. The PSPD a. crosses the supraduodenal part of the CBD posteriorly, and next crosses the pancreatic part of the CBD posteriorly. In posterior crossing, the CBD and PSPD a. lie in close range, separated from each other only by a layer of pancreatic parenchyma at a thickness of 3-12 mm. Variations of the course of the PSPD a. have been described. Prior to anterior crossing of the CBD, the PSPD a. may descend along its left margin in length of 1 cm. Sometimes, instead of anterior crossing of the suprapancreatic part of the CBD, the PSPD a. crosses it posteriorly (27).

According to Woodburne and Olsen (28) and Vandamme (29), the course of this type occurs when the PSPD a. arises from the accessory right hepatic artery originating from the superior mesenteric artery or from the dorsal pancreatic artery. In these cases, the artery is situated behind the pancreas from its beginning. The relation between the origin of the PSPD a. and the CBD is also variable. In 80% of the cases, the proximal part of the PSPD a. is situated on the left side of the common bile duct, and in 10-20% of the cases, on the right side. In the second case, the anterior crossing of the suprapancreatic portion of the CBD does not occur (27). The vascular arch of the PSPD a. around the CBD is the consequence of particular sequences of the embryologic development. At the age of 5 weeks, when the ventral pancreatic bud develops, the PSPD a. lies anteriorly to the CBD and the ventral pancreatic bud. During rotation of the CBD, the anterior surface of the CBD and the ventral pancreatic bud turn posteriorly and to the right pulling at the PSPDa, which takes a lateral position to both of these structures. After finishing the rotation of the pancreas, the PSPD a. has a spiral course around the CBD, entering the posterior surface of the ventral pancreatic bud. The PSPD a., as the vessel supplying the CBD and the ventral pancreatic bud, follows them during embryological development and takes a spiral course. Because of this spiral course around the CBD, the PSPD a. is the main source of the arterial blood supply in its intrapancreatic portion. Two main branches to the CBD (one ascending and one descending) frequently originate at the level of anterior crossing with the CBD. The ascending branch passes superior and along the anterior surface of the CBD, the descending branch passes along its right margin (27).

The supraduodenal artery usually arises from the gastroduodenal artery or the posterior superior pancreaticoduodenal artery. It crosses the CBD anteriorly, runs through the hepatoduodenal ligament and supplies the supraduodenal part of the CBD (6, 27).

The retroduodenal artery is usually a branch of the gastroduodenal artery or the posterior superior pancreaticoduodenal artery, where it supplies the supraduodenal and pancreatic parts of the CBD with arterial blood (5, 6).

The supraduodenal part of the extrahepatic biliary tract is very poorly supplied with arterial blood (2, 3, 5). The vascularization of the supraduodenal portion of the CBD, within the supraduodenal ligament, is critical. The studies published on the PSPD a. are scarce.
and additionally, in some cases, contradictory (3, 30, 31, 32). In 1948, Shapiro and Robillard concluded that the common bile duct is poorly supplied by several end-type arteries, the damage of which would surely lead to biliary stricture and bile leakage (31). In the same year (1948), Douglass and Carter described a rich vascular plexus around the CBD (peri-choledochal plexus), so even skeletonization would not lead to complete damage of the biliary tract vascularization (33). In 1978, Northover and Terblanche described the axial type of vascularization of the supraduodenal part of the common bile duct, with two main arterial vessels, the 3 o’clock artery and 9 o’clock artery, running along the lateral margins of the CBD (31). These arteries run parallel to the supraduodenal part of the CBD. The 3 o’clock artery runs around the left margin of the CBD, while the 9 o’clock artery runs around the right margin of the CBD. Small arteries join the main axial vessels from above and below. The supraduodenal part of the CBD has three main sources of the arterial blood supply. The axial supply of the supraduodenal part of the CBD comes primarily from below (60%), from above (38%), and from the left (2%). Approximately 60% of the blood supply to the supraduodenal bile duct originates inferiorly, from the pancreaticoduodenal and retroduodenal arteries, and 38% of the blood supply originates superiorly, from the right hepatic artery and cystic artery. Only 2% of the arterial blood supply of the supraduodenal CBD is segmental rather than axial. These small segmental arterial branches arise from the common hepatic artery, in the portion of its course within the hepatoduodenal ligament at close range with the CBD (2, 5, 34).

In 1978, Northover and Terblanche described the third marginal artery, the retroportal artery (the 12 o’clock artery), running along the posterior surface of the CBD (2, 33). This vessel arises posteriorly from the celiac trunk of the superior mesenteric artery, and runs to the right, posteriorly to the portal vein the pancreatic head entering the inferior end of the CBD. From this point, the further course of the artery occurs in two variations. In the first of these, the artery ends join the retroduodenal artery at the level of the inferior portion of the supraduodenal CBD. In this type, small branches originating from the trunk of the portal artery run on the posterior surface of the CBD. In the second variety, the retroportal artery runs superior and posterior to the supraduodenal part of the CBD, joining the right hepatic artery posteriorly to the common hepatic duct (as a third axial 12 o’clock artery). The first type of the retroportal artery supplies only the inferior portion of the supraduodenal duct, and the second type of retroportal artery plays an important role in arterial supplying the whole duct from inferior levels to its superior level (2, 34).

In 1993, Rath et al. described three main types of arterial vascularization of the extrahepatic biliary tract: axial, ladder, and mixed (3). The axial type occurs the most frequently. It is formed by one, two, or three vascular arches of marginal arteries running around the CBD (3-, 9-, 12 o’clock arteries described by Northover and Terblanche). The less common (less than 10%) is the ladder type with a single (at left border) or double ladder (at left and right borders). In this type, the choledochal arteries originate at different levels, run horizontally and transversally to the margins of the CBD, and divide at the left border of the bile duct into ascending and descending branches, which anastomose with each other. In the mixed type, both the vascular arches and ladders are present, although in different combinations (3) (fig. 1 and 2).

Knowledge of the biliary tract arterial vascularization, especially in its supraduodenal section, is crucial in hepatobiliary surgery (1, 2, 3). The arterial blood supply of the supradu-

![fig1.png] Fig. 1. Axial arterial distribution of the extrahepatic biliary tract. Tww – common hepatic artery, Twwl – proper hepatic artery, Tzd – gastroduodenal artery, Tdgt – posterior superior pancreaticoduodenal artery, Twp – right hepatic artery, Twl – left hepatic artery, Tp – cystic artery, T3:00 – right marginal artery (3 o’clock), T9:00 – left marginal artery (9 o’clock)
Ischaemia is a main factor responsible for the occurrence of postoperative biliary strictures. Normal vascularization is a necessary factor for proper healing of biliary anastomosis. The investigations on postoperative biliary strictures were performed by Douglass (35), Rains (36), Cameron and Hou (37), Appleby (38), Carlson (39), Northover i Terblanche (2). Cameron i Hou (1962), all of whom thought that ischaemia was the singular factor causing the stricture of the CBD. They induced the stricture by clamping the CBD in the guinea pig for 1 minute, leading to segmental ischaemia (37). Appleby (1959) linked two factors responsible for the occurrence of the postoperative biliary strictures: bile and ischaemia. He thought that bile destroyed only ischaemic tissue, leaving normal tissue undamaged (38). Carlson et al. (1977) presented the changes within the tissue of the CBD leading to the stricture. In an investigation in which he ligated the CBD in dogs, he showed disturbances of collagen matrix of the CBD wall, which was caused by toxic bile activity and mucosal defects that had appeared proximally to the place of the bile duct ligature. The pathologic change of collagen led to thickening of the CBD wall (39). Northover i Terblanche (1979) explained the postoperative biliary stricture aetiology, identifying at ischaemia as the main cause. Ischaemia, caused by clamping of the bile duct clamping or by injury to the arterial vessels of the CBD wall, may damage the ductal mucosa, which makes it sensitive for detrimental toxic bile activity, inducing inflammation and fibrosis. Oedema accompanying such reactions may even occlude adjacent parts of the peri-choledochal arterial plexus, as these vessels are only 0.3 mm or less in diameter. All these processes lead to further ischemia, damage to collagen structures, and fibrosis, until the large part of the bile duct is destroyed. The supraduodenal CBD is the most exposed to this process, because its vascularization is significantly more poor and vulnerable to the injury than its hilar and pancreatic parts (2, 40, 41, 42).

A clear understanding of the blood supply of the extrahepatic bile ducts is a basis of prevention of postoperative biliary anastomoses strictures (2). This knowledge should help to avoid damage to the blood supply of the supraduodenal CBD during surgical procedures in this area. Dissection around the CBD should be limited. It is particularly necessary to avoid excessive dissection along the CBD margins in order to preserve the 3 o’clock and 9 o’clock arteries and their branches to the pericholedochal plexus. When it is possible, the cystic duct should not be divided flush with the CBD to avoid damage to the 9 o’ clock artery. The cystic artery should be divided near the gall-bladder in order to preserve its branches to the CBD. Dissection in the groove between the supraduodenal bile duct and the first part of the duodenum enlarges the retroduodenal artery and its branches to the CBD arising in this area. During performance of the Kocher manoeuvre, the thin fibrous layer situated posteriorly to the pancreatic head and portal vein should be left intact in order to preserve the retroportal artery (2).

Rath iet al. have linked a zone of overlap between the superior and inferior sources of extrahepatic biliary tract vascularization (3). This zone is situated at the level of the inferior border of the cystic duct, which is the boundary zone between the ascending (from below) and descending (from above) circulations. Each area outside this zone has its own vascularization source: the common hepatic duct is supplied by an axis of the right hepatic and cystic artery, and the CBD by an axis of the gastroduodenal and PSPD artery. On this basis, the proposed level of transection in liver transplantation of the CBD is the junction of the inferior border between the cystic duct with the
common hepatic duct, in both the donor and the recipient (3).

Knowledge of the extrabiliary biliary tract vascularization is very useful in reconstructive surgery (39, 42, 44-48). In 1990, Terblanche et al. analysed 19 patients who underwent postoperative repairs of bile duct stricture (41). Terblanche concluded that repair of extrabiliary biliary tract injuries and strictures should involve anastomoses to the well-vascularised upper common hepatic duct tissue. This study supported the hypothesis of an ischaemic basis for recurrent biliary strictures (42, 48). Based on arterial blood supply of the biliary tract, a high hepaticojejunostomy (less than 2 cm below the hepatic duct confluence) should be used to repair biliary strictures. Biliary strictures less frequently occur in a high hepaticojejunostomy than in a low hepaticojejunostomy (more than 2 cm below the hepatic duct confluence) or choledochojejunostomy, as the proximal segment of the common hepatic duct has a better blood supply than its distal part or the CBD. The general rule of using the proximal common hepatic duct also applies for other biliary anastomoses performed during surgical procedures on the liver or pancreas (48).

A surgeon should remember the variability of extrabiliary biliary tract arterial vascularization, and their particular portions, during surgical procedures, particularly cholecystectomy, biliary and biliary-alimentary anastomoses, pancreatoduodenectomy, liver transplantation and other procedures performed within the hepatoduodenal ligament. This knowledge will help avoid many serious postoperative complications.

REFERENCES


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