Hepatic vascular occlusion: which technique?

Eddie K. Abdalla, MD, Roger Noun, MD, Jacques Belghiti, MD

At the beginning of the twentieth century, J.H. Pringle demonstrated that inflow vascular occlusion could reduce liver bleeding [1]. The principle of extrahepatic exposure and control of the inflow and outflow vascular pedicles of the liver was realized in the 1950s, when Jean-Louis Lortat-Jacob reported the first major anatomical liver resection (and extended right hepatectomy) [2]. His observation that vascular control could enable major hepatic resection without excessive blood loss predated the progressive decrease in morbidity and mortality of liver resection over the past 50 years, which has largely been realized as a result of lower blood loss at surgery [3–5]. Although some liver resections today may be safely and routinely performed without vascular clamping, resection with minimal blood loss remains an important concern in hepato-biliary surgery. Thus, despite a period of routine vascular clamping during major hepatic resection, with simultaneous decrease in the morbidity and mortality of surgery, techniques of parenchymal transection improved, and concern arose that ischemia followed by reperfusion associated with vascular clamping could cause injury to the liver parenchyma (particularly in patients with underlying acute or chronic liver disease [6]). The advent of living donation for transplantation revitalized this concern, as it was believed that grafts resected from living donors for transplantation could be harvested without
theoretical negative effects of ischemia induced by hepatic pedicle clamping. Whether there was a true movement away from vascular clamping in major hepatic surgery centers or not cannot be known, and a proportion of major resections for liver tumors in difficult locations require vascular control to enable safe resection. A movement back toward clamping may have been heralded by more recent studies suggesting that a period of ischemia followed by reperfusion to the liver, or “ischemic preconditioning,” might actually improve the tolerance to cold ischemia necessary for liver transplantation [7,8–11]. Certainly, a range of clamping techniques, from hepatic pedicle clamping (Pringle’s maneuver), to segmental vascular occlusion, and from hemi-hepatic clamping to total vascular exclusion, might be included in the hepatic surgeon’s armamentarium in order to facilitate an aggressive but safe approach to hepatic resection. Each technique has a place in liver surgery, each has different systemic and hepatic impact, and some techniques, particularly total hepatic vascular exclusion, can be associated with hemodynamic changes that are not tolerated in some patients [12,13]. A vascular occlusion technique should be selected according to the reason for resection (donor versus tumor surgery), the tumor location, the presence of associated underlying liver disease, the patient’s cardiovascular status, and the experience of the operator. Finally, dissection in preparation for vascular exclusion might be used as a safe “approach technique,” even when eventual clamping is not performed. Standard and newer vascular clamping techniques used in hepatic surgery are presented here, with analysis of advantages, hemodynamic consequences, and indications for each technique. The rationale behind the movement away from and back toward vascular clamping is explored.

**Anatomic basis for vascular control**

The liver receives a dual vascular inflow, providing approximately one quarter of the total cardiac output, or a blood flow of 1500 mL/minute. The portal vein provides 75% of the total hepatic blood flow, and the hepatic artery the remaining 25%. The portal vein originates behind the neck of the pancreas as the confluence of the superior mesenteric and splenic veins, and courses posterior to the bile duct and hepatic artery in the free edge of the lesser omentum. At the hilum of the liver, the vein divides into a shorter, more vertically oriented right branch and a longer, horizontally oriented left branch. The right portal branch may be absent when the right anterior and posterior sectorial veins originate directly from the trunk of the portal vein. Thus the right portal branch can be more difficult to dissect and control than the left portal branch.

The hepatic artery is highly variable, but most commonly arises as a branch of the celiac axis, and enters the hepatoduodenal ligament after providing the right gastric and gastroduodenal arteries; the right and left
branches usually lie on a plane posterior to the bile ducts at the hilum of the liver. In fact, this classical branching pattern is found in only 50% of patients. The accessory or replaced arteries pertinent to vascular clamping include a left artery, which can arise from the left gastric artery, and a right artery, which can arise from the superior mesenteric artery.

Three large hepatic veins lie postero-superior to the liver, just below the diaphragm. In about 20% of cases, a significant right inferior hepatic vein is present. In all cases, a number of small veins drain the posterior sector of the right lobe and the caudate lobe directly into the inferior vena cava (IVC). There are several intrahepatic interconnections (Fig. 1) between each hepatic veins, which can have a significant impact on the performance of and tolerance to each method of clamping.

**Inflow vascular control**

**Hepatic pedicle clamping**

J.H. Pringle realized the value of inflow vascular occlusion to the liver to control bleeding [1]. Now a standard in hepatic surgery, hepatic pedicle clamping (Pringle’s maneuver) interrupts the arterial and portal venous inflow to the liver, but has no direct effect on backflow bleeding from branches of the hepatic veins.

![Fig. 1. Collaterals between hepatic venous territories: (a) between the right and middle hepatic veins; (b) between the right and the inferior hepatic veins; (c) between the right posterior sector of the liver (segments VI and VII) and the caudate veins; (d) between the left liver and the caudate veins.](image-url)
**Technique**

The hepatoduodenal ligament is encircled with a tape and a tourniquet, or a vascular clamp is applied, until the pulse in the hepatic artery disappears distally (Fig. 2). A left hepatic artery originating from the left gastric artery should be occluded if present, and lysis of adhesions in the porta hepatis related to prior surgery should be liberated to avoid injury to the duodenum or IVC, and to ensure adequate inflow vascular control. Either continuous or intermittent clamping can be performed as described below.

**Hemodynamics and limitations**

After pedicular clamping, the decrease in cardiac preload (decrease in pulmonary artery pressure of 5% on average) results in a 10% decrease in cardiac index, but the reflex produced by clamping increases systemic vascular resistance to generate a 10% increase in mean arterial pressure [13]. Pedicle clamping is extremely well-tolerated because caval flow is not interrupted [14]; thus no specific anesthetic management is required, except for continuous monitoring of arterial blood pressure. Unclamping of the hepatic pedicle is associated with a decrease in blood pressure due to the deactivation of the reflex produced by clamping, as well as by ischemia-reperfusion effects [15]. Usually, blood pressure decreases for a few minutes, then returns toward control values (Table 1).

Splanchnic congestion from portal clamping tends to be mild, especially with intermittent clamping. Hyperamylasemia after hepatic resection, at one
Table 1
Comparison of vascular clamping techniques, hemodynamic effects, and limits of clamping duration

<table>
<thead>
<tr>
<th>Clamping technique</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Hemodynamic effects</th>
<th>Clamping duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hepatic pedicle clamping</td>
<td>Continuous Uninterrupted parenchymal transection</td>
<td>Venous backflow bleeding, limited duration</td>
<td>Absent</td>
<td>60 min</td>
</tr>
<tr>
<td></td>
<td>Intermittenta Enables complex resection with prolonged period</td>
<td>Bleeding of venous backflow, transection plane during unclamping</td>
<td>Absent</td>
<td>120 min</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;60 min</td>
</tr>
<tr>
<td>Hemihepatic clamping</td>
<td>Continuous or intermittent Absence of ischemia to remnant liver</td>
<td>Extensive dissection, bleeding from nonocluded hemiliver</td>
<td>Absent</td>
<td>&gt;120 min</td>
</tr>
<tr>
<td>Conventional HVE</td>
<td>Continuous Resection of tumors at hepatic vein confluence with vena cava,</td>
<td>Extensive dissection, fluid loading, not tolerated in 10–15% of patients, increase of pulmonary complications</td>
<td>Present</td>
<td>60 min</td>
</tr>
<tr>
<td></td>
<td>elimates risk for air embolism</td>
<td></td>
<td></td>
<td>&lt;30 min</td>
</tr>
<tr>
<td>HVE with preservation of caval flow</td>
<td>Continuous Eliminates risk for venous embolism or backflow bleeding with minimal hemodynamic consequences</td>
<td>Extensive and complex dissection</td>
<td>Absent</td>
<td>60 min</td>
</tr>
<tr>
<td>Intrahepatic IVC clamping</td>
<td>Intermittent E</td>
<td></td>
<td></td>
<td>&gt;60 min</td>
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<td></td>
<td>Continuous or intermittent Lowers CVP</td>
<td></td>
<td></td>
<td>&lt;60 min</td>
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Abbreviations: HVE, hepatic vascular exclusion; IVC, inferior vena cava; CVP, central venous pressure.
a Intermittent clamping: 15–20 minutes clamped, 5 minutes unclamped.
time thought to relate to portal occlusion during hepatic pedicle clamping, may be more closely related to extent of resection and liver function than portal pressure increase (Table 2) [16]. More important, persistent bleeding during parenchymal transection during inflow occlusion results either from incomplete inflow occlusion or, more significantly, backflow bleeding through the hepatic veins. Incomplete inflow, occlusion can be avoided by application of the pedicle clamp until pulsation in the distal hepatic artery is absent, clamping any accessory hepatic artery and lysis of hypervascular adhesions around the liver. Backflow bleeding is further reduced when the central venous pressure is maintained below 5 cm H$_2$O [17]. The risk of air embolism is increased by a low CVP [18], particularly when the blood inflow is restored, which mobilizes air bubbles trapped in any opened veins. Operating with the patient in 15° head-down position can minimize this risk [19].

If backflow bleeding persists, three basic options exist: (1) lower the CVP; (2) electively clamp the suprahepatic veins; or (3) clamp the IVC, either totally or partially. When the CVP cannot be lowered due to patient intolerance, cardiopulmonary increased resistance, or iatrogenic venous overfilling, venous clamping may be necessary. Clampage of the ipsilateral suprahepatic vein can be accomplished in many cases, because this has usually been dissected before parenchymal dissection is started. Bleeding from the contralateral hepatic vein may persist when the ipsilateral suprahepatic vein is clamped, and another method may be necessary to decrease venous back bleeding. Remaining options, including total vascular exclusion or simple infrahepatic IVC clamping, are discussed below.

**Hepatic tolerance and preconditioning**

Continuous interruption of hepatic inflow to a normal liver under normothermic conditions is safe for up to 60 minutes [20]. Alternatively, the intermittent technique [21,22], 15 to 20 minutes clamped alternating with 5 minutes unclamped, permits total ischemia time up to 120 minutes [23] and beyond [24]. Although no reliable data exist regarding the true limits for clamping, we have observed decreased tolerance for intermittent clamping after extended periods—greater than 1 hour of total ischemia—manifest as a more significant decrease in systemic blood pressure when the clamp is replaced, and a slower return to baseline after unclamping, similar to the “reperfusion syndrome” in liver transplantation.

The hypothesis that sequential periods of ischemia-reperfusion from intermittent clamping could result in greater hepatocellular damage [25] prompted several controlled studies [13,22,26]. No statistical difference in total operative blood loss with continuous versus intermittent clamping has been shown, but better overall parenchymal tolerance to intermittent clamping is evident, particularly in patients with abnormal liver parenchyma (including fatty and cirrhotic livers). As a result of our own controlled study [26], we strongly advocate the use of intermittent clamping in patients with abnormal liver parenchyma.
Table 2  
Comparison of relative technical difficulty, control of blood loss, and physiologic tolerance for various clamping techniques

<table>
<thead>
<tr>
<th>Clamping technique</th>
<th>Technical difficulty</th>
<th>Prevention of bleeding</th>
<th>Hepatic tolerance</th>
<th>Risk for complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hepatic pedicle clamping</td>
<td>Continuous</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Intermittent</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Hepatic pedicle and infrahepatic IVC clamping</td>
<td></td>
<td></td>
<td>+</td>
<td>Splenic rupture, caudate injury</td>
</tr>
<tr>
<td>Partial pedicle clamping</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>–</td>
</tr>
<tr>
<td>HVE (classical)</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>HVE with preservation of caval flow</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Abbreviations: HVE, hepatic vascular occlusion; IVC, inferior vena cava; +, least; ++ +, most.

* if intermittent.
A newer perspective on inflow vascular clamping has emerged from study of the biological response to ischemia-reperfusion [27,28]. Realization that a period of ischemia followed by reperfusion of the liver not only protects the liver from the negative effects of a subsequent period of ischemia, but may also protect distant organs from the systemic effects of organ ischemia [29], led to a study of this technique in humans [7]. Clavien et al revealed that an initial period of ischemia (10 minutes) followed by reperfusion (10 minutes) protects the liver against subsequent prolonged ischemia, and they postulated that some of the benefit of intermittent clamping may actually result from the impact of the first clamp-unclamp sequence as a preconditioning treatment [7]. Preconditioning followed by continuous clamping may have the advantage of avoidance of blood loss during the unclamped period, though no major differences have been shown in terms of blood loss between the continuous versus intermittent clamping approaches. The beneficial effect of preconditioning, however, was shown only for 30 minutes of continuous clamping [7], and intermittent clamping during routine resection may combine the advantages of preconditioning with the potential for unhurried surgery, providing time for complex resection with low blood loss (particularly in patients with abnormal underlying liver).

Even more recently, the potential benefit of preconditioning has brought inflow clamping back to the patients in whom “no clamping” techniques were once considered mandatory—living donors undergoing graft harvest [10]. In an important brief report, Makuuchi’s group outlined the rationale for clamping the hepatic inflow during living-donor hepatectomy. First, selective clamping of the liver that would remain in the donor was shown to be well-tolerated, and subsequently the graft was selectively clamped, which was equally well-tolerated (for the donor and recipient). Finally, routine intermittent hepatic pedicle clamping was used during donor hepatectomy, with no observed differences in graft function compared with donor hepatectomy without hepatic pedicle clamping [10]. The potential protective, rather than detrimental, effect of clamping on the donor graft before the extended ischemia required for transplantation is thus evoked, and underlying biology in this unique situation is only beginning to be studied.

Hemihepatic and segmental vascular clamping

Hemi-hepatic vascular clamping selectively interrupts the arterial and portal venous inflow to the hemi-liver to be resected, provides clear demarcation of the limits of resection, and avoids ischemia to the remnant liver, splanchnic congestion, and systemic hemodynamic consequences [30]. This procedure could be associated with clampage of the ipsilateral hepatic vein (Fig. 3). Segmental vascular clamping was initially described in patients with small hepatocellular carcinoma associated with abnormal liver parenchyma [31,32]. Segmental clamping is designed to minimize ischemic
injury to the liver parenchyma, and to delineate the portal territory of the tumor in order to facilitate segment-oriented hepatic resection.

**Technique**

**Hemi-hepatic vascular clamping.** The hepatic pedicle should be encircled for safety in case clamping is subsequently required. Cholecystectomy and ligation of the cystic duct and artery facilitate exposure of the portal vein, which is approached posterolaterally from the right to avoid devascularization of the common bile duct. Care must be taken to avoid inadvertent injury to a right hepatic artery arising from the superior mesenteric artery. The main portal vein can be dissected, and the consistent branch from the right posterior face of the right portal vein to the paracaval portion of the caudate lobe is ligated. The bifurcation of the portal vein is accessed from the right side, usually after isolation and retraction of the right branch of the hepatic artery. When the caudate lobe is preserved, the dissection of the left branch of the portal vein should be accessed from the left side of the portal pedicle, with attention to one or two small portal branches to the left part of the caudate lobe. The right or left branch of the hepatic artery is identified and encircled. We do not advocate extrahepatic biliary dissection before parenchymal transection, due to the risk for biliary injury [33]. The branches
of the portal vein and hepatic artery supplying the liver to be resected can be cross-clamped or ligated.

**Segmental vascular clamping technique.** Similarly, the hepatic pedicle is encircled for safety. The major right or left branch of the hepatic artery corresponding to the segment to be resected is dissected free in the pedicle and encircled. The portal branch of the segment to be resected is identified by intraoperative ultrasonography, punctured through the liver parenchyma with a cholangiography needle, and confirmed by ultrasonography and by aspiration of venous blood. A balloon catheter is directed over a flexible guide wire to the origin of the portal branch of interest. The corresponding arterial branch is clamped and the ischemic segment is delineated (injection of methylene blue into the portal catheter allows even more precise identification of the segment). When the segment to be resected is adjacent to Cantlie’s line, occlusion of the main hepatic artery may be necessary to obtain a bloodless field during resection.

**Indications, hemodynamics, and limitations**

Hemi-hepatic vascular clamping or segmental clamping was advocated for resection of small, peripheral hepatic lesions in abnormal liver parenchyma, so as to minimize circulatory and biochemical disturbances related to complete liver blood-flow interruption [30,34]. Hemodynamic effects are minimal (see Table 1). The main drawbacks of these methods are the need for significant hilar dissection, and the risk for bleeding from the transected edge of the nonoccluded hemi-liver. Advantages are rarely seen over conventional intermittent pedicular clamping, except when an anatomic demarcation of the resected liver is needed (see Table 2).

**Inflow and outflow vascular control**

**Conventional hepatic vascular exclusion with interior vena cava occlusion**

Hepatic vascular exclusion (HVE) combines total inflow and outflow vascular occlusion of the liver. Total isolation of the liver from the systemic circulation is intended during resection of large tumors adjacent to or involving the major hepatic veins or the IVC. This procedure can be considered when significant backflow bleeding occurs due to persistently elevated central venous pressure, despite efficient hepatic pedicle clamping.

**Technique**

Effective HVE requires a complete mobilization of the liver from its ligamentous attachments and all surrounding adhesions. The IVC is completely freed from the retroperitoneum, requiring the ligation of the right adrenal vein. The IVC is mobilized above and below the liver and encircled. The hepatoduodenal ligament is encircled, as described above,
and a careful search is made for accessory or replaced hepatic arteries (Fig. 4). Clamps are applied in the following order: (1) hepatoduodenal ligament, (2) infrahepatic IVC, and (3) suprarehepatic IVC. Once the surgeon and the anesthesiologist agree that clamping will be tolerated, clamps are reapplied for a duration up to 60 minutes in patients with normal liver. After completion of the parenchymal transection and before removing the clamps, the clamp on the infrahepatic vena cava can be partially released to flush air that might have been trapped and to test for caval integrity. The clamps are then removed in the reverse order in which they were placed.

Technical failure

Inadequate HVE technique will result in the progressive congestion of the liver as a result of: (1) inadequate clamping of the portal pedicle or the IVC, (2) persistent arterial inflow through an unrecognized left hepatic artery or hypervascular perihepatic adhesions, or (3) persistent entry of venous blood into the excluded retrohepatic IVC via anatomical (right adrenal vein) or pathological veins (tumor adhesions). These ineffective vascular exclusions are poorly tolerated hemodynamically and will result in massive bleeding if parenchymal transection is attempted. These problems are typically identified during the vital 5-minute test clamp before transection is performed. Although seemingly counterintuitive, excessive bleeding during TVE may be ameliorated by declamping the suprarehepatic vena cava. This is because flow through retrocaval veins may fill the liver when every connection from the cava to the liver is not controlled [35]. Supracaval declamping provides the path of least resistance for blood from the liver.
toward the heart, rather than backward into the surgical field. Although concomitant supraceliac aortic clamping [36] has been proposed in this situation, the technique has not been widely adopted.

**Hemodynamics and limitations**

The addition of total caval clamping to pedicular clamping results in major hemodynamic consequences. Specific anesthetic management is required, including continuous arterial and pulmonary arterial monitoring using radial artery and Swan-Ganz catheters. Some recommend transesophageal echocardiography to monitor cardiac function and to determine the presence of air in the vascular system [37]. Hemodynamic changes observed during HVE [20,38] included a 10% to 12% decrease in mean arterial blood pressure, a 25% decrease in pulmonary artery pressure, a 40% to 50% decrease in cardiac index, a 50% increase in heart rate, and an 80% increase in systemic vascular resistance (Fig. 5). The suppression of IVC flow produces a marked reduction in venous return, and consequently in cardiac output (between 40% and 60%, depending on the importance of collateral circulation). This reduction in cardiac output is, at least in part, compensated for by an increase in venous tone, an increase in systemic vascular resistance, and tachycardia [38], which is impacted by anesthetic technique [39]. A fall in cardiac output exceeding 50%, or a decrease in mean arterial pressure exceeding 30% (ie, less than 80 mmHg) should lead to consideration for caval declamping (note that compensatory progressive correction of cardiac output and of blood pressure may continue even after the first 5 minutes of clampage). Reduced venous return produces a marked reduction in left ventricular and diastolic volume that can be precisely monitored by transesophageal echocardiography. Classical causes of hemodynamic intolerance to HVE include inadequate fluid loading, technical failure (see below), and insufficient cardiovascular response (see Table 1). Except in case of massive bleeding, it is extremely unusual for an initially well-tolerated HVE (during the trial period) to become poorly tolerated thereafter.
Despite careful hemodynamic monitoring and fluid expansion, HVE is not tolerated in 10% to 15% of patients [13,40]. This poor tolerance, which is unpredictable preoperatively, may result from an inadequate reflex peripheral or from central cardiovascular response to increased cardiac output in the presence of decreased preload. In a prospective study of vascular clamping, we found that HVE was associated with a higher rate of pulmonary complications, which could be related to the higher volume of crystalloid fluid infused before vascular occlusion, or to traumatic injury to the diaphragm or phrenic nerve. Resulting hemi-diaphragmatic dysfunction may contribute to the development of pleural effusion and atelectasis [41]. Other risks include spontaneous splenic rupture during clamping, and caudate lobe injury and hyperamylasemia [13]. After a period of great enthusiasm, highlighted by transplant surgeons, it has been shown that HVE offers little advantage over inflow occlusion in the great majority of cases, even when hepatic vein reconstruction is necessary [42], and thus has a role in only the most selected cases, when other techniques cannot be used (see Table 2).

Inflow occlusion with extraparenchymal control of major hepatic veins—hepatic vascular exclusion with preservation of caval flow

Historically, extraparenchymal control of the main hepatic veins was considered to be dangerous, as a tear in this part of the vein would risk massive blood loss and air embolism [18]. Better understanding of intrahepatic anatomy and advances in surgical techniques allow many liver surgeons to safely expose and control the three main hepatic veins [43]. The association of inflow occlusion (hepatic pedicle clamping) and outflow occlusion by extraparenchymal hepatic vein clamping (Fig. 6) enables HVE without interruption of the IVC flow [44,45].

Technique

Extrahepatic control of the right hepatic vein [43]. Division of the falciform ligament is extended cranially to the upper peritoneal folds of the right and left triangular ligaments. The gutter between the liver, the right hepatic vein, and the middle hepatic vein, is dissected free to the anterior surface of the IVC. At this stage, dissection of a major hepatic vein from above is considered very hazardous and should not be continued. The right lobe is mobilized, and complete exposure of the right and anterior side of the IVC permits retraction of the liver medially and upward. The short retrohepatic veins are ligated and divided. Elevation of the right lobe of the liver leads to a medial compression of the right lateral side of the IVC and the right hepatic vein by the hepatocaval ligament, so that these three structures are in close contact. The right wall of the IVC is dissected bluntly to isolate the hepatocaval ligament, which should be ligated, as it may contain a large hepatic vein. Only after this has been completed should the right hepatic vein be encircled. When a right
inferior hepatic vein is present, it is either encircled or ligated and divided, according to its size and resection type.

**Extrahepatic control of the middle and left hepatic veins.** The left upper aspect of the IVC is exposed by division of the peritoneal reflection above the caudate lobe, and the ligamentum venosum is ligated and divided, exposing the junction of left hepatic vein and the IVC. When the left phrenic vein drains directly into the left hepatic vein it, is ligated and divided. A dissector is inserted from above, in the previously dissected gutter between the right and middle hepatic veins, and passed in close contact with the anterior surface of the IVC beneath the middle hepatic vein. The common trunk is then encircled with a tape. When the confluence of the middle and left hepatic veins is extrahepatic, it is possible to separately encircle these two vessels—otherwise the common trunk of the middle and left hepatic veins can be encircled as a unit.

**Indications, tolerance, hemodynamics, and limitations**

Because caval flow is preserved, this procedure has hemodynamic tolerance similar to that of pediculer clamping. This technique can be
applied intermittently, though this is not usually performed [46]. This technique cannot be used when tumor involves the cavo-hepatic junction in such a way that exposure of the hepatic veins is difficult and dangerous. Additionally, reverse-flow bleeding in the transection plane is not often completely suppressed by clamping of one or several hepatic veins. Persistent bleeding can occur either because there are collateral veins between major hepatic veins, or because the posterior liver plane was not totally mobilized, resulting in bleeding via the multiple caudate lobe veins. Thus, although technically attractive, this clamping technique is often not efficient.

Although selective vascular control can be technically more demanding than HVE, selective techniques enable the preservation of hemodynamic stability, the possibility of intermittent and therefore prolonged application, and the possibility of partial exclusion. The prevention of backflow bleeding or air embolism without having to resort to caval blood flow interruption, with its hemodynamic consequences, represents the main advantage of this method (see Table 1). Depending on the completeness of inflow and outflow occlusion required, total or partial exclusion may be obtained. Total exclusion includes hepatic pedicle clamping with occlusion of the three hepatic veins. Selective clamping is described in the section above (hepatic clamping).

**Infrahepatic inferior vena caval clamping**

As discussed above, an option to reduce back bleeding during inflow clamping is to reduce CVP. The surgeon can compliment the anesthesiologist in this case by simply placing a vascular clamp on the infrahepatic vena cava. Mildly elevated CVP may occur in patients when anesthetic techniques fail to lower CVP, when volume expansion is necessary to maintain systolic pressure in an acceptable level, or, increasingly, in units without specialized anesthetic support experienced with the low-CVP anesthesia necessary for major hepatic surgery. In these cases, this caval clamping technique can lower the CVP and significantly reduce back bleeding from the hepatic veins during hepatic pedicle clamping, without need of extraparenchymal control of main hepatic veins and with minor negative hemodynamic consequences.

**Technique**

Routine retroperitoneal dissection or caval mobilization is not required. In some cases, the IVC has been exposed as part of the procedure to mobilize the right liver for resection. In these cases, a vascular clamp can be placed on the infrahepatic vena cava above the renal veins under direct vision (Fig. 7B, right panel). When caval dissection is not necessary for liver resection, but hepatic venous bleeding results in the setting of elevated CVP, a vascular clamp can be placed directly on the vena cava without dissection, with care to position the clamp above the level of the renal veins and lateral
Fig. 7. Inferior vena caval clamping can be added to routine hepatectomy when elevated CVP leads to backflow bleeding during hepatic pedicle clamping, with few or no hemodynamic consequences. (A) No infrahepatic retroperitoneal dissection is performed—the clamp is placed directly in the suprarenal vena cava. (B) In the case when the liver has been mobilized, the clamp can easily be applied to reduce backflow bleeding.
to the aorta (see Fig. 7A, left panel). The vena cava clamping may be complete or partial.

**Indications, tolerance, and hemodynamics**

Simple vena cava clamping is indicated when, during the course of routine hepatectomy, venous backflow bleeding is encountered in spite of hepatic pedicle clamping. We have found that the CVP falls 70% on average, from a mean 13 mmHg to 4 mmHg after infrahepatic IVC clamping, with a consequent fall in backflow bleeding such that conversion to TVE was not necessary in any case of routine hepatectomy [13]. Systemic pressure falls less than 10% on average (see Table 1). Specific anesthetic monitoring is not required, and the procedure is designed to compliment the anesthetic by mildly decreasing the CVP and thus backflow bleeding, without increasing the difficulty of dissection, and without apparent negative consequences in hepatic function. The technique is simple and extremely well-tolerated. As hepatic surgery moves from specialized centers to centers without anesthesiologists specialized in hepatic surgery, this simple clamping technique can enable low blood-loss surgery when the CVP is slightly elevated.

The reason that infrahepatic caval clamping is tolerated without major hemodynamic effects is not known. Potential explanations are: (1) that this procedure is indicated when CVP is high, thus the consequences of reduced flow toward the heart are limited by already expanded vascular volume; (2) the maintenance of venous flow from diaphragmatic, retroperitoneal and adrenal veins may have an underestimated impact on cardiac filling; and (3) adrenal hormones that continue to circulate from adrenal vein may play a role in reflex blood pressure control [38]. This theoretical advantage of infrahepatic caval clampage over HVE with preserved caval flow reiterates the importance of venous return into the nearly isolated liver via retrocaval and diaphragmatic veins. Similarly, the finding that back bleeding during classical HVE can be reduced by releasing the supracaval clamp likely relates to a similar phenomenon—that the hepatic veins provide the low-pressure outlet for blood in the liver in the presence of venous inflow (infrahepatic caval) and hepatic pedicle inflow clamping.

We consider infrahepatic caval clampage to be a potential adjunct to hepatic pedicle clamping during any routine hepatectomy with persistent backflow bleeding, because of the simplicity, efficacy, and excellent patient tolerance to this procedure.

**Dissection for vascular clamping as an approach technique for hepatectomy**

The techniques of dissection in preparation for extrahepatic vascular control can be used as approach techniques for difficult hepatectomies.
Particularly when tumors are near the hepatic vein-vena cava confluence or attached to the vena cava, dissection and control of the major vascular structures before parenchymal transection ensures the safety of the planned procedure. In some cases, the clamping itself may not be required, but when the vascular pedicles are isolated beforehand, they can be clamped without delay as needed during the progress of the parenchymal transection. In this way, ischemia may be totally avoided or minimized, but patient safety is maximized. Most often, during a complex resection, the venous pedicles are encircled, and the parenchymal transection undertaken using hepatic pedicle clamping. When and if the dissection is carried close to a major venous structure, the clamping can be performed to avoid the risk for air embolism or bleeding, or in the event of a tear in a venous, portal venous, or arterial structure within the liver. Elective clamping permits careful identification and repair in these cases, and helps to avoid the need for urgent conversion from inflow clamping to total clamping.

The liver-hanging maneuver

An additional maneuver can be added to the repertoire of approach techniques for the liver surgeon. Based on the “anterior approach” proposed by Lai et al for large tumors that make right-liver mobilization difficult or impossible [47], Belghiti et al proposed the addition of a lifting technique using a tape passed between the anterior surface of the IVC and the posterior face of the liver [48]. The space between the right and middle hepatic veins is dissected from above, then the anterior plane of the infrahepatic IVC is dissected in the midline, which is uniformly avascular. This permits passage of a vascular clamp behind the caudate lobe to the space between the major veins, which is already prepared (Fig. 8, A and B). A tape is passed, which permits elevation of the hepatic parenchyma away from the IVC, and the parenchymal dissection can be performed without any mobilization of the liver.

This procedure eliminates retraction and compression of the liver remnant as well, and enables parenchymal transection before the need for division of the triangular ligaments, particularly when a large tumor is adherent to the diaphragm. Thus the technique is most useful for bulky right-sided tumors, particularly those with adhesion to or invasion of the diaphragm—often the greatest blood loss during the operative procedure occurs not during parenchymal transection, but during mobilization of the right liver for resection of large tumors [26]. A potential oncologic advantage of this approach is that no compression of the diseased liver may avoid tumor dissemination during mobilization [49]. A similar benefit may be gained by avoiding compression of the remnant liver in patients with significant underlying liver disease, to minimize the risk for postoperative hepatic dysfunction. The hanging maneuver can be used in combination
Fig. 8. (A,B) The liver hanging maneuver facilitates resection without mobilization of the right liver.
with hepatic pedicle clamping and infrahepatic inferior vena cava clamping. Further, we have used the technique to avoid manipulation of either side of the liver, and thus the theoretical negative effects of compression on the graft during harvest from living donors.

Summary

Each vascular occlusion technique has a place in major and minor hepatic resectional surgery, based on the tumor location, presence of associated underlying liver disease, patient cardiovascular status, and experience of the operating surgeon. Understanding of the potential application of different techniques, anticipation of the expected and potential hemodynamic responses, and knowledge of the limitations of each technique are fundamental to appropriate surgical planning adapted to each patient. Experience with the various clamping methods enables an aggressive but safe approach to surgical treatment of hepatobiliary diseases, with acceptable blood loss and transfusion requirements. In all cases, surgical strategy should be defined with the anesthesiologist, particularly in regard to hemodynamic monitoring, in order to optimize perioperative patient management and to minimize the risk for complications such as bleeding and air embolism. Importantly, randomized study has shown that the added dissection, operative, and postoperative risks associated with HVE are not balanced by decreased blood loss compared with hepatic pedicle clamping, except in exceptional cases when tumors involve the major hepatic veins or vena cava. In addition, dissection in preparation for clamping may be used as safe approach techniques to tumors in difficult locations, even when eventual clamping is not performed. Similarly, the liver-hanging maneuver enables resection without mobilization, compression, and manipulation of large tumors.

In the future, renewed interest in the impact of hepatic ischemia and reperfusion may reveal that some clamping methods, in particular inflow occlusion, act as a means of preconditioning before a period of prolonged hepatic ischemia, for complex hepatic resection or for graft harvest from a living donor. Finally, the addition of infrahepatic caval clamping may add a new, simple, effective technique to the armamentarium of the liver surgeon, particularly as more routine hepatic surgery moves from the specialized center to the community.

References


