Liver resections have historically been associated with high morbidity and considerable mortality, directly linked to excessive hemorrhaging. To this day, control of blood loss remains one of the key challenges in liver surgery. A number of approaches can be applied to successfully reduce blood loss. These include selective vascular control (SVC), continuous and intermittent portal triad clamping (PTC), hepatic vascular exclusion with preservation of caval flow (HVEPCF), and total hepatic vascular exclusion (THVE). For resection of peripheral small lesions SVC is preferable since ischemic insult to the remnant of liver is minimized. For more extensive lesions SVC results in unacceptable bleeding and open approach with continuous or intermittent PTC is preferred. Continuous PTC is associated with lower blood loss; with intermittent PTC longer ischemic time is tolerated. Prolonged resections of massive tumors may be best approached by HVEPCF with continuous or intermittent occlusion of hepatic venous drainage. An alternative approach uses inflow occlusion with occlusion of hepatic vein draining the segments being resected. Finally, tumors invading hepatic veins or IVC are best approached using THVE, which allows resection of venous confluence with adequate margins. The drawbacks include significant hemodynamic disturbance and portal hypertension with bowel engorgement. Increasingly complex and extensive hepatic resections necessitate increasingly aggressive methods of vascular control. Under appropriate circumstances each of these methods has a role in liver resections.

**Selective Vascular Clamping (SVC)**

The ligation of vascular pedicle to the segment of the liver being resected is the only method that avoids ischemia and reperfusion injury to the remnant of the liver, which can decrease its ability to hypertrophy and compensate postoperatively. Furthermore, SVC allows a clear demarcation of the boundary between the hepatic segments with intact and disrupted blood supply. Portal hypertension, a major drawback of PTC, is avoided or significantly reduced. The main concern with SVC is the potential for profuse hemorrhage from the cut liver surface. Nonetheless good results have been reported, making SVC an alternative to be considered. A randomized controlled trial by Figueras et al compared standard PTC to SVC in liver resections involving two or less liver segments, finding no significant differences in intraoperative blood loss. Wu et al describe several limitations of the hemihepatic SVC: additional 20 to 30 min are required for dissection of hepatic hilum, the technique is not suitable when the malignant tumor invades the hilar plate, and in patients with dense adhesions of the hilum secondary to previous hepatic artery embolization clamping may be especially challenging. Gotoh et al compare selective ligation of vascular pedicles after intraparenchymal dissection to hilar lobar clamping and to PTC in patients with cirrhosis and hepatocellular carcinoma. The lobar clamping group was found to have significantly shorter operation time and intraoperative blood loss than the other two groups. On the basis of these results Gotoh recommended lobar clamping as a method of vascular control, especially in cirrhotics. These results show that under appropriate circumstances SVC can be used with low risk of excessive hemorrhage, while ischemic injury to the liver is minimized. The role of SVC remains mainly in minor liver resections of peripheral lesions, where severe hemorrhage is less likely to occur.

**Portal Triad Clamping (PTC)**

Hepatic inflow occlusion is simple to perform, involving placement of a vascular clamp over the hepatoduodenal ligament. Care must be taken to identify the presence of any accessory hepatic arteries and the numerous collaterals present in cirrhotics. In the only randomized controlled trial to demonstrate
effectiveness of PTC in controlling blood loss, Man et al report that PTC was associated with lower blood loss per resection area, shorter operative times, and improved postoperative liver function compared to liver resections without extrahepatic vascular control.4 Overall PTC is well tolerated: liver with unimpaired parenchyma can be safely exposed up to 60 min of normothermic ischemia.5 If longer time is required, PTC can be used intermittently with 15-20 min ischemic intervals separated by 5 min reperfusion intervals. The hemodynamic disturbance during PTC is tolerated by most patients.9 However, PTC allows backbleeding from the hepatic veins that can contribute to blood loss. A common way to minimize this involves using low central venous pressure (CVP) anesthesia; this is accomplished with restriction of IV fluids and, if necessary, infusion of intravenous nitroglycerin.10 The danger of low CVP is the increased possibility of potentially lethal air embolism during resection. Another drawback of PTC is portal hypertension and venous stasis. King et al report significant ischemic changes in the bowel following 60 min of PTC.11 Finally, since PTC alone does not control the hepatic veins, in resections of tumors encroaching on the hepatic venous confluence or directly involving intrahepatic vascular structures more extensive methods of vascular control are preferred.

Figure 1. The Pringle maneuver, or portal triad clamping (PTC): portal triad is isolated and controlled with umbilical tape or vascular clamp.

Hepatic Vascular Exclusion with Preservation of Caval Flow (HVEPCF)

Historically, retrohepatic control of hepatic veins was considered dangerous because of the possibility of massive hemorrhage and air embolism with injury to these vital structures. If control of hepatic veins could be established, it offers several key advantages. Surgery can be done in a bloodless field, the danger of air embolism is eliminated, and preservation of caval flow avoids significant hemodynamic disturbance of THVE. The technique of intermittent vascular exclusion can be applied, extending the total ischemic time if needed.12-15 The dissection, however, requires difficult exposure and is technically challenging. Smyrniotis et al compare hepatectomy with THVE or HVEPCF, and report that the THVE group required more intravenous fluids and blood and demonstrated greater postoperative hepatic, pancreatic, and renal function impairment. There was no difference in intra-operative blood loss.15 Comparing PTC to HVEPCF revealed that HVEPCF group was found to have significantly lower blood loss, lower transfusion requirements, and shorter hospital stay than PTC group. On the other hand, the incidence of postoperative complications was similar between the two groups and the postoperative bleeding rate was higher in the HVEPCF group. Another approach is to clamp only the hepatic vein draining the segments being resected. This reduces the length and complexity of dissection, while providing very good control of hepatic venous blood loss. With these advances, many surgeons use HVEPCF as the preferred method of vascular control in major liver resections.
Total Hepatic Vascular Exclusion (THVE)

Total exclusion of the liver from the circulation involves applying clamps to hepatoduodenal ligament, infrahepatic IVC, and suprahepatic IVC. The main advantages of THVE are operating in bloodless field and prevention of air embolism with injury to hepatic veins. It is particularly valuable in resection of tumors that lie in close proximity to major hepatic veins and where resection is technically challenging. A major drawback of IVC occlusion in THVE is the severe hemodynamic disturbance associated with a drop in preload and increase in total peripheral resistance. Most patients can tolerate these changes without hemodynamic instability, provided aggressive infusion of intravenous fluids is used. Between 20% and 30% cannot tolerate the instability. A trial of IVC clamping of 3 to 5 minutes is usually undertaken to assess the change in hemodynamic parameters. The length of ischemia that could be safely tolerated during THVE is proven to exceed 60 min, and can probably be safely extended to 150 min. However, the advantages of THVE over PTC have been controversial. A randomized controlled trial, by Belghiti et al, compared patients undergoing major liver resections using PTC or THVE and found no significant differences in intraoperative blood losses or postoperative liver enzymes. Other major downside of THVE is associated portal hypertension with bowel edema, exacerbated by disruption of portosystemic shunts with occlusion of IVC. The ischemic time limit of THVE cannot be overcome by intermittent clamping, which results in unacceptable hemodynamic instability. Blood loss with THVE is minimized during the actual resection, but can be profound after the unclamping. Potential causes of technical failure with THVE include incomplete clamping, unrecognized anomalous origin of left hepatic artery, or unrecognized venous inflow into excluded segment of the IVC from right adrenal vein or other sources. If the exclusion is not complete, profound hemorrhage can ensue, with blood unable to drain to the heart filling the liver towards the surgical field.

Figure 2. Total hepatic vascular exclusion with cross clamping suprahepatic IVC, infrahepatic IVC, and portal triad clamping

To this day, control of blood loss remains one of the key challenges in liver surgery. A number of approaches can be applied to successfully reduce blood loss and transfusion requirements. These include selective vascular clamping, portal triad clamping, hepatic vascular exclusion with preservation of caval flow, and total hepatic vascular exclusion. Each method has its downsides and offers its unique advantages. For resection of peripheral small lesions SVC is preferable since ischemic insult to the remnant of liver is minimized and danger of profuse hemorrhage is low. For more extensive lesions SVC results in unacceptable bleeding and open approach with continuous or intermittent PTC is preferred. Prolonged resections of massive tumors may be best approached by HVEPCF with continuous or intermittent occlusion of hepatic venous drainage. Finally, tumors invading hepatic veins or IVC are best approached using THVE, which results in significant hemodynamic disturbance and potential ischemic injury, but allows resection of venous confluence with adequate margins. Thus increasingly complex and extensive hepatic resections necessitate increasingly aggressive methods of vascular control.
References