12 Vascular Control in Major Hepatic Resections

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Introduction

After the first major hepatic resection, a left hepatic resection, carried out in 1888 by Carl Langenbuch [1], it took another 20 years before the first right hepatectomy was described by Walter Wendel in 1911 [2]. Three years before, in 1908, Hogarth Pringle provided the first description of a technique of vascular control, the portal triad clamping, nowadays known as the Pringle maneuver [3]. Liver surgery has progressed rapidly since then. Modern surgical concepts and techniques, together with advances in anesthesiological care, intensive care medicine, perioperative imaging, and interventional radiology, together with multimodal oncological concepts, have resulted in fundamental changes. Perioperative outcome has improved significantly, and even major hepatic resections can be performed with morbidity and mortality rates of less than 45% and 4% respectively in high-volume liver surgery centers [4]. Many liver surgeries performed routinely in specialized centers today were considered to be high-risk or non-resectable by most surgeons less than 1–2 decades ago.

Interestingly, operative blood loss remains the most important predictor of postoperative morbidity and mortality, and therefore vascular control remains one of the most important aspects in liver surgery [3, 4]. Bleeding control is achieved by vascular control and optimized and careful parenchymal transection during liver surgery, and these two concepts are cross-linked.

In this chapter, the standard and advanced techniques of vascular control will be described in detail—with main focus on colorectal cancer liver metastases surgery.

Anatomical Fundaments for Vascular Control in Liver Surgery

Thorough knowledge of liver anatomy is the basis of liver surgery. Vascular anatomy of the liver can be explained according to the conventional eight-segments scheme of Couinaud, which is an idealized scheme [5, 6]. The Couinaud scheme is ideally used as a common language to describe the location of lesions, and is based on the localization of the three hepatic veins and the level of the portal bifurcation. The branching of the portal vein defines a right and a left liver, and the three hepatic veins interdigitate with the two portal branches. In reality, liver vascular anatomy

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is much more complex than this idealized scheme. Modern liver surgeons need to be familiar with all anatomical details and variants, in order to perform complex hepatic resections. On the surgical level, understanding of the real branching of the hepatic vessels is necessary—which does not necessarily need to correspond to the theoretical or schematic segmentation [7]. Anatomical orientation in liver surgery is of major importance, as vascular control (resection of selectively devascularized parenchyma) and biliary control (bile ducts run as parts of the portal pedicle) help not only to avoid intraoperative blood loss, but also to avoid postoperative complications (bile leakage, hemorrhage, and infections) [7–9]. In addition, understanding the segmental anatomy is necessary for parenchymal sparing resections, which is especially important in colorectal liver metastases surgery. In many of these patients, two-stage or repeat surgeries take place, and due to chemotherapy-associated liver damage they often suffer from impaired hepatic function, which makes parenchymal sparing resections even more important [10–14].

Inflow–Outflow–Parenchyma

Each major liver resection needs to be planned according to the concept of inflow and outflow vascular control and residual parenchyma. Depending on the localization of the lesion, inflow (hepatic arteries, portal veins, bile ducts) and outflow control (hepatic veins) can be easily achieved, or in more complex cases only be obtained by total hepatic vascular exclusion in combination with ante-situm or ex-situ resection techniques [15]. Certain surgical techniques, such as the maneuver of the lowering of the hilar plate [16] for pedicle (inflow) control, or the Arantius' ligament approach [17] for outflow control of the left hepatic vein, are fundamentals of liver resection techniques. The remaining parenchyma, the so-called future liver remnant, needs to be large enough in size and functional capacity in order to avoid postoperative liver failure. Potential ischemic and ischemia reperfusion damage needs to be taken into account if extended hepatic resections are planned [8]. Parenchymal dissection should be adjusted to the underlying disease and localization of resection, and is also discussed elsewhere in this book [18, 19].

Following, the main strategies according to the inflow–outflow–parenchyma regime are listed:

- Anatomy-related segmental resections and selective vascular control/devascularization of resected areas before parenchymal transection.
- Parenchymal transection phase under low central venous pressure.
- Temporary inflow- and/or combined inflow- and outflow occlusion during the transection phase.

Types of Vascular Control

Occlusion of vascular inflow and/or outflow only makes sense during the actual phase of parenchymal transection. Vascular clamping is generally not used during the phase of mobilization of the liver. The methods of vascular control are summarized in Table 12.1. To minimize excessive blood loss during liver resections, various techniques of vascular control have been developed since the first description of a non-selective inflow occlusion by Pringle in 1908 [3]. Vascular control can be achieved by either inflow- or combined inflow- and outflow control. Both techniques can be either selective or non-selective. Inflow control can be combined and/or performed continuously or in an intermittent fashion, and all techniques of vascular control can be combined with ischemic pre-conditioning of the liver. Hepatic vascular occlusion can also be combined with cold-perfusion techniques and/or ex-situ or ante-situm resection techniques, especially for demanding central resections with involvement of the vena cava and/or hepatic veins. Various review articles and meta-analyses have analyzed the methods of vascular control/occlusion in detail, and randomized-controlled trials investigating the pros and cons of these techniques will be discussed in the next sections [20–24].

Table 12.1 Methods of vascular control in hepatic resections

Inflow control		In- and outflow control	
Non-selective	Selective	Non selective	Selective
Hepatic pedicle occlusion (Pringle maneuver)	Hemihepatic (right or left; hemi-Pringle) or segmental vascular occlusion	Total hepatic vascular exclusion	Selective hepatic vascular occlusion
–Continuous or intermittent			
–With or without ischemic preconditioning			

Portal Triad Clamping

The non-selective inflow occlusion via pedicle clamping is the classical form of vascular control during hepatic resections. The Pringle maneuver is the oldest form of vascular control [3] and also the fastest and easiest to perform, if immediate control of parenchymal bleeding is necessary. The hepatoduodenal ligament is freed from adhesions, in order to avoid injury to the inferior vena cava (IVC) or the duodenum when placing a vascular clamp. Afterwards, the hepatoduodenal ligament is encircled as a whole and a strong vessel loop is placed as a tourniquet, which is kept in place and can be closed permanently or intermittently during phases of parenchymal dissection. The tourniquet (or a vascular clamp) is tightened up to the point where the distal pulse of the hepatic artery disappears. If an aberrant left hepatic artery originates from the gastric artery, it will not be occluded by the pedicle clamping and needs to be occluded separately, if necessary. Pedicle clamping results in a modest cardiac index decrease (due to decreased venous return) and an increase in systemic vascular resistance and mean arterial pressure. In general, the Pringle maneuver is well tolerated, as caval flow is not impaired. After the lowering of the hilar plate maneuver, the pedicle clamping can also be performed separately for the left and right pedicle (Fig. 12.1) and also selectively for the right anterior or posterior pedicle (Fig. 12.2). The Pringle maneuver can be used continuously or intermittently, and also after a short phase of ischemic pre-conditioning to the liver. Numerous randomized controlled trials and meta-analyses have looked at the outcome and best implementation of the Pringle maneuver [25–27]. A recent meta-analysis including eight randomized controlled trials has investigated overall morbidity and mortality, cardiopulmonary and hepatic morbidity, blood loss, transfusion rates, and alanine aminotransferase (ALT) levels in patients undergoing liver resections with or without portal triad clamping. No differences between intermittent portal triad clamping and no

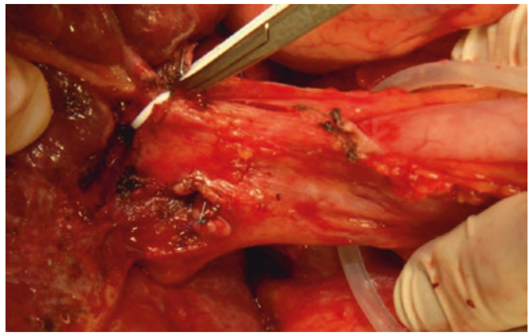

Fig. 12.1 Pringle maneuver. Shown in the figure is a selective Pringle maneuver of the left liver. The transparent loop encircles the portal triad, the white vessel loop is used for a selective left sided hemi-Pringle maneuver

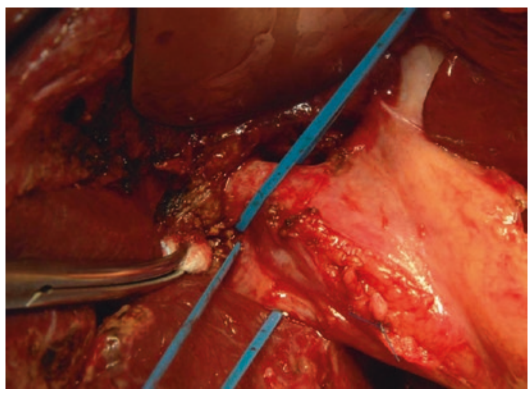

Fig. 12.2 Selective clamping of the right anterior and posterior pedicle. The two blue vessel loops encircle the right anterior and posterior pedicle respectively, and can both be selectively used for clamping and bleeding control

clamping were found with regard to all endpoints. In accordance with these findings, an analysis of patients receiving continuous portal triad clamping with- or without ischemic preconditioning did not reveal any differences with respect to the above mentioned endpoints, except for ALT levels, which were lower in the ischemic preconditioning group [26]. As a conclusion from these analyses, routine use of portal triad clamping cannot be recommended, as it does not alter the intraoperative blood loss or outcome (morbidity and mortality) after liver surgery. Nonetheless, it has its place in liver surgery for individual select cases and/or resection techniques. For example, routine use of the Pringle maneuver can be beneficial during parenchymal resection, using a stapler device, as mean resection time is less than 10 min. No ischemic injury to the liver will occur during this short time, and blood loss can be decreased [19]. With regard to clamping time, it appears safe to use total clamping times of up to 60–90 min, whereas intermittent reperfusion is probably helpful in avoiding ischemic reperfusion injury, at least for a clamping time of more than 20 min: An intermittent portal triad clamping of up to 60 min is probably also safe in patients with compensated cirrhosis, although cirrhosis is known to increase the sensitivity for ischemia reperfusion injury [28–33].

Total- and Selective Hepatic Vascular Exclusion

Total- and selective hepatic vascular exclusion should not be routinely recommended for liver resection procedures. Recent meta-analyses have shown no benefit of hepatic vascular exclusion for perioperative outcome in liver resections [26, 27]. In addition to liver inflow control using portal triad clamping, hepatic vascular exclusion has been proposed to further decrease hemorrhage in major hepatic resections originating from the hepatic veins. Total vascular occlusion for liver surgery combines portal triad clamping with supra- and infrahepatic clamping of the IVC. Selective vascular occlusion is a combination of portal triad clamping with selective hepatic venous clamping, which preserves caval flow and causes less hemodynamic instability. A recent meta-analysis including four randomized controlled trials has compared total- and selective hepatic vascular occlusion with conventional portal triad clamping for liver resections. No differences with regard to outcome, defined as morbidity and mortality, were observed between the portal triad clamping group and hepatic vascular occlusion. However, total hepatic vascular occlusion increased morbidity compared to portal triad clamping alone. Significant differences in reported blood loss were not observed, either [27]. In summary, hepatic vascular occlusion achieved by the above mentioned techniques should be reserved for extended central resections, such as resections involving the vena cava and/or main hepatic veins.

Selective or Total Hepatic Vascular Exclusion Combined with Cold Perfusion

Hypothermic ante-situm or ex-situ resections with total vascular exclusion can be the only possible options to resect central liver lesions with caval involvement [15]. Infiltration of the hepatocaval confluence has been considered a contraindication for liver resections, as achieving tumor-free margins in this area was regarded as technically impossible (Fig. 12.3a, b). However, several techniques, including ante-situm and ex-situ resection techniques, have been introduced to overcome this technical problem, and are discussed in detail elsewhere in this book. These techniques use a total vascular exclusion of the liver, combined with cold perfusion with organ preservation fluid, similar to the back-table preparation of liver transplantation as a common concept [15, 34, 35]. The hypothermic methods allow safer time frames for resection and better access, in comparison to total vascular occlusion without cold-perfusion resulting in warm ischemia and ischemia reperfusion injury, which is not well tolerated by the liver if it exceeds 60 min [36–39]. In general, these types of surgeries should only be

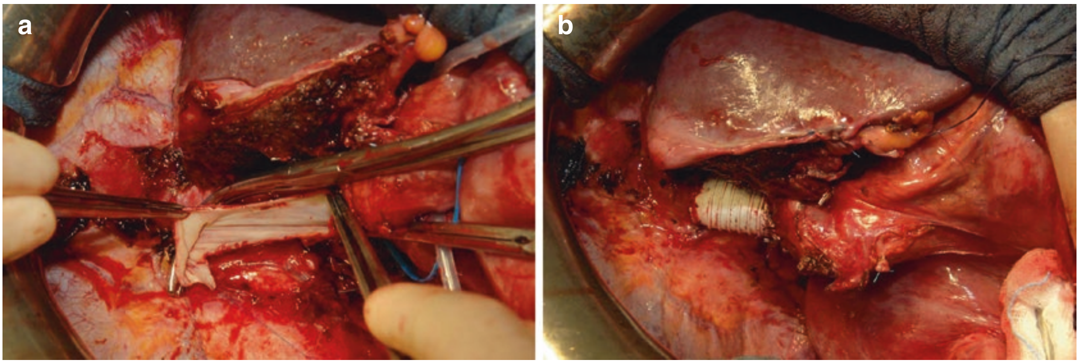

Fig. 12.3 Exclusion of the inferior vena cava. The inferior V. cava is clamped for resection of a central liver metastasis (**a**), and caval flow is reestablished using the implantation of a vascular prosthesis (**b**)

performed in experienced high-volume centers and for selected patients, as reported morbidity is high, with mortality rates reported between 9 and 33%, especially for ex-situ resections [15, 37]. It is noteworthy that 5-year survival rates after extended liver resections including caval resections have been reported as high as 33% [37, 40].

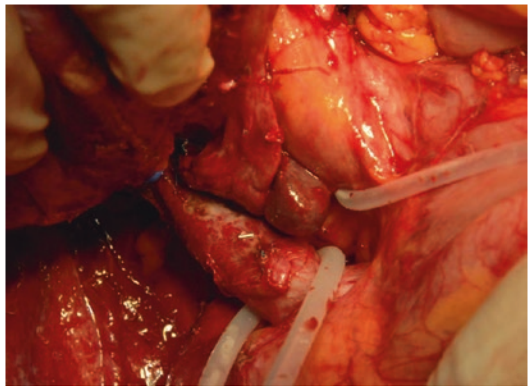

Fig. 12.4 Clamping of the inferior vena cava. Shown is the infrahepatic inferior vena cava which is encircled with a *blue and transparent* vessel loop and can be clamped in order to reduce central venous pressure. Also, the portal triad is encircled with a transparent loop in the same picture

Infrahepatic Inferior Vena Cava Clamping

Bleeding from the hepatic venous system and the sinusoids during parenchymal dissection is directly related to the pressure within the sinusoids in the liver parenchyma. This pressure is directly related to the hepatic venous pressure, which in turn is dependent on the central venous pressure. While clamping the hepatic pedicle for bleeding control during parenchymal transection (Pringle maneuver), bleeding from the sinusoidal system will persist, as the hepatic venous system remains open and patent. A low central venous pressure (CVP) during parenchymal transection phase will result in a low hepatic venous pressure and subsequently less intraoperative bleeding. Achieving a low central venous pressure is not always possible by anesthesiological interventions (fluid restriction, reverse Trendelenburg position, etc.; also see next paragraph), and thus clamping of the IVC has been suggested and evaluated as an alternative approach to reduce hepatic venous pressure and intraoperative bleeding during parenchymal transection (Fig. 12.4). A recent randomized controlled trial has evaluated the effectiveness and safety of IVC clamping for reduction of central venous pressure and bleeding control during elective hepatic resections. Patients were compared to the standard regime for lowering the CVP, namely anesthesiological means such as fluid restriction. IVC clamping resulted in reduced total intraoperative blood loss, mainly because it significantly lowered the blood loss during the parenchymal transection phase [41].

Mortality and morbidity rates were similar compared to the control group, while there was a significantly increased risk of pulmonary air embolism in the IVC clamping group. Due to hemodynamic instability, IVC clamping, as well as lowering the CVP with anesthesiological means, such as fluid restriction and/or reverse Trendelenburg position, is not possible in 10–20% of the patients [24, 41]. Close monitoring and interaction with the anesthesiological team is mandatory for both techniques.

Anesthesiological- and Pharmacological Interventions

The group of Jones et al. has shown that a central venous pressure of less than 5 cm H_2O during liver transection results in a significantly decreased blood loss and transfusion requirement in liver surgery [42]. Certain non-invasive techniques, such as peri- and intraoperative fluid restriction, can lower the CVP during elective liver surgery. CVP lowering increases the risk for air emboli, and experienced anesthesiological care is necessary in order to maintain the central venous pressure between 2 and 5 cm H_2O during the critical surgical phase. Additional options of lowering the central venous pressure, such as IVC clamping or table positioning (reverse Trendelenburg position), can be used and are discussed above [41].

Further anesthesiological and pharmacological methods to decrease the intraoperative blood loss have been evaluated intensely, such as preoperative haemodilution, autologous blood donation, and transfusion and the use of several drugs or anesthesiological regimes (volatile narcotics) in order to prevent ischemia reperfusion injury [22, 43–45]. At this point of time, these methods/techniques are clinically not important. Further trials are necessary for evaluation of these interventions, as there is no current evidence strong enough to support the routine use of any pharmacological or peri-operative intervention in order to reduce intraoperative blood loss during liver surgery.

Laparoscopic Surgery

In theory, most techniques of vascular control can technically be achieved using minimally invasive surgery. Currently, open surgery is considered to be the safest choice for major hepatic and extended resections. The general advantages of laparoscopic surgery have been widely evaluated in the past. These include smaller incisions, faster recovery, less pain, shorter in-hospital stay, less postoperative hernia, less wound infections, and less intraoperative blood loss (due to intra-abdominal pressure and higher magnification) [46–49]. Recently, the second international consensus conference for laparoscopic liver surgery has defined laparoscopic liver resections for minor resections as standard of care, while major laparoscopic liver resections were regarded as innovative procedures, which are still in the experimental phase [50]. Therefore, these procedures should only be performed at high-volume, specialized liver surgery centers, ideally as part of clinical trials.

Conclusion/Summary

- Intraoperative blood loss is one of the single-most important factors related to postoperative morbidity and mortality in liver surgery and should be minimized.
- Improved resection techniques and improved understanding of surgical liver anatomy have led to decreased blood loss during parenchymal resection in recent years.
- Using techniques of vascular clamping cannot be routinely recommended for every liver resection, as no changes in postoperative outcome are observed.
- In major hepatic resection, vascular control is often necessary, and appropriate techniques have to be used as required.
- Liver surgeons need to be competent in all techniques of vascular control.
- Techniques of vascular control can include the inflow or inflow- and outflow, and can be selective or non-selective (Table 12.1).

- Complex liver resections including the hepatocaval confluence may only be possible in combination of total hepatic vascular exclusion with cold perfusion of the liver (ex-situ or ante-situm resections).
- Pharmacological interventions to reduce intraoperative blood loss have not been proven to be effective so far.

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