22 General Technical Aspects of Liver Resections

Silvio Marcio Pegoraro Balzan, Vinícius Grando Gava

Department of Surgery, Hospital Moinhos de Vento, Porto Alegre, and Universidade de Santa Cruz do Sul (UNISC), Santa Cruz do Sul, BRAZIL

- *Knowledge of hepatic segmentation is crucial for safe liver resection. Remnant liver parenchyma should have adequate vascular inflow, vascular outflow, and biliary drainage.*
- *Different methods of vascular control are available and useful to reduce bleeding during hepatectomy. Inflow occlusion is the easiest and best tolerated option. Total vascular exclusion of the liver is required in some cases of tumors close to the debouchment of the hepatic veins and inferior vena cava.*
- *The two main approaches to selective inflow hepatic control are intrafascial and extrafascial (or Glissonean). The first is required for tumors close to the hepatic hilum.*
- *Anterior approach, mainly using the hanging maneuver, seems to reduce blood loss, facilitates "no touch" resection, and reduces the risk of liver damage for mechanical compression of the remnant liver during surgery.*

CONCEPTS OF SEGMENTAL HEPATIC ANATOMY

Segment-oriented liver resections were developed with the goal of preserving the maximum amount of liver parenchyma while maintaining adequate vascular inflow, vascular outflow, and biliary drainage. Two main concepts regarding hepatic segmentation are used for liver resections.

The anatomical description of Couinaud[1] (**Figure 1**) is the most frequently used in hepatic surgery. Couinaud demonstrated that eight hepatic segments are anatomically individualized and can be separately resected. The three main hepatic veins (right, middle, and left) divide the liver into four sectors. Cantlie's line (main portal scissura) divides the liver into two hemilivers: right and left. The right hemiliver comprises the right posterior (segments 6 and 7) and right anterior (segments 5 and 8) sectors. The right portal scissura (where the right hepatic vein runs) separates these two sectors. The left hemiliver comprises segment 2 (left lateral sector), and segments 3 and 4 (medial left sector). These sectors are separated by the left portal scissura (where the left hepatic vein runs). Couinaud's segments 2 and 3 correspond to Goldsmith and Woodburne's left lobe,[2] and segment 4 represents the quadrate lobe. The caudate lobe is a sector that is embryonically and anatomically independent of the right and the left hemilivers. It makes extensive contact with the inferior vena cava.[3] It is of note that the modern nomenclature of liver anatomy and resections considers segments 2 and 3 (instead of only segment 2) as the left lateral ***section***, and segment 4 (instead of segments 4 and 3) as the left medial ***section***. This terminology is different from the Couinaud sectors, based on portal vein ramification, where the left medial ***sector*** includes segments 4 and 3, and the left lateral ***sector*** is represented by segment 2 alone (see *Terminology of Hepatic Resections* below).

The other frequently used anatomical segmental description is called the "Glissonean approach" in liver resections, as described by Takasaki[4] (**Figure 1**). In Takasaki's description, the liver is divided into three segments based on the distribution of the portal branches. The extrahepatic portion of the Glissonean pedicle corresponds to the portal triads in the hepatoduodenal ligament enclosed by connective tissue and peritoneum. The intrahepatic Glissonean pedicles consist of portal triads enclosed by Glisson's sheath. Three secondary Glissonean branches separately enter the liver at the level of the hepatic hilum, contributing to the right, middle, and left Takasaki's segments. Small branches originating from the primary branch nourish one additional region, the caudate area. The right and middle hepatic veins (the left hepatic vein is here considered a tributary of the middle vein) run among the three segments.

In fact, there is a close correlation between the anatomical concepts of Couinaud and Takasaki, as described in **Table 1**. Couinaud's right posterior sector, right anterior sector, and left hemiliver correspond, respectively, to Takasaki's right, middle, and left segments. The caudate lobe, or caudate area, is a portion of liver parenchyma that receives arterial and portal branches (and has biliary branches) from the right and left pedicles, at the level of the hilum, and its veins drain directly into the retrohepatic vena cava. This area of the liver has the appearance of a pyramid, with its apex at the level of the confluence of the main hepatic veins, a side border with the right posterior sector (or right segment of Takasaki), another side border with segment 4 (or left segment of Takasaki), and the other sides in contact with the vena cava and the minor omentum (**Figure 2**).

Each Couinaud's segment receives one or more Glissonean pedicle branches. According to Takasaki, each tertiary Glissonean branch nourishes a cone of liver parenchyma, the so-called "cone unit". Thus, a Couinaud's segment consists of several cone units. The boundaries of hepatic resections can be guided by either Couinaud's segmentation or by Takasaki's concept of cone units. The resection of one Couinaud's segment implies the section of two or more tertiary Glissonean pedicles. On the other hand, Takasaki suggests that more limited resections can be guided by the identification of the parenchyma area supplied by each tertiary branch, i.e. each cone unit could be individually resected (**Figure 3**).

TERMINOLOGY OF HEPATIC RESECTIONS

In order to standardize the nomenclature of the liver anatomy and resections, the "Brisbane 2000 Nomenclature of Liver Anatomy and Resections" was proposed by the Scientific Committee of the International Hepato-Pancreato-Biliary Association (IHPBA). Despite some criticisms, this terminology is very appropriate and recommended by the editors of this textbook. Indeed, this terminology was applied in all chapters.[5]

The Brisbane 2000 terminology is based on arterial and biliary ramifications. The first order division separates the

Table 1. Relationship between hepatic segmentation according to Couinaud's and Takasaki's concepts.

Couinaud's		Takasaki's
Right posterior sector	Segment 6 Segment 7	Right segment
Right anterior sector	Segment 5 Segment 8	Middle segment
Medial left sector	Segment 4 Segment 3	Left segment
Lateral left sector	Segment 2	

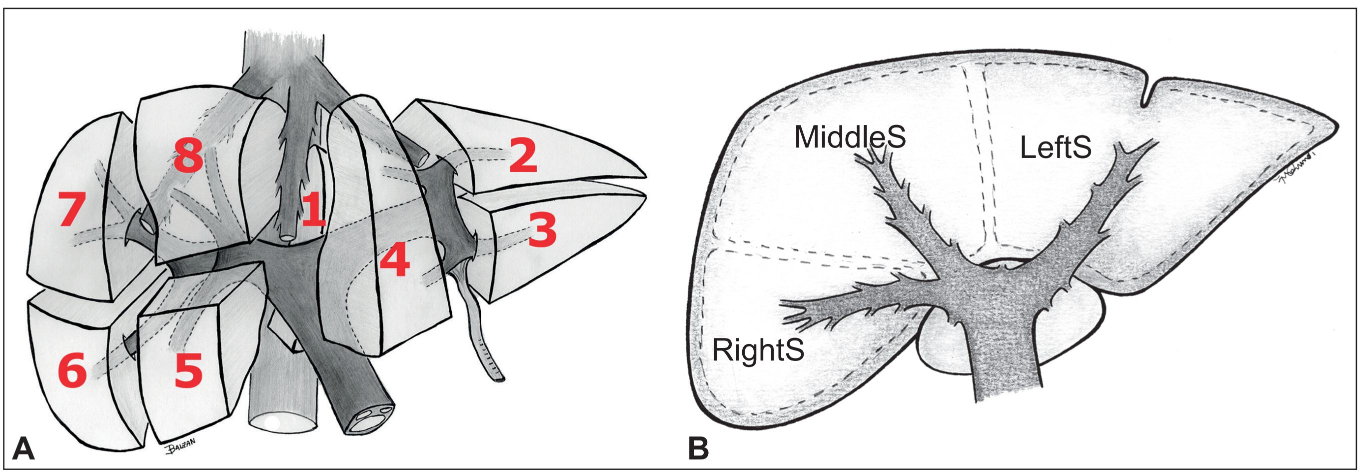

Figure 1. Schematic illustration of hepatic segmentation. **A**) Segmental anatomy according to Couinaud. The middle hepatic vein divides the right hemiliver (segments 5,6,7 and 8) from the left hemiliver (segments 2,3 and 4). **B**) Takasaki's liver segmentation is based on the two major venous trunks (right hepatic vein and middle/left hepatic vein trunk). The right, the middle, and the left segments correspond to Couinaud's segments 6/7, 5/8, and 2/3/4, respectively. The caudate area corresponds to Couinaud's segment 1.

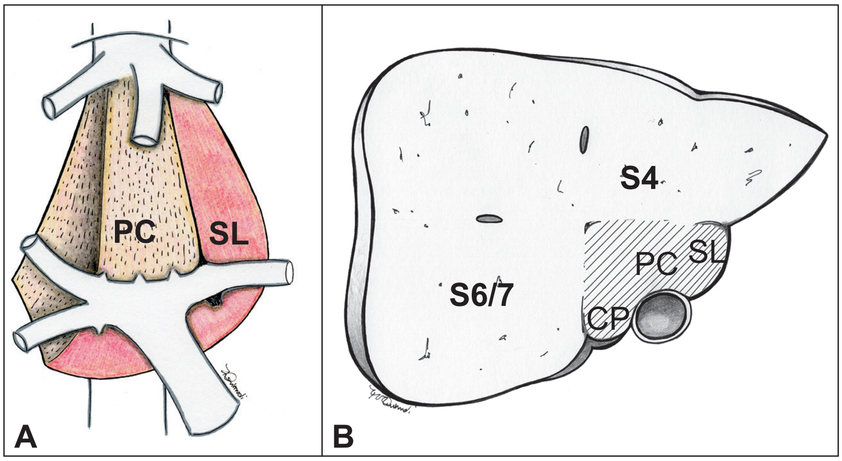

Figure 2. Schematic representation of the caudate lobe (or Segment 1 of Couinaud, or caudate area of Takasaki). This portion of the liver is divided in three parts: Caudate process (CP), Paracaval portion (PC), and Spiegelian lobe (SL). **A**) Anterior view. Hachured area represents the anterior paracaval and the lateral paracaval triangles. **B**) Transversal section demonstrates the depth contact of CP with the right posterior sector (or right segment of Takasaki), and the contact of PC with segment 4. The SL is the bulbous left part of the caudate lobe, seeing through the minor omentum. S4: segment 4; S6/7: segments 6/7.

liver into two hemilivers (right and left) by the "midplane of the liver" (which intersects the gallbladder fossa and the fossa of the inferior vena cava). Two other planes, the left intersectional plane (which passes through the umbilical fissure and the attachment of the falciform ligament) and the right intersectional plane (with no surface marking) are responsible for the second order division, and delimit the four hepatic sections (right posterior and right anterior sections, and left medial and left lateral sections). The delimitation into seven segments (third order division) is done by the association of horizontal intersegmental planes. Segment 1 (**Figure 2**) is a distinct portion of the liver, separate from the right and left hemilivers. It is subdivided into three parts: the Spigelian lobe, the paracaval portion (anterior to the vena cava), and the caudate process (merging indistinctly with the right hemiliver).

In summary, the terminology of anatomy considers two hemilivers (first order division), four sections (second order division), and eight segments (seven derived from the third order division plus segment 1).

It is worth noting that segment 4 is arbitrarily divided into superior (4a) and inferior (4b) parts without an exact anatomical plane of separation. However, there is no individual arterial blood supply for these parts, and the left medial section corresponds to segment 4.

The terminology of hepatic resections is based upon anatomical terminology, as shown in **Figure 4**. Thus, resection of one hemiliver is a hemihepatectomy (right or left hemihepatectomy, also called right hepatectomy or left hepatectomy according to the resected hemiliver), resection of a section is a sectionectomy (right posterior sectionectomy, right anterior sectionectomy, left medial sectionectomy, and left lateral sectionectomy), and resection of a segment is a segmentectomy (for example segmentectomy 1, segmentectomy 5). Resection of three contiguous sections is referred to as a trisectionectomy (right or left trisectionectomy). When segment 1 is resected as part of a procedure, the term "with resection of segment 1", or "extended to segment 1", should be added (for example: "right hepatectomy with resection of segment 1"). Also, the use of the segment number to refer to any resection is correct. For instance, one might describe resection of segments 5-8 (or right hemihepatectomy, or right hepatectomy), resection of segments 2,3 (or left lateral sectionectomy), and resection of segments 5,6 (or bisegmentectomy 5,6). As cited above, note that the left lateral ***section*** (segments 2 and 3) is not the same as the left lateral ***sector*** of Couinaud (segment 2), and similarly, the left medial ***section*** of Brisbane terminology (segment 4) is not the same as the left medial ***sector*** of Couinaud (segments 4 and 3).

MAJOR OR MINOR HEPATECTOMY

The classification of a liver resection as a *major hepatectomy* or a *minor hepatectomy* has some goals such as comparing

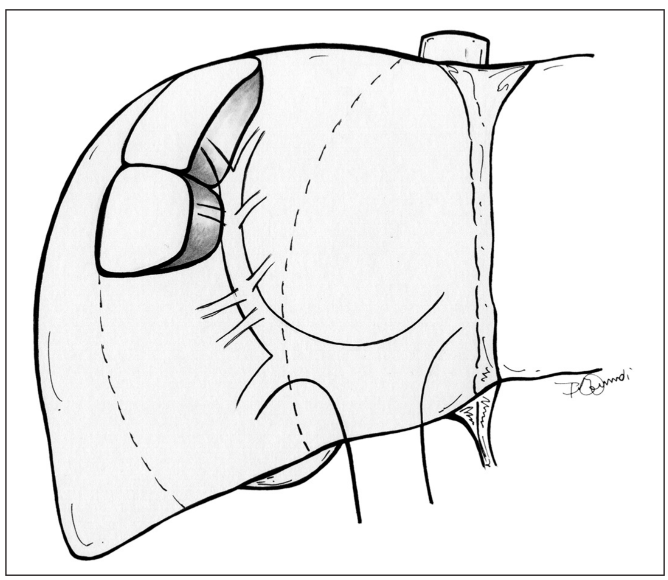

Figure 3. Takasaki's cone unit concept applied to segment 8 of Couinaud. (Adapted from Takasaki.[83])

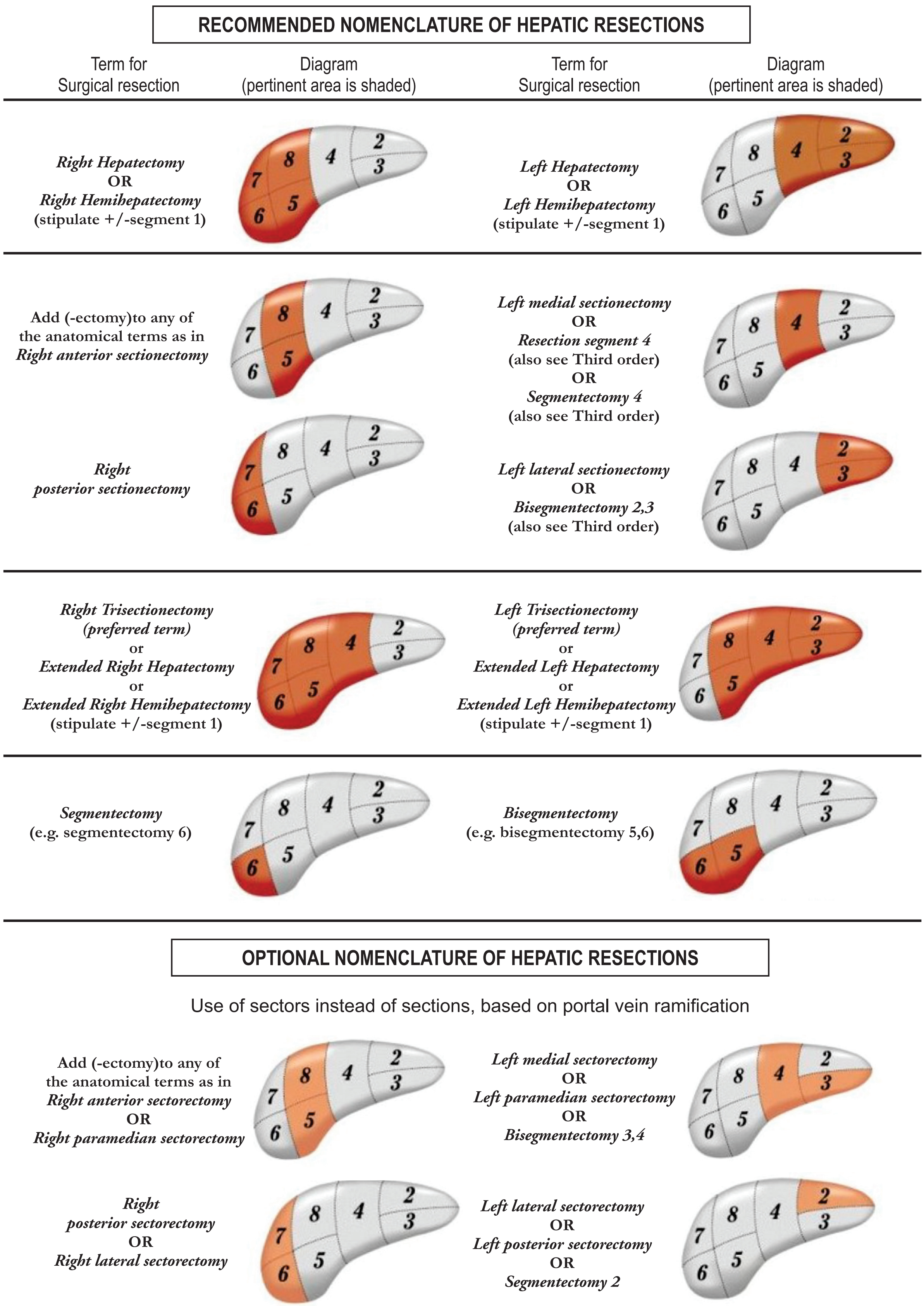

Figure 4. Terminology of hepatic resections. The Arabic numbers represent the respective Couinaud segment. (Adapted from The terminology committee of the IHPBA [5])

results between studies and predicting morbidity and mortality rates. The remnant liver (considering its volume and quality) is the major determinant of complications following a liver resection. The volume of liver resected has a direct relationship with the remnant liver, and classically liver resections have been classified as a **major hepatectomy** when three or more hepatic Couinaud's segments are resected, and a **minor hepatectomy** if up to two Couinaud's segments are resected.

Recently, the cutoff of four or more segments to define a major hepatectomy has been proposed. Based on outcomes after 1,670 consecutive hepatectomies, Reddy et al.[6] found that resection of four or more hepatic segments was associated with poorer outcomes; on the other hand, the outcomes were similar after resection of three or fewer segments.

While the classifications of major or minor hepatectomy based on the number of segments resected are widely used, they are not always indicative of the complexity of the liver resection. For example, a central liver resection of segments 5 and 8 is certainly more complex than a left lateral resection (segments 2 and 3).

INCISION

The majority of hepatic resections are performed through an exclusive abdominal approach. Laparoscopic approach is discussed in **Chapter 27** (Principles of Laparoscopic Liver Resections). For most liver resections, open operative exposure can be achieved through a variety of incisions. The bilateral subcostal incision (with or without a vertical midline extension) can be used to access both hemilivers. However, other accesses have been used to provide adequate exposition with minimal complications. A midline incision from the xiphoid to 2-3 cm above the umbilicus with an oblique or transversal extension to the right flank ("J" or inverted "L" incisions) provides excellent operative exposure and allows for abdominal or thoracic extension if necessary. Another incision, called a "hockey stick" incision, combines a right subcostal incision with a midline extension to the xiphoid (**Figure 5**).

The use of a thoracoabdominal incision (thoraco-phreno-laparotomy) might be useful to approach tumors close to the confluence of the hepatic veins, as it enables an effective retraction of the costal arch. The chest is usually opened through the 9th interspace after division of the costal arch. Frequently used incisions are the J-shaped incision extended laterally to a thoracotomy and median laparotomy extended laterally in the 9th interspace close to the xiphoid (**Figure 5**). The diaphragm can be divided radially from the chest wall to the hiatus, or circumferentially leaving 3 to 4 cm along the chest wall for later approximation. One must be careful to avoid injury to the phrenic nerve. With the combined thoracic approach, the surgeon is able to lift the liver together with the diaphragm, and bleeding from the hepatic veins or inferior vena cava can be easily stopped by digital compression. This exposition allows for resection of tumors invading the diaphragm with proper control of the suprahepatic vena cava and adequate exposition of the hepatic vein confluence (for dissection, resection, and eventual reconstruction). Moreover, in large tumors of the right liver that preclude its mobilization and are not eligible for anterior approach, control of the short hepatic veins can be facilitated by thoracoabdominal incision.

Rarely, resection of small tumors located in the superior hepatic segments can be accomplished exclusively through the chest with the opening of the diaphragm to approach the liver. This strategy is usually reserved for resection of hepatocellular carcinoma in cirrhotic patients to avoid the complications of laparotomy in this subset of patients (i.e., ascites or peritonitis). The difficulty inherent to obtaining vascular inflow control (frequently needed in these patients) and the development of laparoscopic surgery (with fewer complications than laparotomy in cirrhotic patients) have made this approach exceedingly rare.

The selection of the appropriate incision should take into account the hepatic anatomy (especially in cases of repeated hepatectomy and severe atrophy or hypertrophy of certain segments), tumor location and size, and presence of previous incisions (for example, for resection of a primary colorectal tumor). In case exposure of the suprahepatic vena cava and the hepatic veins is needed, it is advisable to choose an incision that allows for adequate thoracic extension.

Adequate exposure is facilitated by the use of appropriate retractors. It is of utmost importance to invest enough time intraoperatively to optimize exposure. Many options of retractors, from various manufacturers, are available. The most useful are those that are fixed to the operating table and allow for cephalad and somewhat anterior retraction of the costal margins.

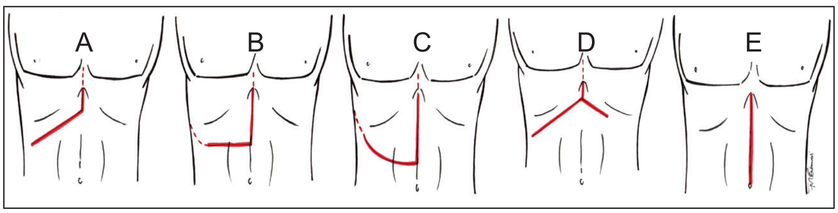

Figure 5. Frequently used incision for open hepatic resections. Dotted lines represent possible extensions. **A**) Hockey Stick Incision; **B**) Inverted L Incision; **C**) J Incision; **D**) Bilateral Subcostal Incision; **E**) Midline Incision.

DRAINAGE

In order to evacuate peritoneal fluid collections, drains can be left in place for diagnostic, prophylactic, or therapeutic purposes.

The potential benefits of prophylactic drainage following liver resection include: i) prevention of possible harmful fluid accumulation (i.e., bile) that can eventually become infected and ii) to detect early postoperative complications (i.e., intra-abdominal bleeding or anastomotic leakage). However, routine prophylactic drainage is not used after hepatic resection due to the risk of secondary infection and the development of interventional radiology to treat occasional deep operative site complications.[7] In general, it is acceptable to drain extensive right resections and procedures with associated biliary reconstruction. In case drainage is performed, the use of a silicone close-suction product (i.e., Jackson-Pratt or Blake) in the resection bed is preferred.

EXPOSITION AND LIVER MOBILIZATION

The extent of liver mobilization depends on the type of hepatectomy to be performed. In most cases, the ligamentum teres and the falciform ligament are divided. The falciform ligament is sectioned in a cephalad direction to the subdiaphragmatic inferior vena cava. Dissection can be continued laterally towards the right and left sides of the inferior vena cava (IVC) in an avascular plane, very close to the liver. The division of the upper part of the falciform ligament enables exposition of the debouchment of hepatic veins into the IVC (**Figure 6**).

If necessary, the left liver is mobilized by sectioning the left triangular ligament. This step can be facilitated by the opening of the ligament close to the IVC and passing an umbilical tape to encircle the left hepatic lobe. A caudal traction on the left lobe facilitates the exposure and section of the left triangular ligament, especially in cases of a large ligament reaching the left abdominal wall laterally. Also, placement of a laparotomy pad under the left triangular ligament between the stomach and the left lobe, and keeping contact with the diaphragm, facilitates the section of the left triangular ligament and avoids injury to the stomach and spleen. The left lobe is pulled upward, and the lesser omentum is divided exposing the Arantius ligament (ligamentum venosum), which is divided near its cephalad insertion (in the left hepatic vein or the common trunk). This maneuver facilitates encircling the common trunk or the left hepatic vein. Care should be taken not to injure the left phrenic vein, which drains into the IVC close to the opening of the hepatic vein common trunk.

Section of the right triangular ligament allows for mobilization of the right liver and access to the right aspect of the retrohepatic vena cava. The liver is pulled downward and the cephalad portion of the right triangular ligament is divided with exposure of the bare area of the right liver (**Figure 7**). Attention should be paid to prevent injury of the right hepatic vein, which is in close proximity to the peritoneum, recovering the transition between the falciform and right triangular ligaments. At this point, blunt dissection making contact with the IVC can help avoid injuries to the diaphragm. After section of the upper portion of the right triangular ligament, the liver is pulled upward and the inferior portion of the ligament is divided. Dissection is performed close to the liver to avoid lesion of the right adrenal. Finally, the liver can be rotated to the left, and the right liver progressively separated from the diaphragm, exposing the entire right bare area of the liver.

Thus, exposition of the retrohepatic vena cava can be obtained after sectioning the falciform, left triangular, and right triangular ligaments. The short retrohepatic veins draining directly from the caudate lobe to the IVC can be divided (**Figure 7**). The upper part of the right side of the retrohepatic vena cava is covered by the vena cava ligament (also called the Makuuchi ligament or caval ligament). This ligament should be divided to complete exposure of the vena cava and the right hepatic vein (**Figure 7**). The vena cava ligament extends behind the vena cava, joining the caudate lobe at the left aspect of the vena cava. This ligament can be avascular, contain vascular and biliary structures, or even be composed of hepatic tissue (creating a ring of parenchyma encircling the vena cava).

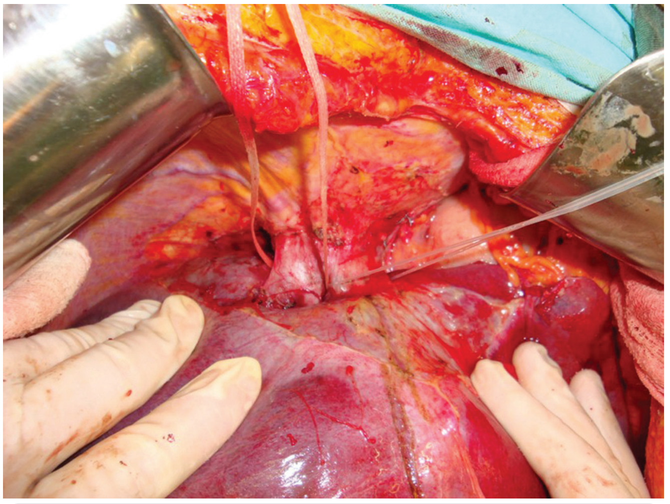

Figure 6. Surgical aspect after section of the falciform, right triangular and left triangular ligaments, and downward traction of the liver. Usually the suprahepatic inferior vena cava is easily identified and dissected (among the arrows). The right hepatic vein and the common trunk (left and middle hepatic veins) can be isolated at this point (umbilical tapes).

The complete mobilization of the liver facilitates adequate intraoperative ultrasound evaluation, as discussed in **Chapter 3** (Intraoperative Assessment of the Liver). In case of tumor attachment to the diaphragm, resection with posterior repair can be performed during liver mobilization. In case of diaphragmatic compromise, the anterior approach might be useful (this topic is discussed later in this chapter).

VASCULAR CONTROL

Blood loss is a major intraoperative complication of liver resections. Blood transfusion is frequently associated with increased operative morbidity and mortality, and poor oncological outcomes (discussed in detail in **Chapter 9** – Morbidity and Mortality after Liver Surgery).[8,9] Vascular occlusion modalities (inflow control or a combination of inflow and outflow control) and techniques of hepatic transection have contributed to minimize blood loss and perioperative blood transfusion. However, the benefit of reduction of bleeding by vascular clamping should be balanced with the resulting liver injury induced by ischemia and reperfusion, especially in patients with a chronic underlying liver disease. Thus, intermittent pedicular clamping (combined with low central venous pressure) has been the preferred vascular clamping method to reduce blood loss with lower morbidity. Safe liver resections with no vascular clamping are possible using low central venous pressure and adequate cross-section methods. Total vascular exclusion of the liver has been limited to tumors involving the major hepatic veins or the IVC close to these veins.[10]

In this chapter, some technical aspects of vascular control are discussed. Complementary reading of **Chapter 23** (Vascular Control and Parenchymal Transection Techniques) is recommended.

INFLOW VASCULAR OCCLUSION

Inflow vascular (arterial and portal) occlusion is an efficient means of reducing bleeding during hepatotomy. Inflow vascular occlusion can be applied to the whole liver or selectively to target areas. Interruption of the inflow to the whole liver is usually obtained by occlusion of the portal vein trunk and the proper hepatic artery. Selective inflow vascular occlusion of the segments to be resected can be performed outside the parenchyma (by intrafascial or Glissonean approaches) or by transection of the relevant vascular structures within the liver substance.

Total inflow vascular occlusion of the whole liver (pedicular control)

Continuous inflow occlusion can be safely applied to a normal liver under normothermic conditions for up to 60 minutes, and for up to 30 minutes in pathological (fatty or cirrhotic) livers.[11] However, longer durations of continuous clamping (90 minutes in normal livers[12–15]) have been reported. Duration of inflow occlusion can be safely prolonged using strategies such as intermittent clamping and hepatic hypothermia, discussed below in this chapter. Intermittent pedicular clamping results in less hepatic ischemia and splanchnic congestion than continuous clamping.

The simplest method of hepatic inflow vascular clamping is the **Pringle maneuver**, described in 1908, which consists of clamping of the hepatoduodenal ligament.[16] Once the lesser omentum is opened, a blunt dissector (or a finger) is passed through the foramen of Winslow and the hepatoduodenal ligament is encircled with an umbilical tape. The entire contents are clamped en masse. Optionally, the structures of the hepatoduodenal ligament can be dissected and the portal vein and hepatic artery occluded individually, avoiding possible bile duct injuries. For both techniques, non-traumatic vascular clamps or tourniquets can be used to perform the Pringle maneuver.[17] Attention should be paid to the identification and clamping of an accessory left hepatic artery originating from the left gastric artery; it generally runs through the lesser omentum and requires individual clamping. Conversely, when present, a right accessory hepatic artery originating from the superior mesenteric artery is clamped in a regular way, as it runs within the hepatoduodenal ligament.

Selective inflow clamping (intrafascial and Glissonean approaches)

Selective inflow vascular occlusion can be used to avoid ischemia of the remnant liver, reduce splanchnic congestion,

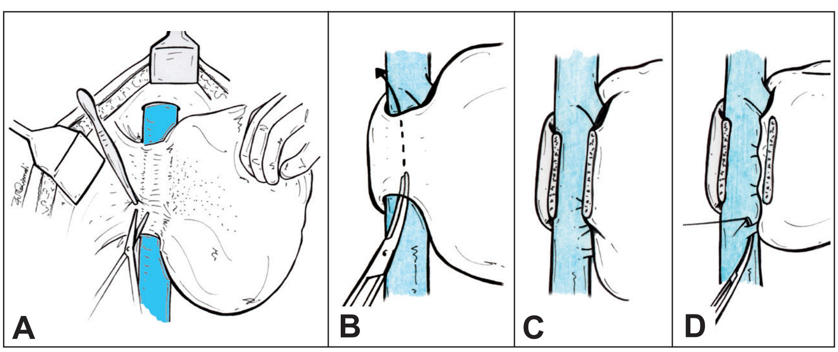

Figure 7. Mobilization of the right hemiliver. **A**) Completion of section of the right triangular ligament. **B**) A tunnel is created by blunt dissection between the vena cava ligament and the vena cava. **C**) Division of the vena cava ligament allows exposition of the right hepatic vein and the right aspect of the retro-hepatic vena cava. **D**) Short retrohepatic veins are sectioned and the retrohepatic vena cava fully exposed.

and to accurately demarcate the limits of the segments to be resected in the hepatic surface by changes in its color. Selective inflow occlusion can be applied to the right or the left hemiliver, or to each hepatic sector (mainly right anterior and right posterior sectors), or even individual segments. Selective inflow occlusion can be definitive (such as by ligature) or temporary (by vascular clamping or tourniquet). Temporary selective occlusion can be useful for resections smaller than the occluded sector. For example, during a wedge resection or a segment hepatic resection of the right liver, a temporary clamping of the right hemiliver can be used to reduce blood loss, preserving the inflow for the left hemiliver. Selective control of the main vascular pedicles can be accomplished by Glissonean approach or by intrafascial hilar dissection. Occlusion of a segmental or subsegmental portal branch can also be performed with vascular balloon insertion into the (sub) segmental portal vein (by intraoperative ultrasound-guided transhepatic puncture[18] or through the superior mesenteric vein[19]) combined with unilateral clamping of the ipsilateral hepatic artery.[18] Segmental or subsegmental portal vein occlusion, aiming to demarcate the area to be resected, can also be accomplished by intraoperative ultrasound-guided finger compression.[20,21] Another technique for segmental demarcation, without portal occlusion, is through the injection of a dye (such as indigo-carmine) by intraoperative-guided puncture in the portal branches of the tumor area to be resected while the hepatic artery at the hilum is clamped.[22]

The two main methods for control of the vascular inflow pedicles are: extrafascial (or Glissonean) and intrafascial approaches. These methods with their variants can be used for most hepatic resections. One exception is tumor compromise of the hilum when combined hepatectomy and resection of the biliary confluence or vascular structures of the hilum preclude the Glissonean approach, which is performed above the hilum. Also, for tumors close to the hepatic hilum (less than 2 cm), the intrafascial approach can help to avoid violation of the tumor margin.

Intrafascial hilar approach (Figure 8)

With the Glissonean approach (intrafascial hilar approach), the portal vein, hepatic artery, and biliary duct are usually dissected in the hilum after opening the peritoneal fascia. To avoid accidental section of structures to be preserved close to the hilum, the vascular structures might be temporarily clamped at this level but sectioned (together with the biliary tract) into the parenchyma, across the section area.

Structures of the right pedicle are more difficult to individualize than those of the left pedicle. The cystic artery is ligated and sectioned and a cholecystectomy is performed. A tube can be placed through the stump of the cystic duct for an eventual further cholangiography or bile leak tests. The peritoneal fascia is generally opened at the right side of the common bile duct and the right hepatic artery identified, usually posteriorly to the common bile duct. The common bile duct, together with the surrounding connective tissue, is pulled to the left and upward. The division of the right hepatic artery facilitates exposition and control of the right portal vein. If the right hepatic artery should not be divided, it can be properly displaced using a Gil-Vernet retractor to facilitate exposure of the right portal vein. The right portal vein is encircled using blunt dissection with a right-angle clamp. Attention should be paid to avoid injury of the inferior and posterior portal branches to the caudate lobe, more precisely those to the paracaval portion of segment 1. If control of the right portal branch is difficult to obtain, the portal vein trunk can be dissected and encircled by the right and posterior aspect of the hepatoduodenal ligament, and a downward traction can enable better exposition of the portal bifurcation. Usually, the right hepatic artery and the portal vein are dissected (and can be sectioned) at the hilum, but the right bile duct is not. The right bile duct is safely sectioned during the parenchymal cross section or at the hilum but without dissection. These strategies avoid direct or ischemic injury of the biliary tract. Structures of the left hepatic pedicle are longer and easier to individualize by intrafascial approach than the right.

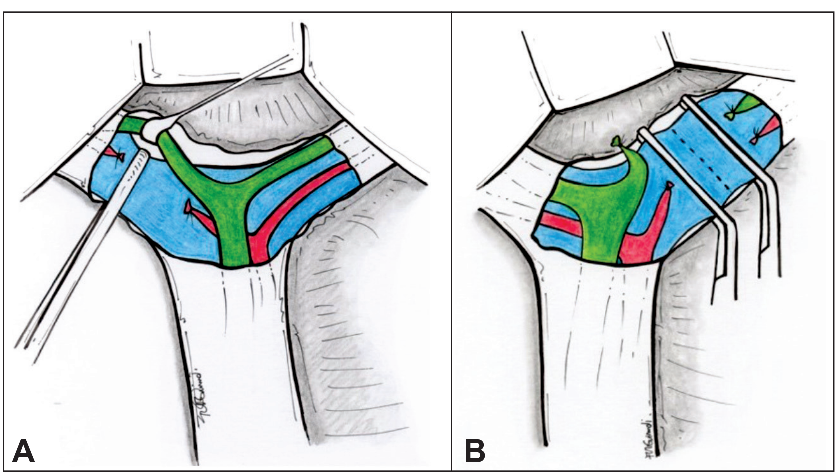

Figure 8. Intrafascial approach to the structures of the right and left hemilivers. **A**) Control of the right portal vein is facilitated by the section of the right hepatic artery (at the right side of the common bile duct). The right hepatic bile duct is pulled upward and to the left by a Gil-Vernet retractor. **B**) Left hemiliver pedicle dissection. The left bile duct is usually long and sectioned to allow easier access to vascular structures.

Optionally, intrafascial approach to the right pedicle can be performed in a posterior to anterior direction; i.e., first dissection and/or section of the right portal vein is achieved and then the right hepatic artery is identified and controlled.

It is important to note that intrafascial dissection is usually performed below the hilar plate, where variations of the hepatic artery and bile duct are frequent. The vascular anatomy should be carefully evaluated by preoperative imaging. The main vascular variations are described in **Chapter 1** and **Chapter 2**.

The standard arterial anatomy occurs in two thirds of patients. The median hepatic artery (to segment 4) has frequent variants, but generally runs anteriorly to or crosses the left hepatic duct. Dissection of the middle hepatic artery from the left hepatic duct is needed for safe section of the left hepatic duct.

Biliary duct variations are also common. In case a variation is suspected, an intraoperative cholangiography should be performed, especially if the bile duct will be sectioned in the hilar plate.

Glissonean approach (extrafascial approach) (Figures 9 and 10)

Glisson's capsule refers to the connective tissue that wraps the hepatic pedicles (hepatic artery, portal vein, and bile duct). With the extrafascial (or Glissonean) approach, the so-called Glissonean pedicles at the hilar plate are detached from the liver parenchyma. Control of the main Glissonean pedicles (left hemiliver, right anterior sector, and right posterior sector from Couinaud's classification; or Takasaki's left, middle, and right segments, respectively) is accomplished extrahepatically at the level of the hepatic hilum following hilar plate lowering.

This approach was initially developed by Launois and Jamieson[23] and enhanced by Takasaki.[4] Since the arterial and biliary variations occur below the hilar plate, this approach does not pose a risk of injury to the elements that supply the remaining liver segments when the pedicles are sectioned above the hilar plate.[24]

The three Takasaki segmental branches (right, middle, and left, corresponding to Couinaud's right posterior sector, right anterior sector, and left hemiliver, respectively) can be encircled separately, and various combinations of pedicle control and section are possible.

The whole right hemiliver pedicles can be encircled by inserting a right-angled clamp in the superior aspect of the hilar plate (after lowering the hilar plate from segment 4), passing posteriorly to the right liver pedicle through an oblique trajectory to reach the transition between segments 7 and 1, at a level on the right of the hepatoduodenal ligament (**Figure 9**). This maneuver can be made more challenging

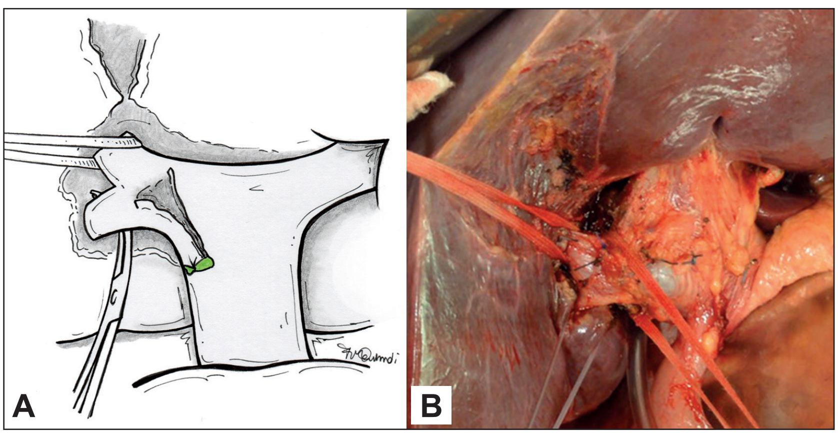

Figure 9. Glissonean approach to right liver pedicles. The hilar plate is lowered and the hepatic parenchyma separated from it. The separation of hepatic parenchyma from the connective tissue is followed until identification of right and middle Takasaki's segment pedicles. **A**) The middle segment pedicle is easily encircled using a blunt clamp. The right Takasaki's segment pedicle is showed being encircled. **B**) Surgical aspect showing the right Takasaki's pedicle encircled by a silicone tube and the middle one encircled by an umbilical tape (pulled upward). The right hemiliver pedicle is encircled by another umbilical tape (pulled downward).

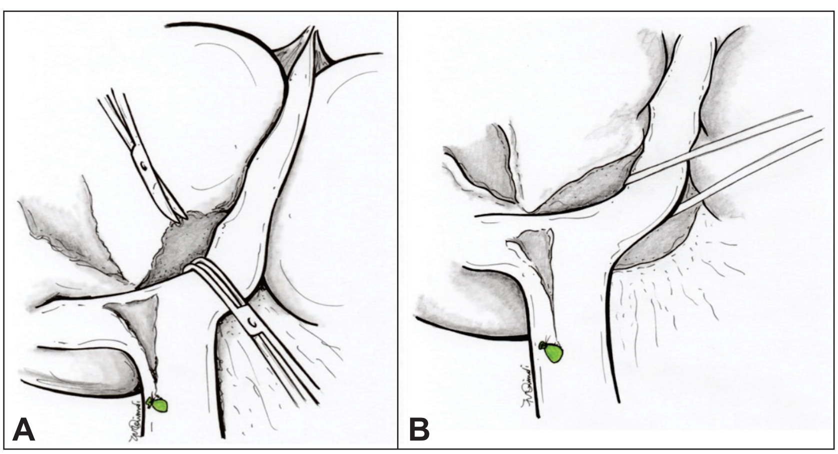

Figure 10. Glissonean approach to left liver. A) The hilar plate is lowered. B) After section of the Arantius's ligament (optional), a blunt clamp is used to dissect the pedicle of the left hemiliver (Left Takasaki's segment).

by the presence of a tertiary order pedicle originating from the posterior aspect of the hepatic hilum.

Control of the right anterior pedicle (Takasaki's middle branch) is possible by introducing a right-angled clamp in the superior aspect of the hilar plate, passing posteriorly to the right anterior pedicle to reach the right side of cystic plate (**Figure 9**). Encircling the right posterior pedicle is more easily performed by a two-step maneuver: First, an umbilical tape is used to encircle the whole right liver pedicles. Second, the right anterior pedicle is encircled from right to left and the end of the umbilical tape is retrieved to exclude the right anterior pedicle from the loop. For a right hepatectomy, both the right anterior and right posterior sectoral branches can be controlled and sectioned together, or they can be sectioned separately to prevent injury to the left branches. Running sutures or vascular staplers can be used. During positioning of clamps or staplers, an umbilical tape is used to retract the hilum away from the section plane.

Both the Glissonean and the intrafascial approaches have also been used for laparoscopic liver resections. Dissection of the three main secondary order Glissonean branches can be performed using the same technique used with open surgery. A simplified method using endovascular stapler and minimal parenchymal dissection was described for right segmental resections, and it is useful for both open and laparoscopic resections. Three small incisions around the hilar plate (one on segment 4, above the hilar plate, another on the right edge of the gallbladder, and another posteriorly on segment 7) are used to introduce vascular staplers including the right and/or middle Takasaki segments (**Figure 11**).[1] A similar method is used for left resections. The Arantius ligament is divided and retracted to facilitate the encircling of left segment pedicle.[25,26]

Couinaud's segment 4, similar to the left lobe (segments 2/3), does not have an individual Glissonean segmental branch. Thus, resection of segment 4, or segments 2/3, usually requires dissection and ligature of multiple branches.

For segmental resections (Takasaki's tertiary branches) of the right and middle Takasaki segments using a Glissonean approach, first the secondary branch (right or middle, respectively) is taped and pulled away from the liver. Then, the pedicle is progressively peeled away from the liver parenchyma and the bases of tertiary branches became visible. Parenchymal incision is required if the secondary branch has a long trunk or is deep. For segmental resections of the left Takasaki segment, the round ligament is pulled upward to expose the left secondary branch (when present, the umbilical bridge of liver parenchyma is sectioned).

OUTFLOW VASCULAR CONTROL

Methods to reduce bleeding through the hepatic venous system (outflow) include non-surgical procedures, such as the use of low central venous pressure (CVP). When a low CVP (<5 mmHg) is not reached by ordinary measures, i.e. pharmacologically or by fluid restriction, clamping (partial or complete) of the infrahepatic inferior vena cava (IVC) is effective in reducing blood loss due to venous backflow during hepatectomy.[27]

Occlusion of the hepatic veins to be resected together with the hepatic specimen is generally the last step of the liver resection. The occlusion and division of the hepatic veins after the parenchymal section allows for the maintenance of adequate outflow during the procedure, and helps to avoid hepatic congestion. Control and occlusion of hepatic veins before parenchymal transection can be used to reduce the bleeding resulting from venous backflow; however, complete blood inflow for the segments drained by the vein to be occluded must also be stopped.

Classical total vascular exclusion (TVE) of the liver is obtained clamping the inflow and outflow by using Pringle maneuver, and suprahepatic and infrahepatic IVC clamping. Also, TVE of the liver can be performed without IVC occlusion, by clamping blood inflow structures (arterial and portal) and the hepatic veins. In this situation, all direct branches from the liver to the IVC should be ligated before TVE. The main technical aspects of vascular outflow control are described below.

Infrahepatic IVC clamping

The infrahepatic IVC is easily encircled above the renal veins. The hepatoduodenal ligament is pulled to the right and the peritoneal reflection between the liver and IVC is sectioned. Careful blunt dissection is performed on each side of the IVC and it is encircled using umbilical tape. Partial or total occlusion can be done by vascular clamp or tourniquet application.

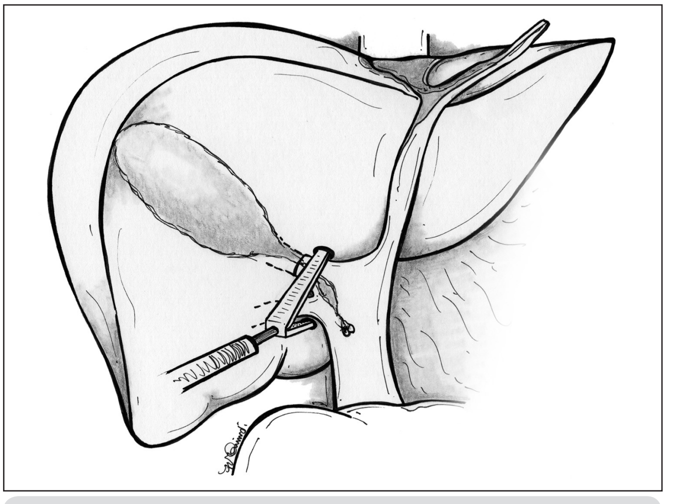

Figure 11. Glissonean approach for right resections using small parenchymal incisions. Vascular stapler is introduced comprising a combination of two incisions according to sections to be resected. (Adapted from Machado et al.[25])

Hepatic vein control

Hepatic veins can be controlled extrahepatically or within the liver during the parenchymal transection. The extrahepatic control of hepatic veins can be necessary, especially in case of tumors close to hepatic veins and the IVC. Central venous pressure should be less than 5 mmHg. The patient is placed in a 15-degree Trendelenburg position to prevent air embolism. Thoracic-abdominal incision allows for the best exposure of the suprahepatic IVC, and hepatic veins and should be used in some cases of large tumors at the junction of the hepatic veins and the vena cava.

Extrahepatic control of the right hepatic vein

After mobilization of the liver by section of the falciform ligament and right and left triangular ligaments, the liver is turned to the left to expose the retrohepatic IVC (**Figure 7**). The filamentous fibrous tissue covering the suprahepatic IVC (between the diaphragm and the liver) is opened, and dissection downward is performed between the right hepatic vein and the common left/middle hepatic veins trunk, making contact with the anterior wall of the IVC. The vena cava ligament (Makuuchi's ligament) is divided to complete exposition of the lateral aspect of the IVC. The short retrohepatic veins are ligated and sectioned (large accessory hepatic veins could need clamping and running sutures) to free the anterior aspect of the IVC (**Figure 7**). A blunt dissector or clamp is then used to carefully encircle the right hepatic vein from below in an upward direction to join the previously dissected space between right and middle hepatic veins. A vascular stapler can be used alternatively to clamping and section followed by running suture for definitive control of the right hepatic vein (**Figure 12**).

Extrahepatic control of the left and middle hepatic veins

The falciform ligament and left triangular ligament are sectioned. Section of the falciform ligament exposes the upper surface of the left and middle hepatic veins. The leaves of the left triangular ligament separate close to the left hepatic vein. The left lobe is then turned anteriorly and to the right. The gastrohepatic ligament (lesser omentum) is sectioned and the ligamentum venosum (Arantius ligament) exposed. It runs between the caudate lobe and segments 2 and 3, from the left portal vein to the left hepatic vein (**Figure 13**). This ligament is sectioned close to its fixation in the left hepatic vein. Subsequently, dissection is performed in contact with the anterior surface of the vena cava, creating a tunnel from the left to the right up to the previously created space between the right and middle hepatic veins. This maneuver results in encircling of the common trunk of middle/left hepatic veins. Sometimes, the section of the left diaphragmatic vein enables better exposure of the extrahepatic portion of the left hepatic vein. More proximal dissection (close to the liver parenchyma) of the common trunk permits control of the left hepatic vein alone. To control only the middle hepatic vein, first a tape is used to encircle the common trunk, and subsequently the left-side end of the tape is retrieved by forceps introduced beneath the left hepatic vein from the right to the left. Occasionally, the left and the middle hepatic veins drain separately into the IVC.

Total vascular exclusion of the liver is discussed in another topic in this chapter.

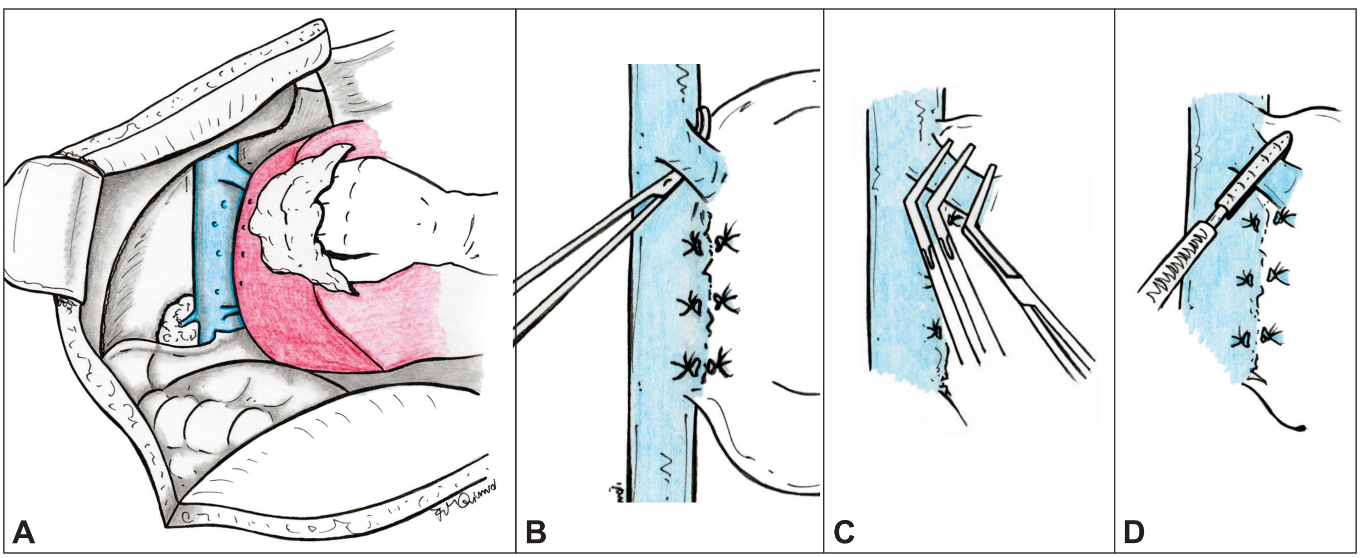

Figure 12. Extrahepatic control of the right hepatic vein. **A** and **B**) After mobilization of the liver and section of the vena cava ligament a clamp is carefully used to progressively create a tunnel beginning on the anterior aspect of IVC below the debouchment of the right hepatic vein and ending in a space previously create between the right hepatic vein and the trunk of middle/left hepatic veins. **C**) extrahepatic clamping before section and suture of right hepatic vein. **D**) Alternatively a vascular stapler can be used to section of right hepatic vein.

PARENCHYMAL TRANSECTION

Since perioperative blood loss and blood transfusion are factors that are predictive of postoperative complications, liver transection is one of the most important steps during hepatectomy. Many different methods have been put forward in order to reduce excessive bleeding during parenchymal transection. This chapter summarizes methods for liver transection and treatment of the cross section. The many options to avoid bleeding and heterologous blood transfusion in hepatic resections are discussed in **Chapter 9** (Morbidity and Mortality after Liver Surgery) and in **Chapter 23** (Vascular Control and Parenchymal Transection Techniques).

METHODS FOR PARENCHYMAL TRANSECTION

The main goal during liver transection is to divide the hepatic parenchyma with minimal bleeding. For this purpose, many techniques and devices have been tested. Frequently, one device is used to divide the parenchyma (such as the clamp-crush technique, ultrasonic dissector, or water jet) and another to accomplish the hemostasis. The visualization of intraparenchymal vessels and their control prior to division leads to a reduction in blood loss. Hemostasis of small vessels (less than 3 mm in diameter) can be achieved by thermocoagulation, ties, or surgical clips. Larger vessels and biliary branches usually require other methods, such as suture ligatures or vascular staplers. Among the several methods available for parenchymal transection, none of them has been demonstrated to be more effective than the others. The combined use of available methods seems to be an adequate option, taking into account the characteristics of each device and the skills and features of the surgeon.[28–30] Detailed description of transection methods can be found in **Chapter 23** (Vascular Control and Parenchymal Transection Techniques).

Knowledge of the intrahepatic anatomy helps the surgeon during hepatic transection (**Figure 14**). Intraoperative ultrasound provides information about the main structures to be sectioned during transection.

In cirrhotic patients, parenchymal transection can be a more challenging step during liver resection. The firmness of the liver substance prevents the destruction of the parenchyma with preservation of the vascular and biliary structures, and the clamp-crush technique may not work adequately. In this case, the use of devices that coagulate while transecting may be useful.

TREATMENT OF THE LIVER CROSS SECTION

Omentoplasty. Apposition of the greater omentum to the liver cross-section area was used in the past for reduce bleeding. However, following the development of modern techniques of anesthesia and parenchymal transection, omentoplasty is no longer recommended with this goal in mind.[31] Some authors suggest using it after left liver resections to avoid gastroparesia due to adhesions between the stomach and the raw surface of the liver.

Topical sealants. A variety of topic sealants have been used over the raw surface of the liver after hepatectomy.

Collagen (the main component of extracellular matrix) has been used in several formulations (sponges, compresses, powder). It is applied on the raw surface of the liver serving as

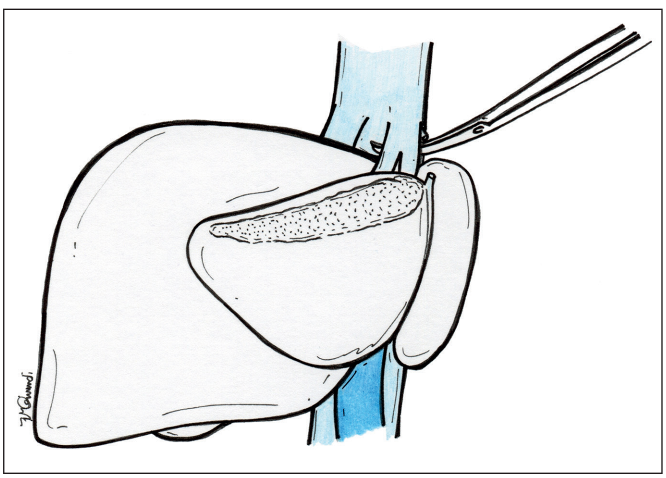

Figure 13. Extrahepatic approach and dissection of the left and middle hepatic veins. The left lobe of the liver is completely mobilized after section of the falciform and left triangular ligaments. The Arantius' ligament is divided allowing the exposure of the window between the IVC and the left hepatic vein. The common trunk (left and middle hepatic veins) or the left hepatic vein can be easily controlled.

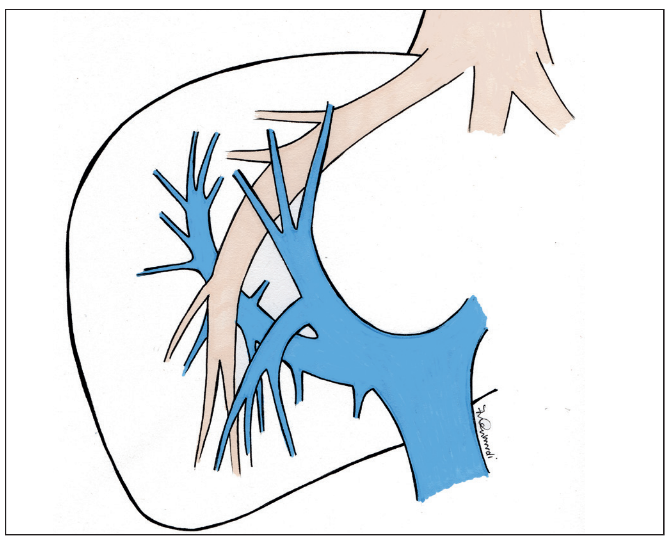

Figure 14. The relative position of the hepatic veins and Glissonean pedicles in the right liver. In the upper part of the liver most of Glissonean pedicle branches intersect those of the hepatic veins, while in the lower part almost all branches run parallel to the hepatic veins.

a matrix for the formation of the platelet clot. Its hemostatic mechanism is based on the mechanical adhesive effect.[32,33]

Products derived from fibrin and fibrinogen have been used as topical hemostatic agents in liver surgery by reproducing hemostatic biological mechanisms. Many products are available with different combinations of composition (such as thrombin, thrombin + fibrinogen, thrombin + collagen, or thrombin + collagen + fibrinogen) and formulation (such as glue, compress, or sponge), but with the same goal: optimal platelet adhesion and clot formation.

Results regarding the use of these products to avoid intraoperative blood loss and/or postoperative complications are controversial.[34–38] The use of fibrin derivative combinations has also been reported to reduce postoperative biliary leak.[39,40]

Biliary control. The incidence of biliary complications after major hepatectomy remains elevated, reaching 10%. Biliostasis of large biliary ducts on the cross-section plane is usually obtained by suture ligation or surgical clips. Ischemia and necrosis on the surface of cross section could be sources of postoperative biliary leakage, resulting in biliary fistulae or biloma. However, the method used for parenchymal transection does not seem to affect the occurrence of bile leakage.

A variety of intraoperative tests have been used to identify and treat bile leaks during liver resections. However, despite their efficacy in identifying intraoperative leakage, the postoperative clinical impact is inconclusive. In fact, most bile leaks originating from the parenchyma surface resolve spontaneously or after non-surgical procedures. Despite that, all bile leaks identified intraoperatively should be treated. Methods for intraoperative detection of bile leakage and biliostasis vary from simple procedures, such as keeping gauze in contact with the section surface for several moments and observing the presence of yellow dyed areas, to more complex procedures demanding specific apparatus, such as indocyanine green fluorescence cholangiography.

Formal intraoperative cholangiography has no impact on the clinical incidence of postoperative biliary leakage; however, it can be useful to verify biliary anatomy and biliary permeability of the remnant liver. Another simple method to verify the continuity between the intrahepatic biliary tree of the remnant liver and the common bile duct is the injection of air through the cystic duct stump during intraoperative hepatic ultrasound. The occurrence of artifacts inside the parenchyma tissue confirms continuity between the main bile duct and intrahepatic biliary tree.

ANTERIOR APPROACH AND HANGING MANEUVER

The anterior approach consists of initial vascular inflow control and parenchymal transection without prior mobilization of the liver.[41,42] The potential advantages of this approach are i) the reduction of intraoperative blood loss and transfusion requirements (more easy liver mobilization after transection), ii) probably diminished tumor cell dissemination (the "no touch" technique), iii) reduction of postoperative liver failure (avoidance of pedicle torsion and mechanical compression of the remnant liver), and iv) reduced risk of bacterial translocation into the bloodstream in case of cholangitis or pyogenic abscesses. However, bleeding control in the deeper parenchymal plane can be difficult.

The "liver hanging maneuver" was initially described as a procedure in which the liver was lifted by a tape passed between the anterior surface of the vena cava and the liver. After the initial description of the hanging maneuver for right hepatectomy, many variants were developed for application in most anatomical hepatic resections. This maneuver provides effective vascular control, making the anterior approach safer and easier.[43,44]

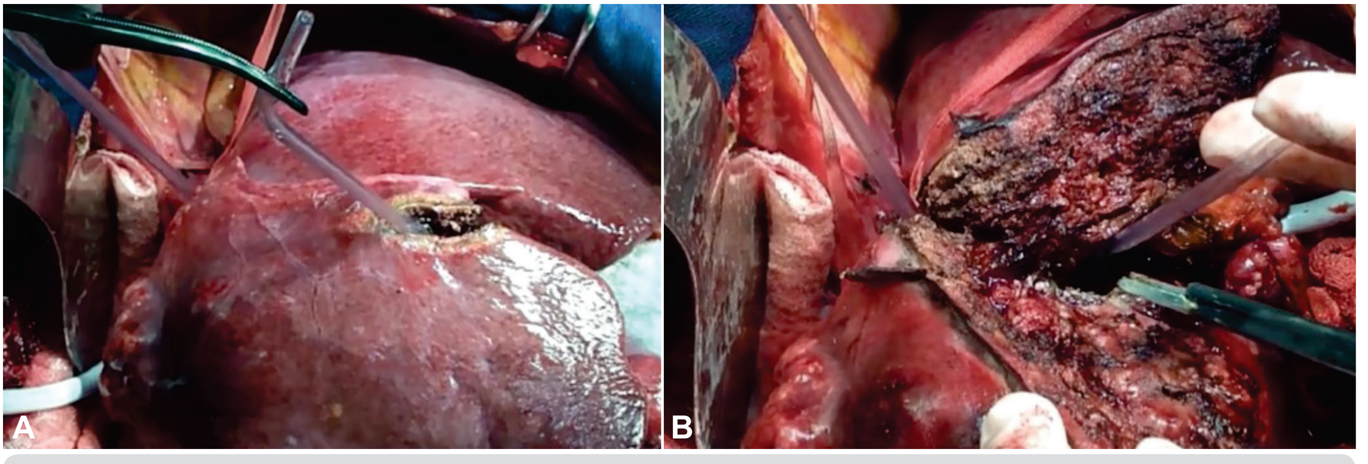

Figure 15. Use of liver-hanging maneuver during a right trisectionectomy. **A**) The nasogastric tube guide the plan of transection and **B**) it is used to upward traction to reduce bleeding and to facilitate the cross section exposition.

For resections in which the parenchymal transection reaches the anterior surface of the IVC, the first step is to create a tunnel between the anterior surface of the IVC and the liver. The hepatoduodenal ligament is retracted to the left, and the inferior aspect of hepatic segment 1 is lifted from the IVC. The anterior aspect of the IVC is dissected and the short hepatic veins are ligated and divided. This dissection is extended upward until it can be performed under direct visualization to minimize the length of the blind dissection of the next steps. Afterward, the anterior aspect of the suprahepatic IVC is exposed and an "up to down" dissection of the space between the right and the middle hepatic veins is performed. This dissection is done for 2-3 cm along a right oblique axis and making contact with the IVC. The next step is usually a blind dissection, where the retrohepatic tunnel between the previously dissected spaces in the infrahepatic and suprahepatic IVC is created. This blind dissection can be performed "down to up" using a blunt curvilinear instrument (such as a Debakey aortic clamp or Kelly forceps), or "up to down" introducing a nasogastric tube that is pushed downward. Alternatively, retrohepatic dissection can be guided by intraoperative ultrasound,[45] or it can even be performed by direct visualization using endoscope or laparoscope.[46] Through the retrohepatic tunnel a nasogastric tube (or an umbilical tape) is placed for continuous upward traction during parenchymal transection.[43] This strategy enables continuous guidance for the correct cross-section plane and provides control of backflow bleeding on the cross section (**Figure 15**).

The liver hanging maneuver can be applied in a variety of anatomical liver resections. Depending on of the type of resection required, the nasogastric tube is positioned along the anterior surface of the IVC or along the ligamentum venosum (Arantius ligament). The upper end of the nasogastric tube can be repositioned between the middle and the left hepatic veins. The lower end can be placed behind one or two of the Glissonean pedicles. However, more than one tube can be used for central resections. The many possible combinations according to the position along the precaval space or along the Arantius ligament, and the placement of the upper and the lower ends of the tube(s), define different planes of parenchymal transection, as illustrated in **Figures 16** and **17**. These planes are used for different anatomical hepatic resections. For central hepatic resections, the combination of two hanging maneuvers can be used to determinate each plane of section. Guidance for caudate lobe resection alone is possible by positioning the tube along the precaval space, the upper end passing behind the common trunk of the middle/left hepatic veins, and finally along the Arantius ligament.

The main limitation factor for the liver hanging maneuver is the presence of adhesions between the IVC and the liver. On the other hand, this is a particular indication for anterior approach (**Figure 18**). Conditions such as cirrhosis; large tumors; direct tumor invasion of major hepatic veins, diaphragm, or retroperitoneum; contact of the tumor with the IVC; and preoperative transarterial chemoembolization and/or portal vein embolization are not contraindications to the liver hanging maneuver.[47,48]

TOTAL VASCULAR EXCLUSION OF THE LIVER and HYPOTHERMIA

Some hepatic tumors are difficult to resect, or demand associated vascular resections and reconstructions. The use of total vascular exclusion, as initially described by Huguet et al.,[49] enables this kind of resection. The technique consists of complete occlusion of vascular inflow (arterial and portal) and outflow (generally controlling the IVC above and below the liver). This technique allows for very effective control of bleeding. However, TVE of the liver is less tolerated than inflow occlusion alone, probably due to the stoppage of blood backflow by the hepatic veins. A liver with no underlying liver disease is capable of tolerating continuous total normothermic ischemia for as long as one hour. Also, temporary occlusion of the IVC can cause hemodynamic instability (reduction of cardiac output coupled with increased systemic vascular resistance), and the release of toxic substances accumulated during ischemia can result

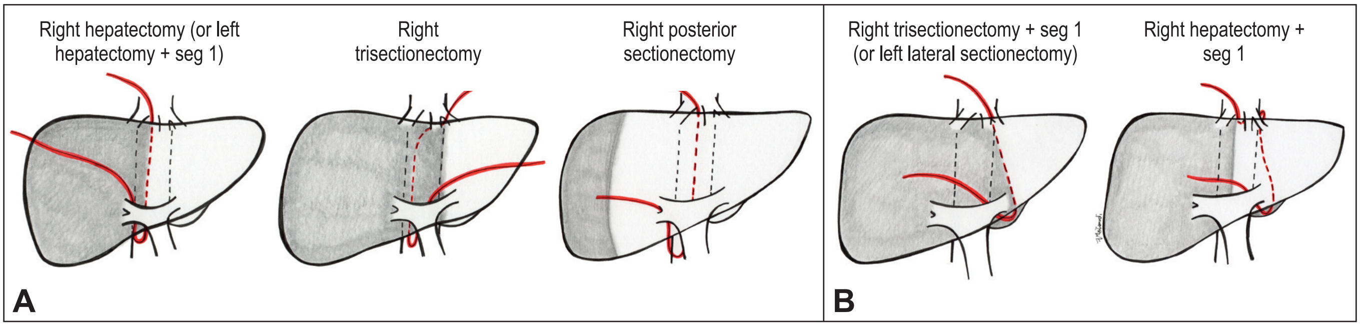

Figure 16. Various techniques for liver resection with hanging maneuver using a single tube. **A**) Tube along the anterior surface of the inferior vena cava. **B**) Tube along the Arantius' ligament. Adapted from Liddo et al.

in severe injury by ischemia-reperfusion syndrome. Thus, TVE is used almost exclusively in cases of hepatectomy associated with hepatic veins or IVC reconstruction. In most other cases, inflow vascular clamping (continuous or intermittent) and low central venous pressure anesthesia are sufficient means of controlling bleeding. Strategies to minimize parenchymal injury during TVE or during inflow control of the liver include preconditioning, hypothermia, and perfusion with cold organ preservation solutions. To overcome hemodynamic instability, a venovenous bypass may be installed to drain the splanchnic blood into the systemic circulation.

Hypothermia may reduce the ischemic injury to the remnant liver, being particularly useful in patients with underlying chronic liver disease. Reduction of the liver temperature is usually obtained by vascular infusion of cool solution (through the portal vein during hepatic vascular exclusion) or by topical hypothermia on the liver surface (with ice pack or ice slush under inflow vascular control or TVE).[50–54]

Inflow control for TVE of the liver is obtained by Pringle maneuver or by separate arterial and portal clamping. It is crucial to identify and control any anomalous arterial branch to the liver, such as an accessory left artery originating from the left gastric artery and running through the hepatogastric ligament. Outflow occlusion is classically obtained by control of the IVC above the hepatic veins (between the diaphragm and the liver) superiorly, and above the renal veins inferiorly. If the IVC is clamped inferiorly below the right adrenal vein, it should be identified and ligated. The persistent entry of blood flow into the liver (resulting from pathological retrohepatic vessels in case of tumor adhesions, or even from inadequate occlusion of clamped vessels) results in progressive congestion of the liver and hemodynamic intolerance.[14]

Alternatively, TVE can be achieved with no IVC occlusion. In this case, outflow occlusion is achieved by clamping the hepatic veins, and all short veins that drain directly to the IVC must be ligated (vascular exclusion with caval flow preservation). This technique is hemodynamically well tolerated.

Also, it is possible to obtain a total caval clamping with total vascular exclusion of the hepatic segments to be resected, but preserving the perfusion of the remnant liver (selective total vascular exclusion).[55] This approach is mainly used for right side hepatectomy combined with vena cava resection; in this case, the inflow and outflow of the remnant liver is preserved by selective hilar clamping and oblique occlusion of the suprahepatic inferior vena cava, keeping the left hepatic vein (or the common trunk) out from the clamping. This method, such as the vascular exclusion with caval flow preservation, avoids the use of venovenous bypass, since the blood flow through the left liver reduce splanchnic congestion and hemodynamic variations.

Venovenous bypass (**Figure 19**) has been used to prevent some of the drawbacks of normothermic total vascular occlusion, such as hemodynamic intolerance and splanchnic congestion, which are at least partially responsible for ischemia-reperfusion syndrome. The safe time limit of liver tolerance to total vascular exclusion with venovenous bypass seems to be up to roughly 120 minutes.[56] Venovenous bypass consists of carrying, by the bio-pump, the blood from the portal vein and inferior vena cava to the superior vena cava system. The internal jugular vein and femoral vein are cannulated percutaneously or by surgical dissection. Another cannula is placed into the superior mesenteric vein, inserted

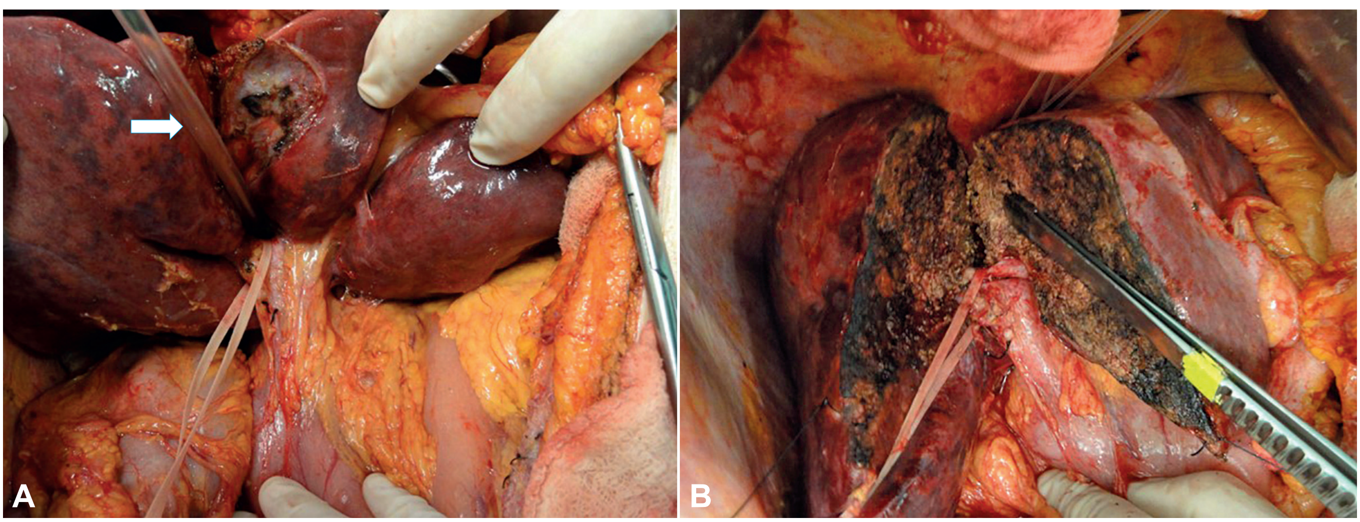

Figure 17. Right hepatectomy using hanging maneuver and Glissonean approach. **A**) After encircling of the right hepatic pedicle (umbilical tape) the tube used for the hanging maneuver (arrow) is repositioned to not include the portal pedicle. **B**) This maneuver facilitates the parenchymal transection before section of portal pedicle.

through the portal vein. Thus, after clamping of the inflow (arterial and portal) and the outflow (infrahepatic IVC and suprahepatic IVC), the bypass is started, gathering blood from the splanchnic system and IVC territories and carrying it to the superior vena cava system.

Hypothermic perfusion and topical hypothermia

Liver resections requiring complex reconstruction of hepatic venous outflow and a long time of total vascular exclusion may benefit from techniques of hypothermic perfusion of the liver and topical hypothermia. With the use of hypothermia and organ preservation solutions, tolerance to the ischemic phase can be extended to four hours, allowing for complex resections and reconstructions by *in situ*, *ante situm*, or even *ex-vivo* (*ex-situ*) procedures. Total vascular exclusion of the liver is a condition to apply hypothermic perfusion.[57]

In situ hypothermic perfusion refers to the cold perfusion of the liver through the portal vein, and the liver resection is performed through standard techniques. ***Ante situm*** liver surgery refers to the division of the suprahepatic IVC and the rotation of the liver forward to allow access to the retrohepatic vena cava and hepatic vein confluence. ***Ex situ*** resection comprises the complete removal of the liver from the body and perfusion with cold preservation solution on a back table.

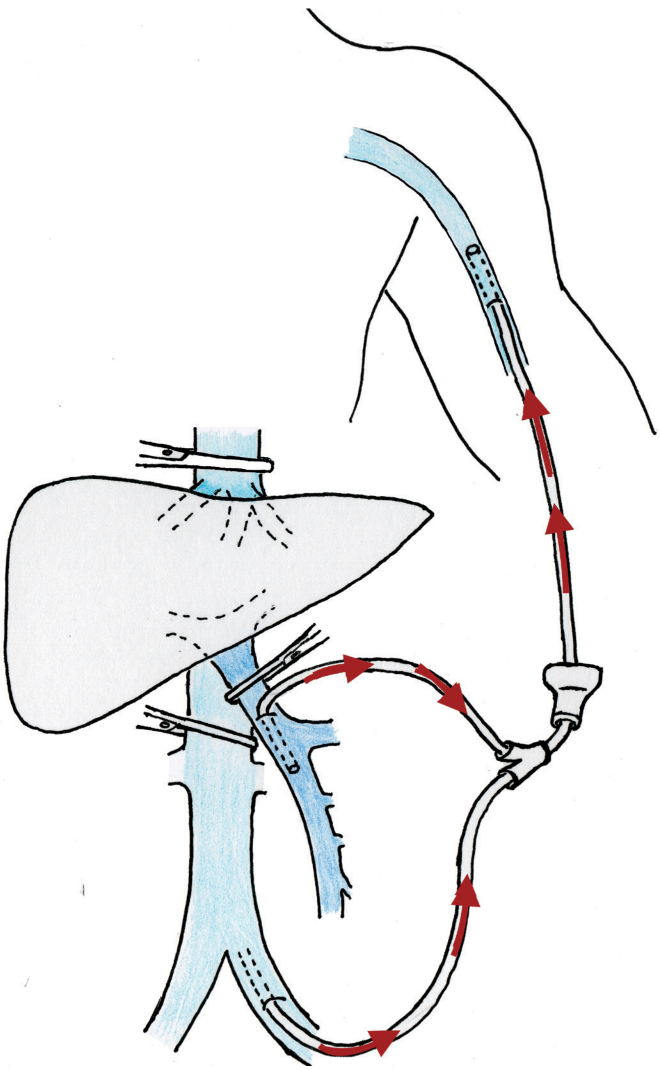

Figure 18. Venovenous bypass. The blood from the portal vein and inferior vena cava is carry, by the bio-pump, to the superior vena cava system.

Usually, the perfusion of cold preservation solution is through a cannula placed into the portal vein of the side to be resected and directed into the contralateral portal vein (side to be preserved) to avoid subsequently portal vein repair, or optionally into the main portal vein. Cold (4^{o} C) standard organ preservation solutions, such as University of Wisconsin (UW) solution or histidine-tryptophan-ketoglutarate (HTK), can be used. The resection is completed in a bloodless field. Before vascular anastomotic completion, the liver is flushed with 5% albumin or ringer lactate solution, and then the blood inflow and outflow are reestablished.

In situ and ***ante situm*** hypothermic perfusion techniques have been associated with acceptable mortality rates of less than 10% in many centers. *In situ* perfusion requires standard liver mobilization and total vascular exclusion techniques. A cannula into the portal vein is used to perfusion of cold solution and a cava venotomy made to discharge. Optionally, the liver can be cooled by superficial application of ice. This technique can be used additionally to cold perfusion or eventually alone. For the *ante situm* technique the division of the suprahepatic IVC is added to allow mobilization of the liver, which remains connected by the hepatic pedicle. The advantage is a generous access to hepatic veins confluence and retrohepatic IVC with the necessity of only one vascular anastomosis (cavo-caval anastomosis).

In situ hypothermic perfusion can be used when a single hepatic vein or the IVC requires reconstruction. In general, most parenchymal transections can be performed before the total vascular occlusion and the hypothermic perfusion applied only during vascular resection and reconstruction.

Ante situm liver resections (*in vivo* hypothermic perfusion and venovenous bypass) were first described by Hannoun et al.,[58] and this method is useful for patients with large liver tumors that invade all three hepatic veins at the hepatic venous confluence, and reconstruction of hepatic veins is necessary.[58–60]

Ex situ liver resection with hypothermic perfusion is a high mortality surgery (up to 30%).[53] This procedure was developed by Pichlmayr et al.[61] and a venovenous bypass is required. The portal vein is dissected and sectioned below its bifurcation; the proper hepatic artery is divided at the level of its origin (in the junction with the gastroduodenal artery). The suprahepatic and infrahepatic IVC are clamped and transected, and the liver removed. Optionally the liver can be removed with preservation of the IVC, in cases of involvement of all hepatic veins but with no involvement of the IVC. In this case a temporary portocaval shunt is used to prevent splanchnic congestion.

Topical hypothermia requires inflow vascular control. The temperature of the remnant liver is decreased to 20-28º Celsius by application of ice packs or slush on the liver surface.

LYMPHADENECTOMY AND BILIARY RESECTION

The role and extent of a **lymphadenectomy** concurrently with a hepatectomy for malignant tumors of the liver are controversial. Most superficial and deep lymphatics of the liver drain into lymph nodes at the hepatic hilum and gastrohepatic omentum, and then enter the abdominal/retroperitoneal lymphatic system. Only superficial lymphatics from the convex surface of the liver run along the hepato-caval confluence, reaching the mediastinal lymphatic system.[62] Lymphadenectomy could be limited to hepatoduodenal ligament (more frequent site of lymph node metastases) and pancreaticoduodenal region, or it can be extended up to celiac axis or para-aortic lymph nodes.[63–66] Extended lymphadenectomy seems useful in selected cases of hilar cholangiocarcinoma. Regional lymphadenectomy for some primary and metastatic liver tumors could provide prognostic data, assist selection of patients for adjuvant therapy, and even improve survival in patients with limited nodal involvement. Detailed indications for and extension of lymphadenectomy are discussed in the pertinent chapters.

Extended **biliary resection** is part of the curative surgical treatment of hilar cholangiocarcinoma and some cases of gallbladder cancer. Habitually, resection of caudate lobe is added due to the early tumoral extension to bile ducts from this segment.

Lymphadenectomy combined with biliary resection

The distal common bile duct is dissected and sectioned close to the upper margin of the head pancreas. If a more extended resection of the distal bile duct is indicated, the posterior superior pancreatoduodenal artery should be divided to allow the pursuit and section of the bile duct into the head of the pancreas. The skeletonization of the hepatoduodenal ligament begins with the dissection of the lymph nodes behind the portal vein. The main portal vein is encircled in the lower portion of the hepatoduodenal ligament and the common hepatic artery is also identified and encircled at this level. The vascular skeletonization is then advanced up to the hepatic hilum. All structures and tissues except the portal vein and hepatic artery are resected. The upper limit of resection depends of the type of liver resection to be performed (**Figure 20**). Biliary reconstruction is usually by hepaticojejunal anastomosis with Roux-en-Y limb.

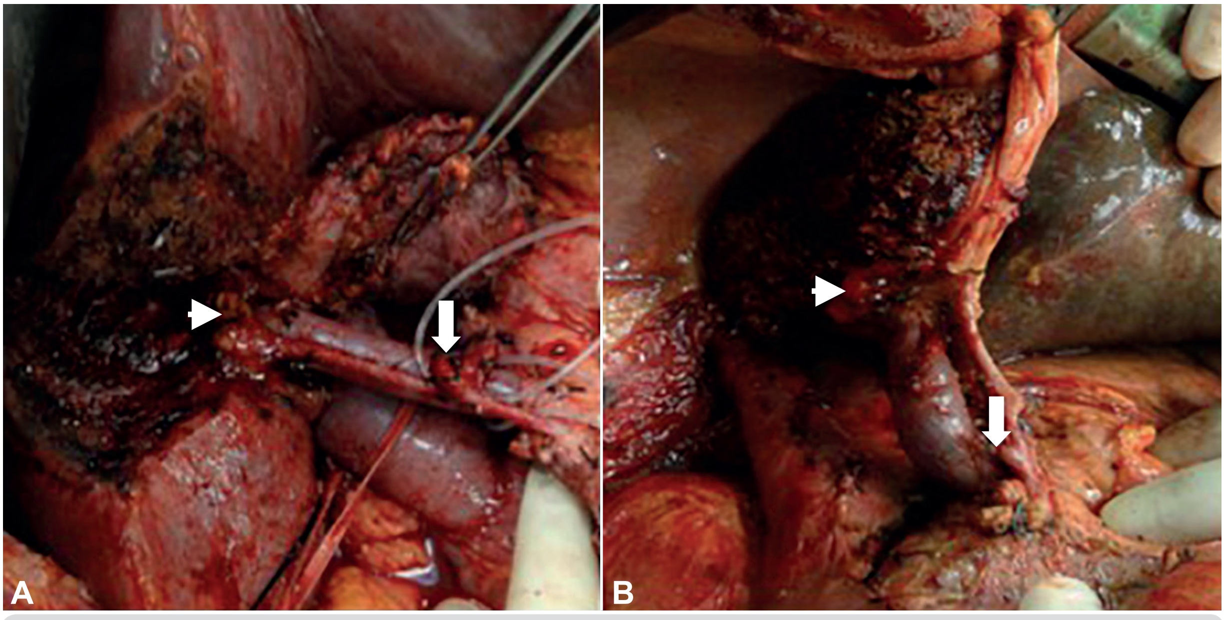

Figure 19. Surgical aspect of hilar vascular skeletonization. **A**) During an anterior hepatectomy for cholangiocarcinoma. Arrow shows the stump of the sectioned left hepatic artery. Arrowhead indicates the opened right posterior bile duct. Note the inferior vena cava encircled by an umbilical tape posteriorly. **B**) During a right extended trisectionectomy for hilar cholangiocarcinoma. Arrow shows right hepatic artery sectioned close its origin. Arrowhead indicates the opened left bile duct. Note the round ligament pulled upward and the complete resection of segment 1.

VASCULAR RESECTION AND RECONSTRUCTION

Resection of **major vessels** during hepatectomy can represent a valuable therapeutic option in selected cases. Surgical techniques in hepatobiliary surgery have evolved and the reconstruction of hepatic vessels can be performed with acceptable morbidity and mortality. Malignant involvement of major vessels is associated with poor prognosis; however, an aggressive surgical approach can represent the only potential of long-term survival. Thus, major vascular resection to achieve a R0 resection can expand the role of liver resection in selected cases of primary and metastatic liver tumors, and hilar cholangiocarcinoma.[55,67–74]

ARTERIAL RESECTION AND RECONSTRUCTION

If arterial resection is needed, reconstruction can be performed before the complete tumor resection, to avoid long hepatic ischemia of the remnant parenchyma. The hepatic artery to be revascularizated (left or right hepatic artery) should be dissected distally to the tumor level and encircled. If the length between the two stumps to be anastomosed is short a primary direct anastomosis is possible. The resected segment can also be replaced by an arterial or venous homologous graft, or by a synthetic graft. Also, arterial supply can be obtained by the displacement of arterial branches, such as the use of the splenic artery (after distal section) to anastomose with right or left hepatic artery.

In some rare situations, when an arterial reconstruction is not possible, an arterioportal shunt (portal arterialization) could help to avoid biliary ischemia by increasing the oxygenation of the portal vein. This procedure can be accomplished by an anastomosis between an arterial branch (such as splenic artery or proper hepatic artery) and the portal vein. However, an excessive arterial flow into the portal circulation can lead to portal hypertension. Thus, various techniques of portal arterialization have been reported to avoid excessive portal hypertension, such as mesenteric arterial branch (up to 3 mm in diameter) anastomosis with mesenteric venous branch.

HEPATIC VEINS AND IVC RESECTION AND RECONSTRUCTION

Minor tumor extension compromising the IVC (narrowing of less than 30%, length less than 2 cm) can be resected by using a laterally positioned vascular clamp, while maintaining or not maintaining a partial flow through the IVC (**Figure 21**). For more extensive compromising of the IVC, a total flow occlusion is needed. Partial IVC resection can be followed by *primary repair* (if it results in a narrowing of no more than 50% of the IVC diameter). If the defect is larger than can be repaired primarily, a *patch* (of autologous veins, bovine pericardium, parietal peritoneum, or Gore-Tex) can be used. After resection of a segment of IVC, a primary end-to-end can be performed or the resected segment can be replaced using an *interposition graft* (Gore-Tex or autologous grafts) (**Figure 22**).

Large tumors or those compromising a high segment of the IVC (near the debouchment of the hepatic veins) usually require total vascular exclusion of the liver. If the tumor spares the debouchment of at least one of the hepatic veins it is possible place the clamps on the IVC preserving the flow of the hepatic vein to be preserved. Thus, resection

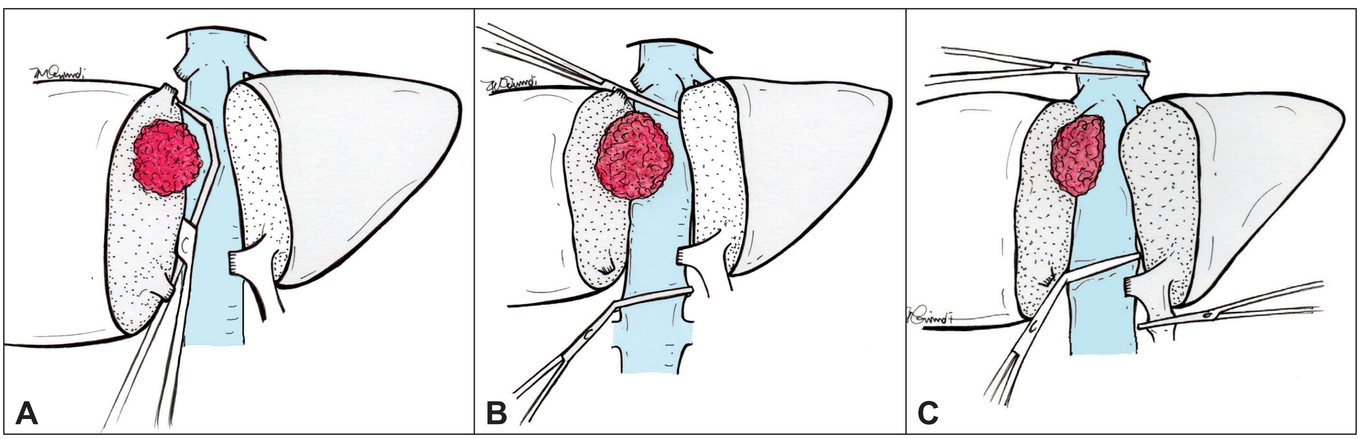

Figure 20. Hepatectomy combined to inferior vena cava (IVC) resection. **A**) Lateral clamping of the IVC after right portal pedicle and right hepatic vein section and parenchymal transection. Useful for tumors compromising up to 30% of the IVC. **B**) Total clamping of the suprahepatic IVC, but keeping the flow through the common trunk (left/middle hepatic veins), and the infrahepatic IVC. Useful for tumors close to the debouchment of the right hepatic vein. Figure shows the right portal pedicle sectioned and the parenchyma partially transected. Note that the blood flow through the remnant liver is kept. **C**) Total vascular exclusion of the liver; the suprahepatic and infrahepatic IVC is clamped together with the portal pedicle. Useful for tumors compromising the debouchment of the right hepatic vein.

can be performed with continued perfusion of the liver and reduced hepatic ischemic time.

Hepatic vein reconstruction

Hepatic vein reconstruction is usually indicated in extended resection with compromise of the third hepatic vein, or when the best outflow possible is required to optimize remnant liver function (**Figure 23**).

The technique for vascular reconstruction depends on the extent of vascular resection. Hepatic veins transected close to the IVC can be directly reimplanted. When multiple hepatic vein orifices are present a variety of reconstruction techniques are possible, including use of grafts and/ or transformation of various orifices in only one to be reimplanted. The IVC can be replaced by artificial graft or by an autologous graft made from other veins or peritoneum. If the hepatic veins cannot be anastomosed to the native vena cava, they can be implanted on triangle aperture on the graft.

In cases of resection of segments 7 and/or 8 requiring resection of the right hepatic vein, the short hepatic veins draining directly to the IVC should be preserved to prevent congestion of the remnant segments.

Generally, the hepatic veins can be controlled extrahepatically. For reconstruction of the right hepatic vein, its distal extremity should be skeletonized for a distance of 1 cm to achieve enough space to the placement of a vascular clamp in the caval side. The proximal side of the right vein is identified, controlled and divided intrahepatically during the parenchymal division. Resection and reconstruction of left hepatic vein is similar. In cases where resection of all the three hepatic veins is necessary, the liver is usually completely mobilized off of the vena cava.

The reconstruction after resection of a hepatic vein segment can be by primary anastomosis (if the proximal stump is close to the distal stump) or by graft interposition. In the primary reconstruction the implantation of the proximal stump of the hepatic vein can be done on the distal stump or it can be reimplanted lower down on the IVC (or on a prosthetic replaced vena cava in case of caval resection). If the primary reconstruction is not possible, autologous graft can be used. Autologous venous grafts can be harvested from a variety of vessels, such as the internal jugular vein, left renal vein, extern iliac vein, superficial femoral vein, inferior mesenteric vein, or the portal vein of the resected specimen. Customized venous grafts can be created from lesser veins, such as the saphenous vein or ovarian vein, to avoid deficiency or complications associated with sacrificing intrinsic thicker veins. When more than one tributary vein must be reconstructed, the cited options can be used individually for each tributary or "Y" grafts used. For the creation of a customized graft from veins with a diameter lesser than that need, two or more pieces of vein can be opened longitudinally and sutured side-by-side around a drain tube to obtain a cylindrical graft with the adequate diameter. A similar procedure is used for graft creation from parietal peritoneum.

PORTAL VEIN RESECTION AND RECONSTRUCTION

Portal vein bifurcation is often involved in hilar cholangiocarcinoma, gallbladder carcinoma, and intrahepatic cholangiocarcinoma. Hepatectomy with en-bloc portal vein resection is a demanding procedure but may represent the

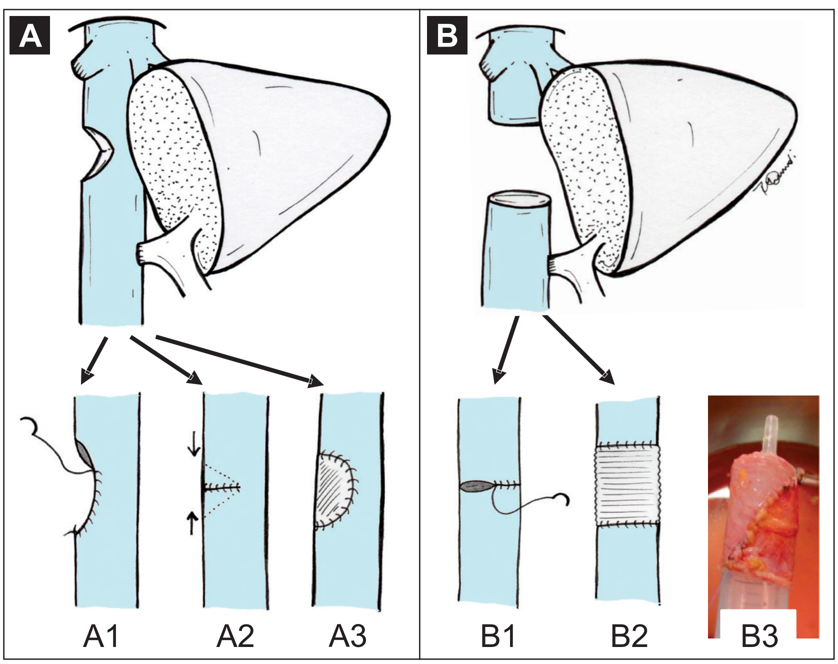

Figure 21. Options of inferior vena cava (IVC) reconstruction. **A**) After lateral partial resection of IVC options for reconstruction include primary repair (A1) (if suture results in narrow of less than 50% of the IVC diameter), transversal suture (A2) (to avoid narrowing of IVC) if defect allow adequate approximation of edges, and replacement of the defect (A3) with a patch. **B**) After resection of a complete segment of IVC, it can be reconstructed by a direct end-to-end anastomosis (B1) if approximation of edges is possible, or by replacement of the resected segment (B2) with an interposition graft. B3) surgical aspect of a tube of peritoneum molded to replace a segment of IVC.

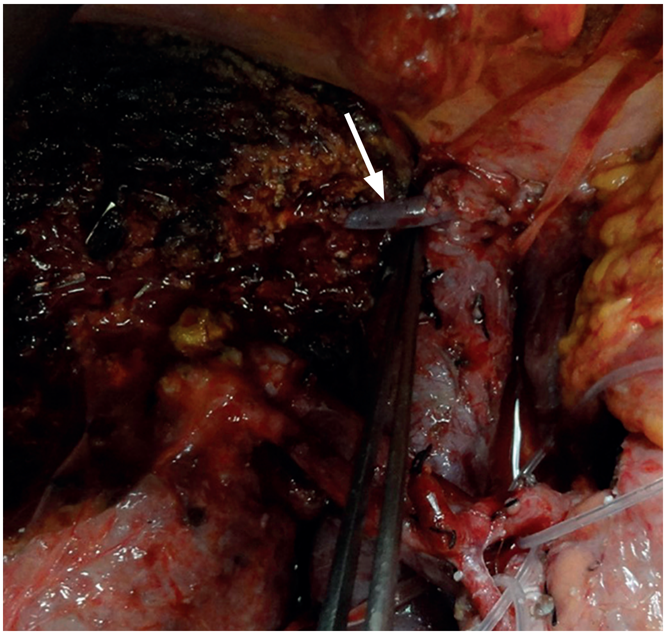

Figure 22. Reconstruction of hepatic vein draining segment 7 using a graft from the inferior mesenteric vein (arrow) after an anterior hepatectomy.

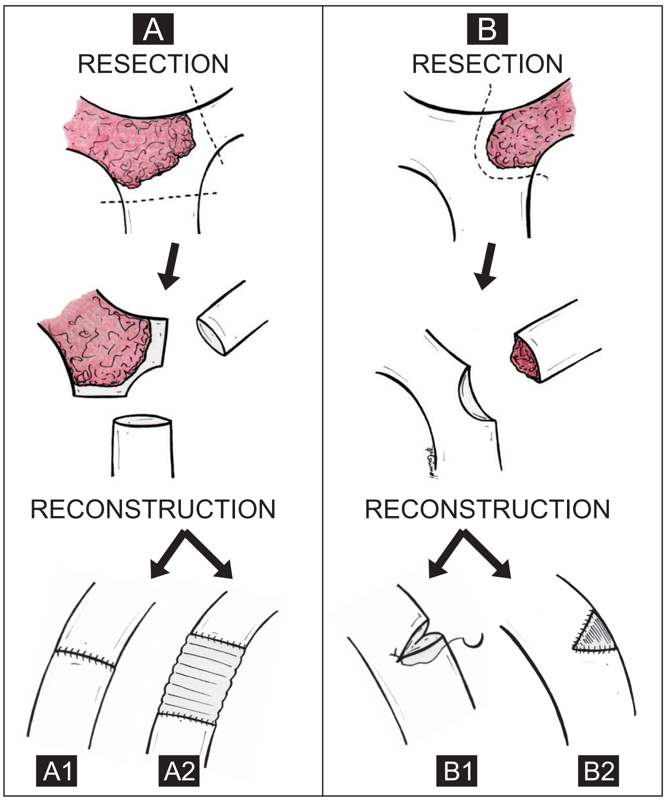

Figure 23. Resection of portal vein bifurcation (PVB) and portal reconstruction. **A**) Resection of PVB and right portal vein. Reconstruction by end-to-end anastomosis without (A1) or with (A2) graft interposition. **B**) Resection of PVB (wedge resection) and left portal vein. Reconstruction with primary repair (B1) or graft patch (B2), according to extend of the defect.

only curative treatment in many cases. Also, resection of hepatocellular carcinoma with tumor thrombi extending to portal bifurcation or main trunk can improve survival. Extent of portal vein resection depends of the tumor involvement and the type of liver resection to be performed.

Portal resection usually starts with dissection and taping of the main portal trunk and the portal vein to the lobe to be preserved. The bile duct and hepatic artery to the lobe to be resected are divided. After clamping of the portal trunk and the portal vein to the remnant liver, the portal trunk is opened and resection of portal vein performed according to the tumor involvement. Reconstruction after partial resection of the portal bifurcation can be by direct closing, as shown in **Figure 24**. When a segment of the portal bifurcation is resected, reconstruction can be performed with end-to-end anastomosis or the defect can be covered with a patch graft (**Figure 24**). Similar to reconstruction of hepatic arteries, portal vein reconstruction can be prior to hepatic dissection.[75–77]

EVALUATION OF THE REMNANT LIVER

Conceptually, for a safe hepatic resection the remnant liver should have a sufficient volume of parenchyma (larger volumes required for diseased parenchyma), which must have adequate inflow, outflow and biliary drainage. The precise evaluation of parenchymal function is a challenging topic discussed in other chapters of this textbook.

The minimal amount of functional remnant liver is also something controversial and it is depending not only from the parenchyma condition, but it also depends on the complexity of the anticipated resection, simultaneous procedures, and patient comorbidities.

The safe limit of the liver remnant volume can be assessed by different methods: i) rate of liver remnant volume and total liver volume (LRV/TLV), ii) rate of liver remnant volume and body weight (LRV/BW), and iii) liver remnant volume and body surface area (LRV/BSA).

Accepted remnant liver volume in the absence of underlying liver disease is 20% of the total functional liver (LRV/TLV), or 0.5% of the body weight (LRV/BW). In patients with underlying liver disease (cirrhosis or hepatitis), a LRV/TLV of 40% is suggested, and in patients with chemotherapy-associated liver injury or severe steatosis the threshold LRV/TLV is 30%.

The total liver volume (TLV) can be obtained in two ways: i) calculation of standardized total liver volume (or total estimated liver volume – TELV) utilizing body surface area or body weight and ii) actual liver volume calculated with imaging techniques. Note that tumor volumes are considered nonfunctional liver parenchyma and should be subtracted from TLV. In patients with multiple tumors, the calculation of the actual liver volume by imaging can be inaccurate. Also, areas of non-functioning liver for biliary or vascular obstruction are not properly estimated. On the other hand, the calculation of standardized total liver volume related to the body surface area is a precise method that prevents the error variability associated with each measurement. The formula TELV = - 794 + 1267 x BSA (BSA = body surface area) is an example to calculate the total liver volume. Body surface area can be calculated by various formulas, such as [BSA (m^2) = 0.20247 x Height(m)$^{0.725}$ x Weight(kg)$^{0.425}$].

OPTIMIZATION OF THE REMNANT LIVER

Patients that are initially poor candidates for liver resection because of an insufficient future remnant liver can benefit from multiple advances to improve resectability rates. These advances include strategies of: i) shrinkage of liver tumors (allowing parenchymal sparing liver resection techniques), ii) minimizing injury of the future remnant liver (optimizing its functioning), and iii) increasing of the remnant liver (allowing more extensive resections). Systemic and/or regional chemotherapy induces tumor size reduction in a variety of hepatic malignancies, and it is discussed in the pertinent chapters in this textbook. Preconditioning is a useful technique to prevent injury from ischemia-reperfusion syndrome in selected cases. Ischemic preconditioning consists of a short period of liver ischemia to "prepare" the liver for a long period of clamping.[78–80] Techniques to increase the future remnant liver include portal vein embolization or ligation and two-stage resections.

Portal vein embolization and portal vein ligation. Occlusion of the portal supply of certain hepatic segments induces the hypertrophy of the other ones. Percutaneous right portal vein embolization prior an extended right trisectionectomy is the main use of the method. Additional embolization of portal branches to segment 4 increases the hypertrophy of future remnant segments 2 and 3. Portal vein embolization has been shown to be more effective than portal vein ligation to induce contralateral hypertrophy. This topic is detailed in **Chapter 7** (Portal Vein Embolization, Transarterial Chemoembolization, and Radiofrequency Ablation).

Two-stage hepatectomy. The first description of two-stage hepatectomy was for the treatment of bilateral liver metastases. Most commonly, the first operation is to clear one hemiliver from all macroscopic disease, usually by either resection or ablation. Combined intraoperative portal vein ligation or postoperative portal vein embolization of the hemi-liver to be resected is performed. After four to six weeks, the second operation is performed to complete the disease resection.

Variations of the method include: i) associating liver partition and portal vein ligation (ALPPS), and ii) first major hepatic resection followed by minor resection of the remnant liver. With the ALPPS procedure, in addition to clearance of the future remnant liver and contra-lateral portal vein occlusion, a hepatotomy (total or partial) is associated. This procedure seems to increase the hypertrophy rate of the future remnant liver; however, it is associated with high morbidity.[81] In cases of very small future remnant liver, a technique of major liver resection as the first step allows for a greater rate of hypertrophy of the remnant liver.[82]

SUGGESTED READING

Takasaki, K. Glissonean pedicle transection method for hepatic resection: a new concept of liver segmentation. *J. Hepatobiliary Pancreat. Surg.* **5**, 286–291 (1998).

This paper summarizes the hepatic segmentation and the method of hepatic resection based on the distribution of Glissonean pedicles. Each of the three hepatic segments is nourished by a secondary branch that can be isolated outside the liver during the so-called "Glissonean approach" for hepatic resections.

Abdalla, E. K., Noun, R. & Belghiti, J. Hepatic vascular occlusion: which technique? *Surg. Clin. North Am.* **84**, 563–585 (2004).

A review including the anatomic basis and methods for vascular occlusion, in addition to the indications, hemodynamic responses and limitations of different techniques.

Liddo, G. *et al.* The liver hanging manoeuvre. *HPB (Oxford).* **11**, 296–305 (2009).

The liver hanging maneuver was first described by Belghiti et al. in 2001 as a safe approach to anterior approach on right hepatectomy. Since this first report, the maneuver has been used for a variety of liver resections. This paper summarizes main technical aspects and applications of the hanging maneuver.

REFERENCES

1. Couinaud, C. Liver Anatomy: Portal (and Suprahepatic) or Biliary Segmentation. *Dig. Surg.* **16**, 459–467 (1999).
2. Goldsmith, N. A. & Woodburne, R. T. The surgical anatomy pertaining to liver resection. *Surg. Gynecol. Obstet.* **105**, 310–318 (1957).
3. Abdalla, E. K., Vauthey, J. N. & Couinaud, C. The caudate lobe of the liver: implications of embryology and anatomy for surgery. *Surg. Oncol. Clin. N. Am.* **11**, 835–848 (2002).
4. Takasaki, K. Glissonean pedicle transection method for hepatic resection: a new concept of liver segmentation. *J. Hepatobiliary Pancreat. Surg.* **5**, 286–291 (1998).
5. The_terminology_committee_of_the_IHPBA. The Brisbane 2000 terminology of hepatic anatomy and resections. *HPB* **2**, 333–339 (2000).
6. Reddy, S. K. *et al.* A standard definition of major hepatectomy: resection of four or more liver segments. *HPB (Oxford).* **13**, 494–502 (2011).
7. Squires, M. H. *et al.* Value of primary operative drain placement after major hepatectomy: a multi-institutional analysis of 1,041 patients. *J. Am. Coll. Surg.* **220**, 396-302 (2015).
8. Asahara, T. *et al.* Perioperative blood transfusion as a prognostic

indicator in patients with hepatocellular carcinoma. *World J. Surg.* **23**, 676–80 (1999).
9. Katz, S. C. *et al.* Operative blood loss independently predicts recurrence and survival after resection of hepatocellular carcinoma. *Ann. Surg.* **249**, 617–23 (2009).
10. Gurusamy, K. S., Sheth, H., Kumar, Y., Sharma, D. & Davidson, B. R. Methods of vascular occlusion for elective liver resections. *Cochrane database Syst. Rev.* CD007632 (2009).
11. Delva, E. *et al.* Vascular occlusions for liver resections. Operative management and tolerance to hepatic ischemia: 142 cases. *Ann. Surg.* **209**, 211–218 (1989).
12. Hannoun, L. *et al.* Liver resection with normothermic ischaemia exceeding 1 h. *Br. J. Surg.* **80**, 1161–1165 (1993).
13. Abdalla, E. K., Noun, R. & Belghiti, J. Hepatic vascular occlusion: which technique? *Surg. Clin. North Am.* **84**, 563–585 (2004).
14. Huguet, C. *et al.* Liver ischemia for hepatic resection: where is the limit? *Surgery* **111**, 251–259 (1992).
15. Midorikawa, Y. *et al.* A comparative study of postoperative complications after hepatectomy in patients with and without chronic liver disease. *Surgery* **126**, 484–491 (1999).
16. Pringle, J. H. V. Notes on the Arrest of Hepatic Hemorrhage Due to Trauma. *Ann. Surg.* **48**, 541–549 (1908).
17. Chouillard, E. K., Gumbs, A. a & Cherqui, D. Vascular clamping in liver surgery: physiology, indications and techniques. *Ann. Surg. Innov. Res.* **4**, 2 (2010).
18. Shimamura, Y. *et al.* Selective portal branch occlusion by balloon catheter during liver resection. *Surgery* **100**, 938–941 (1986).
19. Ou, J. R., Chen, W. & Lau, W. Y. A new technique of hepatic segmentectomy by selective portal venous occlusion using a balloon catheter through a branch of the superior mesenteric vein. *World J. Surg.* **31**, 1240–1242 (2007).
20. Torzilli, G. *et al.* Anatomical segmental and subsegmental resection of the liver for hepatocellular carcinoma: a new approach by means of ultrasound-guided vessel compression. *Ann. Surg.* **251**, 229–235 (2010).
21. Torzilli, G. *et al.* Total or partial anatomical resection of segment 8 using the ultrasound-guided finger compression technique. *HPB (Oxford).* **13**, 586–591 (2011).
22. Makuuchi, M., Hasegawa, H. & Yamazaki, S. Intraoperative ultrasonic examination for hepatectomy. *Ultrasound Med. Biol.* **Suppl 2**, 493–497 (1983).
23. Launois, B. & Jamieson, G. G. The importance of Glisson's capsule and its sheaths in the intrahepatic approach to resection of the liver. *Surg. Gynecol. Obstet.* **174**, 7–10 (1992).
24. Yamamoto, M., Katagiri, S., Ariizumi, S., Kotera, Y. & Takahashi, Y. Glissonean pedicle transection method for liver surgery (with video). *J. Hepatobiliary Pancreat. Sci.* **19**, 3–8 (2012).
25. Machado, M. A. *et al.* Laparoscopic resection of left liver segments using the intrahepatic Glissonian approach. *Surg. Endosc.* **23**, 2615–2619 (2009).
26. Cho, A. *et al.* Arantius' ligament approach for the left extrahepatic Glissonean pedicle in pure laparoscopic left hemihepatectomy. *Asian J. Endosc. Surg.* **5**, 187–90 (2012).
27. Otsubo, T. *et al.* Bleeding during hepatectomy can be reduced by clamping the inferior vena cava below the liver. *Surgery* **135**, 67–73 (2004).
28. Scalzone, R., Lopez-Ben, S. & Figueras, J. How to transect the liver? A history lasting more than a century. *Dig. Surg.* **29**, 30–34 (2012).
29. Aloia, T. A., Zorzi, D., Abdalla, E. K. & Vauthey, J. N. Two-surgeon technique for hepatic parenchymal transection of the noncirrhotic liver using saline-linked cautery and ultrasonic dissection. *Ann. Surg.* **242**, 172–177 (2005).
30. Lesurtel, M., Selzner, M., Petrowsky, H., McCormack, L. & Clavien, P. A. How should transection of the liver be performed?: a prospective randomized study in 100 consecutive patients: comparing four different transection strategies. *Ann. Surg.* **242**, 814–22 (2005).
31. Paquet, J. C. *et al.* Prevention of deep abdominal complications with omentoplasty on the raw surface after hepatic resection. The French Associations for Surgical Research. *Am. J. Surg.* **179**, 103–109 (2000).
32. Baik, S. H. *et al.* Development and analysis of a collagen-based hemostatic adhesive. *J Surg. Res.* **164**, e221–228 (2010).
33. Kohno, H. *et al.* Comparison of topical hemostatic agents in elective hepatic resection: a clinical prospective randomized trial. *World J. Surg.* **16**, 966–969 (1992).
34. Frilling, A. *et al.* Effectiveness of a new carrier-bound fibrin sealant versus argon beamer as haemostatic agent during liver resection: a randomised prospective trial. *Langenbecks Arch. Surg.* **390**, 114–120 (2005).
35. Fischer, L. *et al.* Hemostatic efficacy of TachoSil in liver resection compared with argon beam coagulator treatment: an open, randomized, prospective, multicenter, parallel-group trial. *Surgery* **149**, 48–55 (2011).
36. Figueras, J. *et al.* Application of fibrin glue sealant after hepatectomy does not seem justified: results of a randomized study in 300 patients. *Ann. Surg.* **245**, 536–542 (2007).
37. Briceno, J. *et al.* A prospective study of the efficacy of clinical application of a new carrier-bound fibrin sealant after liver resection. *Arch. Surg.* **145**, 482–488 (2010).
38. Achneck, H. E. *et al.* A comprehensive review of topical hemostatic agents: efficacy and recommendations for use. *Ann. Surg.* **251**, 217–228 (2010).
39. Toti, L. *et al.* Reduction in bile leaks following adult split liver transplant using a fibrin-collagen sponge: A pilot study. *Dig. Liver Dis.* **42**, 205–209 (2010).
40. Hayashibe, A., Sakamoto, K., Shinbo, M., Makimoto, S. & Nakamoto, T. New method for prevention of bile leakage after hepatic resection. *J. Surg. Oncol.* **94**, 57–60 (2006).
41. Liu, C. L. *et al.* Anterior approach versus conventional approach right hepatic resection for large hepatocellular carcinoma: a prospective randomized controlled study. *Ann. Surg.* **244**, 194–203 (2006).
42. Liu, C. L., Fan, S. T., Lo, C. M., Tung-Ping Poon, R. & Wong, J. Anterior approach for major right hepatic resection for large hepatocellular carcinoma. *Ann. Surg.* **232**, 25–31 (2000).
43. Liddo, G. *et al.* The liver hanging manoeuvre. *HPB (Oxford).* **11**, 296–305 (2009).
44. Belghiti, J., Guevara, O. A., Noun, R. & Saldinger, P. F. Liver hanging maneuver : a safe approach to right hepatectomy without liver mobilization. J. Am. Coll. Surg. **7515**, 109–111 (2001).
45. Kokudo, N. *et al.* Ultrasonically Assisted Retrohepatic Dissection for a Liver Hanging Maneuver. *Ann. Surg.* **242**, 651–654 (2005).
46. Lai, P. B. *et al.* Safe modification of the liver-hanging maneuver by endoscopic-assisted dissection of the retrohepatic tunnel. *Surg. Today* **37**, 915–917 (2007).
47. Ogata, S. *et al.* Two hundred liver hanging maneuvers for major hepatectomy: a single-center experience. *Ann. Surg.* **245**, 31–35 (2007).
48. Ettorre, G. M. *et al.* Modified liver hanging maneuver during orthotopic liver transplantation with inferior vena cava preservation: results after 120 consecutive applications. *Transpl. Proc* **39**, 1881–1882 (2007).
49. Huguet, C., Nordlinger, B., Galopin, J. J., Bloch, P. & Gallot, D. Normothermic hepatic vascular exclusion for extensive hepatectomy. *Surg. Gynecol. Obstet.* **147**, 689–93 (1978).
50. Imakita, M., Yamanaka, N., Kuroda, N., Kitayama, Y. & Okamoto, E. Does topical cooling alleviate ischemia/reperfusion injury during inflow occlusion in hepatectomy? Results of an experimental and clinical study. *Surg. Today* **30**, 795–804 (2000).
51. Yamanaka, N., Dai, C. L. & Okamoto, E. Historical evolution of hypothermic liver surgery. *World J. Surg.* **22**, 1104–7 (1998).
52. Kim, Y.-I. *et al.* 101 hepatectomies under continuous inflow occlusion following simple in-situ liver cooling in patients with chronic liver diseases. *Hepatogastroenterology.* **51**, 1093–1098
53. Azoulay, D. *et al.* In situ hypothermic perfusion of the liver versus standard total vascular exclusion for complex liver resection. *Ann. Surg.* **241**, 277–285 (2005).

54. Hoti, E., Salloum, C. & Azoulay, D. Hepatic Resection with in situ Hypothermic Perfusion Is Superior to Other Resection Techniques. *Dig. Surg.* **28**, 94–99 (2011).
55. Varma, D., Ogata, S. & Belghiti, J. Isolated total caval clamping with "preserved remnant liver perfusion" for combined hepatic and venacaval resection in tumors involving venacava. *Surgery* **141**, 112–116 (2007).
56. Mizuno, S. *et al.* Total vascular hepatic exclusion for tumor resection: a new approach to the intrathoracic inferior vena cava through the abdominal cavity by cutting the diaphragm vertically without cutting the pericardium. *J. Hepatobiliary Pancreat. Sci.* **17**, 197–202 (2010).
57. Dubay, D. *et al.* In situ hypothermic liver preservation during radical liver resection with major vascular reconstruction. *Br. J. Surg.* **96**, 1429–1436 (2009).
58. Hannoun, L. *et al.* Ex-situ in-vivo liver surgery. *Lancet* **337**, 1616–1617 (1991).
59. Yamamoto, Y. Ante-situm hepatic resection for tumors involving the confluence of hepatic veins and IVC. *J. Hepatobiliary Pancreat. Sci.* **20**, 313–323 (2013).
60. Mehrabi, A. *et al.* Hypothermic ante situm resection in tumors of the hepatocaval confluence. *Dig. Surg.* **28**, 100–108 (2011).
61. Pichlmayr, R. *et al.* Technique and preliminary results of extracorporeal liver surgery (bench procedure) and of surgery on the in situ perfused liver. *Br. J. Surg.* **77**, 21–26 (1990).
62. Agrawal, S. & Belghiti, J. Oncologic resection for malignant tumors of the liver. *Ann. Surg.* **253**, 656–665 (2011).
63. Ercolani, G. *et al.* The role of lymphadenectomy for liver tumors: further considerations on the appropriateness of treatment strategy. *Ann. Surg.* **239**, 202–209 (2004).
64. Jaeck, D. *et al.* Significance of hepatic pedicle lymph node involvement in patients with colorectal liver metastases: a prospective study. *Ann. Surg. Oncol* **9**, 430–438 (2002).
65. Kitagawa, Y. *et al.* Lymph node metastasis from hilar cholangiocarcinoma: audit of 110 patients who underwent regional and paraaortic node dissection. *Ann. Surg.* **233**, 385–392 (2001).
66. Bennett, J. J. *et al.* Perihepatic lymph node micrometastases impact outcome after partial hepatectomy for colorectal metastases. *Ann. Surg. Oncol.* **15**, 1130–1136 (2008).
67. Hemming, A. W., Mekeel, K., Khanna, A., Baquerizo, A. & Kim, R. D. Portal vein resection in management of hilar cholangiocarcinoma. *J. Am. Coll. Surg.* **212**, 604–13 (2011).
68. Hemming, A. W. *et al.* Resection of the liver and inferior vena cava for hepatic malignancy. *J. Am. Coll. Surg.* **217**, 115–24 (2013).
69. Oldhafer, K. J. *et al.* Long-term experience after ex situ liver surgery. *Surgery* **127**, 520–527 (2000).
70. Lodge, J. P., Ammori, B. J., Prasad, K. R. & Bellamy, M. C. Ex vivo and in situ resection of inferior vena cava with hepatectomy for colorectal metastases. *Ann. Surg.* **231**, 471–479 (2000).
71. Madariaga, J. R., Fung, J., Gutierrez, J., Bueno, J. & Iwatsuki, S. Liver resection combined with excision of vena cava. *J. Am. Coll. Surg.* **191**, 244–250 (2000).
72. Sarmiento, J. M., Bower, T. C., Cherry, K. J., Farnell, M. B. & Nagorney, D. M. Is combined partial hepatectomy with segmental resection of inferior vena cava justified for malignancy? *Arch. Surg.* **138**, 624–630 (2003).
73. Nuzzo, G. *et al.* Complex liver resection for hepatic tumours involving the inferior vena cava. *Eur. J. Surg. Oncol.* **37**, 921–927 (2011).
74. Malde, D. J., Khan, A., Prasad, K. R., Toogood, G. J. & Lodge, J. P. A. Inferior vena cava resection with hepatectomy: Challenging but justified. *HPB* **13**, 802–810 (2011).
75. Wu, C. C. *et al.* An appraisal of liver and portal vein resection for hepatocellular carcinoma with tumor thrombi extending to portal bifurcation. *Arch. Surg.* **135**, 1273–1279 (2000).
76. Ebata, T. *et al.* Hepatectomy with portal vein resection for hilar cholangiocarcinoma: audit of 52 consecutive cases. *Ann. Surg.* **238**, 720–727 (2003).
77. Kondo, S. *et al.* Portal vein resection and reconstruction prior to hepatic dissection during right hepatectomy and caudate lobectomy for hepatobiliary cancer. *Br. J. Surg.* **90**, 694–697 (2003).
78. Petrowsky, H. *et al.* A prospective, randomized, controlled trial comparing intermittent portal triad clamping versus ischemic preconditioning with continuous clamping for major liver resection. *Ann. Surg.* **244**, 921–928 (2006).
79. Montalvo-Jave, E. E. *et al.* Role of ischemic preconditioning in liver surgery and hepatic transplantation. *J. Gastrointest. Surg.* **13**, 2074–2083 (2009).
80. O'Neill, S. *et al.* Meta-analysis of ischaemic preconditioning for liver resections. *Br. J. Surg.* **100**, 1689–700 (2013).
81. Alvarez, F. A, Ardiles, V., Sanchez Claria, R., Pekolj, J. & de Santibañes, E. Associating liver partition and portal vein ligation for staged hepatectomy (ALPPS): tips and tricks. *J. Gastrointest. Surg.* **17**, 814–821 (2013).
82. Balzan, S. M. P., Gava, V. G., Magalhaes, M. a & Dotto, M. L. Outflow modulation to target liver regeneration: something old, something new. *Eur. J. Surg. Oncol.* **40**, 140–143 (2014).
83. Takasaki, K. *Glissonean pedicle transection method for hepatic resection*. (Springer, Tokyo, Japan, 2007).