Liver resections were first described centuries ago, but until the latter half of the 20th century, the majority of such resections were performed for management of either injuries or infections. Today, these procedures are performed not only for treatment of acute emergencies (e.g., traumatic injuries or abscesses) but also as potentially curative therapy for a variety of benign and malignant hepatic lesions.1-5

The first planned anatomic resection of a lobe of a liver is credited to Lortat-Jacob, who in 1952 performed a right lobectomy as treatment for metastatic colon cancer.6 It was not until the 1980s, however, that major hepatectomies became commonplace. Since then, the safety of these operations has improved dramatically, and as safety has improved, the indications for hepatic resection have become better refined as well. Currently, resection of as much as 85% of the functional liver parenchyma is being performed at numerous centers with an operative mortality of less than 2%. The duration of hospitalization is typically less than 2 weeks, and almost all individuals regain normal hepatic function.7

In this chapter, we focus on the technical aspects of hepatic resection, emphasizing efficiency and safety and taking into account recent developments, current controversies, and special operative considerations (e.g., the cirrhotic patient and repeat liver resection). Detailed discussions of the indications for hepatic resection are available elsewhere.8-10

Hepatic Anatomy

Familiarity with the surgical anatomy of the liver is essential for safe performance of a partial hepatectomy.11 In 1998, as a response to the confusion created by the various anatomic nomenclatures applied to the liver, the International Hepato-Pancreato-Biliary Association (IHPBA) appointed a committee that was charged with deriving a universal terminology for hepatic anatomy and hepatic resections. In 2000, the recommendations of this committee were accepted at the IHPBA’s biannual meeting in Brisbane. Accordingly, this system for naming the anatomic divisions of the liver and the corresponding resections has come to be known as the Brisbane 2000 terminology.12

In the Brisbane 2000 system, the anatomy of the liver may be thought of in terms of first-order, second-order, and third-order divisions, all of which are based on the underlying vascular and biliary anatomy rather than on surface features [see Figure 1]. At the first level, the liver is divided into two hemilivers (right and left). At the second level, it is divided into four sections (right posterior, right anterior, left medial, and left lateral). At the third level, it is divided into nine segments, each of which is supplied by a portal pedicle; further branching of the pedicles subdivides the sections into their constituent segments. These major hepatic veins occupy three planes, known as the central, or principal, scissura, which represents the division between the right hemiliver and the left. The left hepatic vein runs in the left scissura between segments 2 and 3 (which together make up the left lateral section). In most persons, the left and middle hepatic veins join to form a common trunk before entering the vena cava. Occasionally, a large inferior right hepatic vein is present that may provide adequate drainage of the right hemiliver after resection of the left even when all three major hepatic veins are ligated.13

The portal vein and the hepatic artery divide into left and right branches below the hilum of the liver. Unlike the major hepatic veins, which run between segments, the portal venous and hepatic arterial branches, along with the hepatic ducts, typically run centrally within segments [see Figure 1]. On the right side, the hepatic artery and the portal vein enter the liver substance almost immediately after branching. The short course of the right-side extrahepatic vessels and the variable anatomy of the biliary tree make these vessels vulnerable to damage during dissection.14 In contrast, the left branch of the portal vein and the left hepatic duct take a long extrahepatic course after branching beneath segment 4. When these vessels reach the base of the umbilical fissure, they are joined by the left hepatic artery to form a triad, which then enters the substance of the left hemiliver at this point. It must be emphasized that proximal to the base of the umbilical fissure, the left-side structures are not a triad. A consequence of the long extrahepatic course of the left-side structures is that for tumors that involve the hilum (e.g., Klatskin tumors), when a choice exists between an extended right hepatectomy and an extended left hepatectomy [see Operative Technique, below], most surgeons choose the former because the greater ease of dissection on the left side facilitates preservation of the left-side structures. Knowledge of the relative anatomic courses of the portal veins, the hepatic arteries, and the hepatic ducts is the basis of the classical extrahepatic dissection for control of hepatic inflow [see Operative Technique, Right Hepatectomy, Step 6 (Extrahepatic Dissection and Ligations), below].

The fibrous capsule surrounding the liver substance was described by Glisson in 1654.15 It was Couinaud,16 however, who demonstrated that this fibrous capsule extends to envelop the por-
tal triads as they pass into the liver substance. Thus, within the liver, the portal vein, the hepatic artery, and the hepatic duct running to each segment of the liver lie within a substantial sheath. This dense sheath allows rapid control of inflow vessels to specific anatomic units within the liver and permits en masse ligation of these vascular structures in a maneuver known as pedicle ligation [see Operative Technique, Right Hepatectomy, Step 6—Alternative (Intrahepatic Pedicle Ligation), below].17

Preoperative Evaluation

Cross-sectional imaging modalities such as computed tomography, magnetic resonance imaging, and ultrasonography play an important role in enhancing the safety and efficacy of hepatic resection. These modalities, along with biologic scanning techniques such as positron emission tomography (PET), are also invaluable for staging malignancies so as to improve patient selection and thereby optimize long-term surgical outcome.3

At a minimum, all candidates for hepatic resection should undergo either CT or MRI. These imaging tests not only identify the number and size of any mass lesions within the liver but also delineate the relations of the lesions to the major vasculature—data that are crucial for deciding whether to operate and which operative approach to follow.

Use of contrast enhancement during CT scanning is vital for accurate definition of the vascular anatomy. In fact, data from thin-slice (1 to 2 mm) images captured by current spiral (helical) CT scanners can be reconstructed to provide angiographic pictures whose level of detail rivals that of direct angiograms [see Figure 2]. Triple-phase scans (including a noncontrast phase, an arterial phase, and a venous phase) are recommended: these yield the best definition and characterization of intrahepatic lesions. For example, some vascular tumors become isodense with liver parenchyma after contrast injection. By first obtaining noncontrast scans and then obtaining contrast scans at two different times after contrast injection, the examiner stands a better chance of visualizing such tumors.

For small tumors, a CT variant known as CT portography is recommended. In this technique, contrast material is injected through the superior mesenteric artery, and images are obtained during the portal venous phase. The normal liver receives the majority of its nutrient blood from the portal vein and is therefore contrast-enhanced in this phase. Tumors, on the other hand, usually derive their nutrient blood from the hepatic artery and therefore appear as exaggerated perfusion defects. CT portography is the most sensitive test available for identifying small hepatic tumors.18

MRI may also be valuable for characterizing lesions and defining them vis-à-vis the vasculature. It is particularly helpful in diagnosing benign lesions such as hemangiomas, focal nodular hyperplasia, and adenomas. Whenever any of these benign lesions is suspected, MRI is usually indicated. With regard to surgical plan-
ning, magnetic resonance angiography (MRA) is useful for identifying the major hepatic veins and clarifying their relations to any tumor masses. Over the past decade, biologic scanning, in the form of 18F-fluorodeoxyglucose positron emission tomography (FDG-PET), has emerged as an invaluable technique for preoperative staging of patients with hepatic malignancies. In patients with metastases to the liver who are being considered for hepatic resection, FDG-PET allows better determination of candidacy for operative management, thereby both reducing the incidence of nontherapeutic laparotomy and improving long-term survival in cases where resection is indicated. The role of FDG-PET in the workup of patients with primary hepatocellular carcinoma (HCC) is less clear, in that many tumors cannot be distinguished from the surrounding liver through assessment of glucose metabolism alone.

Imaging recommendations may be summed up as follows. A triple-phase CT should be obtained for most patients under consideration for hepatic resection. If diagnostic doubt remains after CT, particularly if the differential diagnosis includes an asymptomatic benign tumor, MRI should be performed. If questions remain after CT as to the extent of hepatic venous or major biliary involvement, MRI or duplex ultrasonography should be considered. If small tumors are encountered, CT portography should be performed. Duplex ultrasonography, by demonstrating the vascular hilar structures, the hepatic veins, and the inferior vena cava, renders angiography unnecessary in many cases. For patients with liver metastases from a primary colorectal cancer, breast cancer, or melanoma, an FDG-PET scan should be performed before hepatic resection. Direct hepatic angiography is rarely required, and inferior vena cavaography is almost never needed.

**Operative Planning**

**PREPARATION**

In general, preparation for hepatic resection is much the same as that for other major abdominal procedures. All patients who are older than 65 years or have a history of cardiopulmonary disease undergo a full cardiopulmonary assessment. It was once commonly believed that patients 70 years of age or older were poor candidates for major liver resection, but this notion has been dispelled by more recent data. Advanced chronologic age is not a complete contraindication to hepatectomy.

Anemia and coagulopathy, if present, are corrected. All patients are now encouraged to donate two units of autologous blood before a major hepatectomy. As an alternative, hemodilution, whereby a portion of the patient’s blood volume is withdrawn intraoperatively and reinfused immediately after the completion of the heptectomy, may be considered.

Appropriate single-dose antibiotic prophylaxis is administered.

**ANESTHESIA**

Decisions regarding anesthesia should take into account the possibility of baseline hepatic dysfunction, as well as the postoperative hepatic functional deficits resulting from resection of a major portion of the hepatic parenchyma.

The most important consideration, however, is the possibility of major intraoperative hemorrhage. Suitable monitoring and sufficient vascular access to permit rapid transfusion should be in place. At some centers, fluid resuscitation and blood transfusion are begun early in the course of resection to increase intravascular volume as a buffer against sudden blood loss. At Memorial Sloan-Kettering Cancer Center (MSKCC), we favor the opposite approach, whereby a low central venous pressure is maintained during resection. The rationale for our preference is that generally, most of the blood lost during hepatic resection comes from the major hepatic veins or the vena cava. If central venous pressure is kept below 5 mm Hg, there is less bleeding from the hepatic venous radicles during dissection. Reduction of intrahepatic venous pressure can be facilitated by performing the dissection with the patient in a 15° Trendelenburg position, which increases venous return to the heart and enhances cardiac output. Central venous pressure is maintained at the desired level through a combination of anesthesia and early intraoperative fluid restriction. The minimal acceptable intraoperative urine output is 25 ml/hr.

The need for intraoperative blood transfusion can be minimized by accepting hematocrits lower than the common target figure of 30%: 24% in patients without antecedent cardiac disease and 29% in patients with cardiac disease. If blood loss is estimated to reach or exceed 20% of total volume or the patient becomes hemodynamically unstable, transfusion is indicated.
PATIENT POSITIONING

The patient should be supine: to date we have not found a lateral position to be necessary even for the largest of tumors. Electrocardiographic leads should be kept clear of the right chest wall and the presternal area in case a thoracoabdominal incision is necessitated by the position of a tumor or by intraoperative hemorrhage. Preparation and draping should therefore also allow for exposure of the lower chest and the entire upper abdomen down past the umbilicus. A crossbar or a similar device that holds self-retaining retractors should be used to elevate the costal margin. Some surgeons prefer ring-based self-retaining retractors. In our experience, although these retractors are adequate for most resections, the rings tend to restrict lateral access, thereby potentially hindering posterior dissection, particularly of the vena cava.

ANATOMIC VERSUS NONANATOMIC RESECTION

The key decision in planning a hepatectomy is whether the resection should be anatomic or nonanatomic. For treatment of malignant disease, anatomic resection is usually favored because the long-term outcome is better. Anatomic resections permit excision of parenchymal areas distal to the index tumors, where there is a high incidence of vascular micrometastases. In addition, they are significantly less likely to have positive margins than nonanatomic resections are. In a large series of hepatectomies for metastatic colorectal cancer, wedge or nonanatomic resections were associated with a 19% rate of positive margins.31 In one examination of the increasing preference for anatomic resections over wedge resections, wedge resections were associated with a 16% rate of positive margins, compared with a 2% rate for anatomic resections.32

There are two oncologic settings where nonanatomic resections are favored. In patients with HCC, viral hepatitis and cirrhosis are often complicating factors. Cirrhotic patients tolerate resection of more than two segments of functional parenchyma poorly. For these patients, the smallest resection that will achieve complete tumor excision is favored, even if it is a wedge resection. For management of metastatic neuroendocrine tumors, in which resections are merely debulking procedures designed to alleviate symptoms, nonanatomic resections are accepted because cure is highly unlikely.

Hepatic resections for benign hepatic tumors are usually performed for one of three reasons: (1) to relieve symptoms (e.g., pain or early satiety), (2) because the diagnosis is uncertain, or (3) to prevent malignant transformation. A goal of such resections should be to spare as much normal parenchyma as possible. Consequently, lesions such as hemangiomas, adenomas, complex cysts, and focal nodular hyperplasia are often excised by means of enucleation or another nonanatomic resection with limited margins.

Operative Technique

Theoretically, any hepatic segment can be resected in isolation. For practical purposes, however, there are six major types of anatomic resection. Until comparatively recently, most authors have followed the commonly used terminology of Goldsmith and Woodburne in referring to these procedures.33 Some authors have preferred other systems of nomenclature, based on the anatomic descriptions of Couinaud34 or Bismuth.35 In this chapter, however, we use the Brisbane 2000 terminology for hepatic resections [see Figure 3].

The essential principles of all anatomic hepatectomies are the same: (1) control of inflow vessels, (2) control of outflow vessels, and (3) parenchymal transection. To illustrate these principles, we begin by outlining the steps in a right hepatectomy [see Figure 3a] in some detail, describing both extrahepatic vascular dissection and ligation and the alternative approach to inflow control, intrahepatic pedicle ligation. Left hepatectomy [see Figure 3b] and other common anatomic resections [see Figures 3c, d, e, f] share a number of steps with right hepatectomy; accordingly, we discuss them in somewhat less detail. Further detail on these procedures is available in other sources.35,36

RIGHT HEPATECTOMY

Step 1: Laparoscopic Inspection

Experience from MSKCC35,36 and other centers39,40 indicates that laparoscopy allows detection of unresectable disease and prevents the morbidity associated with a nontherapeutic laparotomy. We generally perform laparoscopy immediately before laparotomy during the same period of anesthesia. The laparoscopic port sites are placed in the upper abdomen along the line of the intended incision [see Step 2, below]. The first two ports are usually 10 mm ports placed in the right subcostal area along the midclavicular line and along the anterior axillary line. These ports allow inspection of the abdomen and of the entire liver, including the dome and segment 7. The port along the right anterior axillary line is particularly suitable for laparoscopic ultrasound devices. If additional ports are necessary, a left subcostal midclavicular port is usually the best choice.
Step 2: Incision

For the majority of hepatic resections, most surgeons use a bilateral subcostal incision extended vertically to the xiphisternum [see Figure 4]. Our own preference, however, is to use an upper midline incision extending to a point approximately 2 cm above the umbilicus, with a rightward extension from that point to a point in the midaxillary line halfway between the lowest rib and the iliac crest [see Figure 4]. We find that this incision provides superb access for either right- or left-side resection, without the wound complications often encountered with trifurcated incisions (e.g., ascitic leakage and incisional hernia). On rare occasions (e.g., in the resection of large, rigid posterior tumors of the right hemiliver), a right thoracoabdominal incision may be required. In a series of nearly 2,000 resections at MSKCC, however, a thoracoabdominal incision was performed in only 3% of patients; the most common indication was repeat liver resection after previous right hepatectomy [see Repeat Hepatic Resection, below].

Step 3: Abdominal Exploration and Intraoperative Ultrasonography

The liver is palpated bimanually. Intraoperative ultrasonography is systematically performed to identify all possible lesions and their relations to the major vascular structures. This modality is capable of identifying small lesions that preoperative imaging studies and palpation of the liver may miss. The lesser omentum is incised to allow palpation of the caudate lobe and inspection of the celiac region for nodal metastases. A finger is passed from the lesser sac inferior to the caudate lobe through the foramen of Winslow to permit identification of the portal vein and palpation of the portocaval lymph nodes. The hillock lymph nodes are palpated, and any suspicious nodes are removed for frozen-section examination. The entire abdomen is inspected for evidence of extrahepatic tumor if the operation is being done to treat cancer.

Step 4: Mobilization of Liver

Once the decision is made to proceed with hepatic resection, the liver is fully mobilized by detaching all ligamentous attachments on the side to be resected. (Some surgeons defer completion of mobilization to a later stage in the procedure.) In particular, the suprahepatic inferior vena cava and the hepatic veins above the liver are dissected to facilitate the subsequent approach to the hepatic veins [see Step 7, below]. Once the liver is mobilized, further palpation is done to detect any small lesions that may have been obscured initially. This additional palpation is particularly important on the right side because before mobilization, the posterior parts of the liver cannot be effectively palpated, and intraoperative ultrasonography may fail to detect small lesions in this area.

If, in the course of mobilization, tumor is found to be attached to the diaphragm, the affected area of the diaphragm may be excised and subsequently repaired.

Step 5: Identification of Arterial Anomalies

Any hepatic arterial anomalies present should be identified before resection is begun. With good preoperative imaging, the arterial anatomy is usually defined with sufficient exactitude before laparotomy. It is also possible to gain a clear picture of the arterial anatomy intraoperatively by means of simple maneuvers that do not involve major dissection.

The lesser omentum should be examined to determine whether there is a vessel coursing through its middle to the base of the umbilical fissure, and the hepatoduodenal ligament should be palpated with an index finger within the foramen of Winslow to see whether there is an artery in the gastropancreatic fold on its medial aspect. The usual bifurcation of the hepatic arteries occurs low and medially in the hepatoduodenal ligament, and the left hepatic artery normally travels on the medial aspect of the ligament to reach the base of the umbilical fissure. Thus, if an artery is palpable in the medial upper portion of the hepatoduodenal ligament, it is the main left hepatic artery. Any vessel seen in the lesser omentum must therefore be an accessory left artery. If no pulse is found in the medial upper portion of the hepatoduodenal ligament, the vessel in the lesser omentum must be a replaced left hepatic artery. The right hepatic artery usually travels transversely behind the common bile duct (CBD) to reach the base of the cystic plate. A vertically traveling artery on the lateral hepatoduodenal ligament must therefore be either a replaced or an accessory right hepatic artery, probably arising from the superior mesenteric artery.

Step 6 (Extrahepatic Dissection and Ligation): Control of Inflow Vessels

The classic approach to extrahepatic control of the inflow vessels in a right hepatectomy involves extrahepatic dissection and ligation [see Figure 5]. The cystic duct and the cystic artery are ligated and divided. The gallbladder may be either removed or left attached to the right hemiliver, according to the surgeon’s preference. The usual practice is to ligate first the right hepatic duct, then the right hepatic artery, and finally the right portal vein, working from anterior to posterior. Our preference, however, is to work from posterior to anterior, as follows.

The sheath of the porta hepatitis is opened laterally. Dissection is then performed in the plane between the CBD and the portal veins.
vein. To facilitate this dissection, the CBD is elevated by applying forward traction to the ligated cystic duct. The portal vein is then followed cephalad until its bifurcation into the left and right portal veins is visible. In a small percentage of patients, the left portal vein arises from the right anterior branch of the portal vein. If the main right portal vein is ligated in a patient who exhibits this anatomic variant, the portion of the liver remaining after resection will lack any portal flow. There is usually a small portal branch that passes from the main right portal vein to the caudate process. Ligation of this branch untethers another 1 to 2 cm of the right portal vein.

**Figure 5** Right hepatectomy. For control of the inflow vessels of the right hemiliver, the liver is retracted cephalad to allow exposure of the porta hepatitis. (a) The gallbladder is resected to allow access to the bile duct and hepatic vessels. (b) The right hepatic duct is ligated to allow access to the hepatic artery and the portal vein. (c) After the right hepatic artery is divided, the right portal vein is controlled and divided. Alternatively, the vessels may be approached from a posterolateral direction and the portal vein and hepatic artery may be divided first, with the hepatic duct left intact until the parenchymal transection.

**Figure 6** Right hepatectomy. Glisson’s sheath is a vascular and biliary pedicle that contains the portal triad. If this sheath is not violated, the entire pedicle can be suture-ligated or staple-ligated with confidence and safety.
portal vein, thereby allowing safer dissection and ligation. The right portal vein is usually clamped with vascular clamps, divided, and oversewn with nonabsorbable sutures. Once this is done, the right hepatic artery is visible behind the CBD and can easily be secured and ligated with nonabsorbable sutures. Because of the multitude of biliary anatomic variations, we usually leave the right hepatic duct intact until parenchymal dissection [see Step 8, below] is begun, when this structure can be secured higher within the hepatic parenchyma and divided with greater safety.

**Staple ligation** Vascular staplers may be used for stapling the right or the left portal vein during extrahepatic vascular dissection; however, suture ligation of the extrahepatic portal veins is such a straightforward technical exercise that staplers add little except cost.

**Step 6—Alternative (Intrahepatic Pedicle Ligation): Control of Inflow Vessels**

The observations of Glisson and Couinaud (see above) that the nutrient vessels to the liver are contained within a thick connective tissue capsule [see Figure 6] were the basis for the initial proposal by Launois and Jamieson that intrahepatic vascular pedicle ligation could serve as an alternative to extrahepatic dissection and ligation for controlling vascular inflow to the liver. This alternative technique has the advantages of being rapid and of being unlikely to cause injury to the vasculature or the biliary drainage of the contralateral liver. Given adequate intrahepatic definition and control of the portal triads supplying the area of the liver to be resected, one can readily isolate the various major pedicles by using simple combinations of hepatotomies at specific sites on the inferior surface of the liver [see Figure 7].

The right hemiliver is completely mobilized from the retroperitoneum. The most inferior small hepatic veins are ligated, and the inferior right hemiliver is mobilized off the vena cava. Incisions are then made in the liver capsule at hepatotomy sites A and B [see Figure 7]. The first incision is made though the caudate lobe. The full thickness of the caudate lobe is divided with a combination of diathermy, crushing, and ligation. The second incision is made almost vertically in the medial part of the gallbladder bed. Both incisions must be fairly substantial and reasonably deep. Care must be taken to avoid the terminal branches of the middle hepatic vein, which are the most common source of significant bleeding. By means of either finger dissection or the passage of a large curved clamp, a tape is then placed around the right main sheath [see Figure 8]. This tape can be pulled medially to provide better exposure of the intrahepatic right pedicle and to retract the left biliary tree and portal vein away from the area to be clamped and divided. Clamps are then applied, the right pedicle is divided, and the stumps are suture-ligated.

In practice, for right hepatectomies, we prefer to isolate the right anterior and posterior pedicles separately [see Figure 8] and ligate them individually. This measure ensures that the left-side structures cannot be injured. Any minor bleeding from a hepatotomy usually ceases spontaneously or else stops when Surgicel is placed into the wound.

**Staple ligation** The use of staplers is now well established for liver resections, and we find that staple ligation greatly increases the speed with which intrahepatic portal pedicle ligations can be performed. To control the intrahepatic portal pedicles for a right hepatectomy, incisions are made at hepatotomy sites A and B [see Figure 7]. Ultrasonography directed from the inferior aspect of the liver helps determine the depth at which the right pedicle lies, which is usually 1 to 2 cm from the inferior surface. The right main pedicle is then secured either digitally or with a curved blunt clamp (e.g., a renal pedicle clamp), and an umbilical tape is placed around it [see Figure 9a]. The hilar plate in the back of segment 4 is lowered via an incision at hepatotomy site C [see Figure 7] to ensure that the left-side vascular and biliary structures are mobilized well away from the area of staple ligation. A transverse anastomosis (TA) vascular stapler is applied to the right main pedicle while firm countertraction is being applied to the umbilical tape to pull the hilum to the left [see Figure 9a]. The stapler is fired, and the pedicle is divided [see Figure 9b].

**Troubleshooting** There are several important guiding principles that should be followed in deciding on and performing intrahepatic pedicle ligation. The most important principle is that...
in patients undergoing operation for cancer, an intrahepatic pedicle approach should not be used when a tumor is within 2 cm of the hepatic hilum. In such cases, extrahepatic dissection should be performed to avoid violation of the tumor margin.

From a technical standpoint, removal of the gallbladder greatly facilitates isolation and control of right-side vascular pedicles in a right hepatectomy. Application of the Pringle maneuver decreases bleeding during hepatotomy and isolation of the pedicle. Finally, the lowest hepatic veins behind the liver should be dissected before any attempt is made to isolate the right-side portal pedicles: incising the caudate lobe without dividing the small hepatic veins draining this portion of the liver to the vena cava can lead to significant hemorrhage.

**Step 7: Control of Outflow Vessels**

Control of the outflow vasculature begins with division of the hepatic veins passing from the posterior aspect of the right hemiliver directly to the vena cava. After the right hemiliver is completely mobilized off the retroperitoneum by dividing the right triangular ligament, it is carefully dissected off the vena cava. Dissection proceeds upward from the inferior border of the liver until the right hepatic vein is exposed. Complete mobilization of the right hemiliver is particularly critical for tumors close to the vena cava. The right hepatic vein is then isolated, cross-clamped, divided, and oversewn [see Figure 10]. Unless the tumor or lesion involves the middle hepatic vein close to its junction with the vena cava, the middle hepatic vein usually is not controlled extrahepatically for right-side resections and is easily secured during parenchymal transection.

If there is a large tumor residing at the dome of the liver, gaining control of the hepatic veins and the vena cava may prove very difficult. If so, one should not hesitate to extend the incision to the chest by means of a right thoracoabdominal extension. The morbidity of a thoracoabdominal incision is preferable to the potentially catastrophic hemorrhage that is sometimes encountered when the right hepatic vein is torn during mobilization of a rigid right hemiliver containing a large tumor.

**Staple ligation** Staple ligation has proved useful for outflow control during hepatectomy. When the tumor is in proximity to
the hepatic vein–vena cava junction, extrahepatic control of the hepatic veins is essential for excision of the tumor with clear margins, and it limits blood loss during parenchymal transection. Ligating the hepatic veins, particularly with a large and rigid tumor in the vicinity, can be a technically demanding and dangerous exercise. Tearing the hepatic vein or the vena cava during this maneuver is the most common cause of major intraoperative hemorrhage.

The endoscopic gastrointestinal anastomosis (GIA) stapler is well suited for ligation of the major hepatic veins, in that it has a low profile and is capable of simultaneously sealing both the hepatic vein stump on the vena cava side and the one on the specimen side.

For staple ligation of the right hepatic vein, the right hemiliver is mobilized off the vena cava. Any large accessory right hepatic vein encountered can be staple-ligated, as can the tongue of liver tissue that often passes from the right hemiliver behind the vena cava to the caudate lobe. The right hepatic vein is then identified and isolated. It is the practice of some authors to introduce the stapler from the top of the liver downward, but we find that in most patients, the liver is sufficiently high in the surgical wound to render this angle of introduction technically impracticable. Accordingly, we introduce the stapler parallel to the vena cava and direct it from below upward.

Parenchymal division is then begun along the line demarcated by the devascularization of the right hemiliver. The line of transection along the principal plane is marked with the electrocautery and then cut with scissors. Stay sutures of 0 chronic catgut are placed on either side of the plane of transection and used for traction, separation, and elevation as dissection proceeds.

Many special instruments have been proposed for use in parenchymal transection, including electrocauteries, ultrasonic dissectors, and water-jet dissectors. We find that for the majority of hepatic resections, blunt clamp dissection is the most rapid method and is quite safe. In essence, a large Kelly clamp is used to crush the liver parenchyma. The relatively soft liver substance dissects away, leaving behind the vascular and biliary structures, which are then ligated. With this technique, the principal plane of the liver can usually be transected in less than 30 minutes.

In cirrhotic patients, the clamp-crushing technique may not work as well because of the firmness of the liver substance: the vessels often tear before the parenchyma does. Accordingly, in cirrhotic patients, ultrasonic dissectors that coagulate while transecting the parenchyma may be a better choice. Water-jet dissectors may be useful in defining the major intrahepatic vascular pedicles or the junction of the hepatic vein and the vena cava, particularly if tumor is in close proximity.

After the specimen is removed, the raw surface of the hepatic remnant is carefully examined for hemostasis and biliary leakage. Any oozing from the raw surface may be controlled with the argon beam.
beam coagulator. Biliary leaks should be controlled with clipping or suture ligation. The retroperitoneal surfaces should also be examined carefully for hemostasis, and the argon beam coagulator should be used where necessary.

**Step 9: Closure and Drainage**

The abdominal wall is closed in one or two layers with continuous absorbable monofilament sutures. The skin is closed with staples or with subcuticular sutures. Drains are unnecessary in most routine cases; sometimes, in fact, they may exert harmful effects by leading to ascending infection or fluid management problems if ascites develops. There are four clinical situations in which we routinely place a drain: (1) clear biliary leakage, (2) an infected operative field, (3) a thoracoabdominal incision, and (4) biliary reconstruction. In the case of the thoracoabdominal incision, a drain is placed to ensure that biliary leakage does not develop into a fistula into the chest.

**LEFT HEPATECTOMY**

**Steps 1 through 5**

Left hepatectomy involves removal of segments 2, 3, and 4, and sometimes 1 and 9 as well. The first five steps of the procedure are much the same as those of a right hepatectomy.

**Step 6 (Extrahepatic Dissection and Ligation): Control of Inflow Vessels**

Extrahepatic control of vascular inflow vessels can be achieved in essentially the same fashion as in a right-side resection. Our preference is to start the dissection at the base of the umbilical fissure. The left hepatic artery is divided first. The left branch of the portal vein is then easily identified at the base of the umbilical fissure. The point at which the left portal vein is to be divided depends on the extent of the planned parenchymal resection [see Figure 13]: if the caudate lobe is to be preserved, the left portal vein is ligated just distal to its caudate branch (line B); if the caudate lobe is to be removed, the left portal vein is ligated proximal to the origins of the portal venous branches to this structure (line A).

**Figure 12** Right hepatectomy. The parenchyma can be quickly and safely transected by means of the clamp-crushing technique. Large vessels and biliary radicles are visualized and ligated or clipped. This is usually done in tandem with inflow occlusion (i.e., the Pringle maneuver). Alternatively, the parenchyma can be bluntly dissected away by means of the finger-fracture technique.

**Step 6—Alternative (Intrahepatic Pedicle Ligation): Control of Inflow Vessels**

If the hepatectomy is being done to treat benign disease or to remove a malignancy that is remote from the base of the umbilical fissure, we highly recommend performing stapler-assisted pedicle ligation in preference to extrahepatic dissection and ligation. The left portal pedicle is identified at the base of the umbilical fissure. The hilar plate is lowered through an incision at hepatotomy site C [see Figure 7], and a second incision is made in the back of segment 2 at hepatotomy site E [see Figure 7], thereby allowing isolation of the left portal pedicle with minimal risk of injury to the

**Figure 13** Left hepatectomy. Ligation of vascular pedicles at specific sites in the left hemiliver interrupts inflow to specific areas. Ligation at A interrupts inflow to the entire left hemiliver, as well as the caudate lobe. Ligation at B interrupts blood flow to the left liver while sparing the caudate lobe. Ligation at C devascularizes segment 2, and ligation at D devascularizes segment 3. Ligation at E and F devascularizes segment 4.
hilum. If the caudate lobe is to be removed as well, incisions should be made at hepatotomy sites C and F [see Figure 7] to allow isolation of the main left portal pedicle proximal to the vessels nourishing the caudate. The portal pedicle is isolated and secured with an umbilical tape. There is some risk that in the course of securing the left portal pedicle, the middle hepatic vein, which lies immediately lateral to the left portal pedicle, may be injured. To minimize this risk, firm downward traction is applied to the umbilical tape, and a TA-30 vascular stapler is placed across the left portal pedicle [see Figure 14]. The pedicle is then stapled and divided.

**Step 7: Control of Outflow Vessels**

The left hemiliver is retracted to the patient’s right, and the entire lesser omentum is divided. The ligamentum venosum is identified between the caudate lobe and the back of segment 2 and is then divided near its attachment to the left hepatic vein; this measure facilitates identification and dissection of the left and middle hepatic veins anterior to the inferior vena cava. The left and middle hepatic veins are isolated in preparation for division.

Control of the left hepatic vein is quickly and safely accomplished with staple ligation. In approximately 60% of patients, the left and middle hepatic veins join to form a single trunk before entering the vena cava. In a left hepatectomy, the middle hepatic vein is often left intact; accordingly, if this is the surgeon’s intent, it is vital to protect the middle hepatic vein while ligating the left. After the left hepatic vein is identified, an endoscopic GIA-30 vascular stapler is directed from above downward [see Figure 15] to ligate this vessel. The liver is retracted to the right to permit visualization of the junction of the left and middle hepatic veins. If ligation of the middle hepatic vein is desired as well, as is the case when there is tumor in proximity to the vessel, this can be accomplished with a staple directed along the same path used for left hepatic vein ligation.

**Steps 8 and 9**

Parenchymal transection and closure are accomplished in much the same manner in a left hepatectomy as in a right hepatectomy (see above).

**OTHER ANATOMIC RESECTIONS**

In the ensuing review of the other major anatomic resections, we focus primarily on the major points in which they differ from right and left hepatectomy. More detailed discussions of these operations are available in specialty texts on liver resection.35,36

**Right Trisectionectomy (Extended Right Hepatectomy)**

A right trisectionectomy (extended right hepatectomy) involves removal of the right hemiliver along with segment 4—that is, all liver tissue to the right of the falciform ligament [see Figure 3c]. The initial steps of this operation are the same as those of a right hepatectomy, up through division of the right inflow vessels and the right hepatic vein.

The next step is devascularization of segment 4. The umbilical fissure is dissected to permit identification of the vascular pedicles to segments 2, 3, and 4, which lie within this fissure [see Figure 13]. In most cases, the lower part of the umbilical fissure is concealed by a bridge of liver tissue fusing segments 2 and 3 to segment 4. After this tissue bridge is divided with diathermy, the ligamentum teres is retracted caudally to reveal the vascular pedicles from the umbilical fissure to segment 4 (lines E and F [see Figure 13]). We generally suture-ligate these pedicles before dividing them.

The liver tissue is then transected immediately to the right of the falciform ligament, from the anterior surface back toward...
the divided right hepatic vein. The middle hepatic vein is generally left intact until it is encountered in the upper part of the dissection, at which point it is controlled and either sutured or staple-ligated.

**Left Lateral Sectionectomy**

A left lateral sectionectomy involves removal of only segments 2 and 3—that is, all liver tissue to the left of the falciform ligament [see Figure 3d]. These segments are mobilized by dividing the left falciform and triangular ligaments. As this is done, care must be taken not to injure the left hepatic and phrenic veins, which lie on the medial portion of the left triangular ligament.

The falciform ligament is retracted caudally, and the bridge of liver tissue between segment 4 and segments 2 and 3 is divided with diathermy. Dissection is then performed within the umbilical fissure to the left of the main triad. The vascular pedicles to segments 2 and 3 usually are then readily dissected and controlled (lines C and D [see Figure 13]). Control of these pedicles within the umbilical fissure is particularly important for tumor clearance if tumor is in proximity to the umbilical fissure: if the condition is benign or if tumor is remote from the umbilical fissure, the liver may be split anteroposteriorly just to the left of the ligamentum teres and the falciform ligament, and the vascular pedicles may be identified and ligated as they are encountered in the course of parenchymal transection.

Once the inflow vessels have been ligated, the left hepatic vein is identified and then divided either before parenchymal transection or as the vessel is encountered near the completion of parenchymal transection. If there is tumor near the dome, it is particularly important for tumor clearance that the left hepatic vein be controlled and ligated early and outside the liver.

**Left Trisectionectomy (Extended Left Hepatectomy)**

A left trisectionectomy (extended left hepatectomy) involves resection of segments 2, 3, 4, 5, and 8, and sometimes 1 and 9 as well [see Figure 3e]. In essence, it is a left hepatectomy combined with a right anterior sectionectomy; it may or may not include excision of the caudate lobe. This complex resection is usually undertaken to excise large tumors that occupy the left hemiliver and cross the principal scissura into the right anterior section.

In this procedure, it is essential to preserve the right hepatic vein, which constitutes the sole venous drainage of the hepatic remnant. Usually, however, parenchymal transection must be performed along the course of this vein; thus, the major potential danger in the operation is injury to the vessel, which could lead to hemorrhage or hepatic failure from venous congestion of the hepatic remnant. In addition, because the blood supply to segment 7 often arises from the right anterior portal pedicle or from the junction of the right anterior and posterior pedicles [see Figure 8], there is a risk that the operation may result in devascularization of a large portion of the hepatic remnant. Finally, because of the great variability of the biliary anatomy and the extensive intrahepatic dissection required in this procedure, there is a significant risk of biliary complications. For all of these reasons, left trisectionectomies are rarely performed outside major centers.

In the planning of a left trisectionectomy, particularly close attention must be paid to preoperative imaging investigations so that the right-side intrahepatic vessels and biliary structures can be accurately delineated. Thin-slice CT or MRI images in the form of arterial, portal venous, and hepatic venous reconstructions [see Figure 2] are quite helpful in this regard. For large tumors encroaching on the hepatic hilum or on the junction of the right anterior and posterior pedicles, direct angiography may still be necessary.

The liver is fully mobilized by dividing not only the left triangular ligament but also the ligaments on the right. This step is essential for identifying the correct plane of parenchymal dissection and for ensuring safe dissection along the right hepatic vein.

The initial dissection is the same as for a left hepatectomy. The liver is turned to the right side and the portal triad approached. The inflow vessels to the left hemiliver are ligated, and the left hepatic vein and the subdiaphragmatic inferior vena cava are dissected free. The left and middle hepatic veins are controlled and ligated in the extrhepatic portions of their courses. The left hemiliver is thereby freed, and dissection on the right hemiliver is greatly facilitated.

Next, the plane of transection within the right hemiliver is defined. This plane is horizontal and lies lateral to the gallbladder fossa and just anterior to the main right hepatic venous trunk in the right scissura, halfway between the right anterior pedicle and the right posterior pedicle. The plane can be approximated by drawing a line from just anterior to the right hepatic vein at its insertion into the vena cava to a point immediately behind the fissure of Gans. This line can be accurately defined by clamping the portal pedicle to the right anterior section of the liver. If the tumor is remote from the junction of the right anterior and posterior portal pedicles, the anterior pedicle is controlled as outlined earlier [see Right Hepatectomy, Step 6—Alternative (Intrahepatic Pedicle Ligation), above]. A vascular clamp is placed on the pedicle and the line of demarcation on the liver surface inspected before the pedicle is divided. If segment 7 appears to be ischemic as well, further dissection must be done to identify and protect the origins of the vessels supplying segment 7.

Parenchymal dissection is then carried out from below upward, with bleeding controlled by means of low central venous pressure anesthesia and intermittent application of the Pringle maneuver. If the caudate lobe is to be removed as part of the total resection, the veins draining the caudate must be controlled before parenchymal transection.

**Segment-Oriented Resection**

Each segment of the liver can be resected independently. In addition, resections involving only the right posterior section (segments 6 and 7) [see Figure 3f] or the right anterior section (segments 5 and 8) are not uncommon. Extensive and excellent descriptions of so-called segment-oriented hepatic resection are available elsewhere.

**Postoperative Care**

I.V. fluids administered postoperatively should include phosphorus for support of liver regeneration. For large-volume hepatic resections, electrolyte levels, blood count, and prothrombin time (PT) are checked after the operation and then daily for 3 to 4 days. Packed red blood cells are administered if the hemoglobin level falls to 8 mg/dl or lower, and fresh frozen plasma is given if the PT is longer than 17 seconds. Postoperative pain control is best achieved with patient-controlled analgesia (PCA). Because of the decreased clearance of liver-metabolized drugs after a major hepatectomy, selection and dosing of pain medications should be adjusted accordingly. An oral diet can be resumed as early as postoperative day 3 unless a biliary-enteric anastomosis was performed.

Peripheral edema is common after major hepatic resections and may be treated with spironolactone. If an unexplained fever occurs or the bilirubin level rises when other hepatic function parameters are normal, an intra-abdominal bile collection may be present, and...
a CT scan should be obtained. Percutaneous drain placement usually brings about resolution of such collections after a few days; reoperation is rarely necessary.

Special Considerations

TOTAL VASCULAR ISOLATION FOR CONTROL OF BLEEDING

For control of bleeding during liver parenchymal transection, a technique known as total vascular isolation can be used as an alternative to the Pringle maneuver. In this technique, the liver is isolated by controlling the inferior vena cava (both above and below the liver), the portal vein, and the hepatic artery. This approach is based on techniques developed for liver transplantation and on the observation that the liver is capable of tolerating total normothermic ischemia for as long as 1 hour. Its primary advantage is that while the liver is isolated, little or no bleeding occurs. It does, however, have disadvantages as well. In some patients, temporary occlusion of the inferior vena cava causes hemodynamic instability as a consequence of reduced cardiac output coupled with increased systemic vascular resistance. Cardiac failure with marked hypotension, cardiac arrhythmia, and even cardiac arrest may ensue. In addition, when hepatic perfusion is restored, the sudden return of stagnant potassium-rich blood to the systemic circulation can aggravate the situation. For these reasons and because bleeding is generally well controlled with low central venous pressure anesthesia, we believe that total vascular isolation is useful only in rare cases. The clinical data published to date support this view. A prospective study from 1996 found that total vascular isolation had no major advantages over the approach described earlier [see Operative Technique, Right Hepatectomy, Step 8, above] and was actually associated with greater blood loss.

The one setting where we believe that total vascular isolation may have a significant role to play is in the surgical management of hepatic tumors, particularly very large tumors that compromise the vena cava or the hepatic veins. To extend the duration of vascular isolation in this setting, a venovenous bypass that vents the splanchic blood into the systemic circulation may be used. To further minimize parenchymal injury during vascular isolation, the liver may be perfused with cold organ preservation solutions. For extensive vascular invasion that necessitates major vena caval or hepatic venous reconstruction, some authors have suggested that the liver can be removed during venovenous bypass and resection and reconstruction performed extracorporeally.

Although there are clinical situations that call for venovenous bypass and ex vivo resection, in practice, these techniques are very rarely necessary: short-length vena cava resection and reconstruction can be performed quite safely without resort to them. In fact, involvement of the retrohepatic vena cava at a level below the major hepatic veins can generally be treated with simple excision of the affected segment without replacement, particularly if complete obstruction at this level has already led to established collateral circulation.

HANGING MANEUVER IN MAJOR HEPATECTOMY

The classic technique for a right hepatectomy (see above) involves complete mobilization of the right hemiliver before vascular control and parenchymal transection. In cases where the tumor has invaded the retroperitoneum or diaphragm, however, such mobilization may be difficult. Moreover, in cases where the tumor is a large, soft, vascular one such as HCC, the earlier mobilization of the right hemiliver may increase the risk of tumor rupture. Finally, division of the vascular inflow and outflow vessels before manipulation of the tumor has the theoretical advantage of preventing vascular dissemination of cancer cells caused by compression of the tumor. For these reasons, some authors proposed an anterior approach whereby the liver parenchyma is transected from the anterior surface to reach the vena cava, with ligation of the inflow and outflow vasculature carried out before mobilization of the right hemiliver. This approach is now widely followed for resection of HCC.

Subsequently, other authors proposed a modification of this technique whereby dissection is performed along the anterior surface of the vena cava and a tape passed in this plane to lift the liver and thereby facilitate transection of the parenchyma and ligation of the vasculature [see Figure 16]. The first step in this so-called hanging maneuver is to dissect the space between the right and middle hepatic veins downward for approximately 2 cm. Next, dissection is performed between the vena cava and the caudate lobe on the left side of the inferior right hepatic vein. A clamp is then passed along this plane in the notch between the right and middle hepatic veins, and an umbilical tape is passed for suspension of the liver. Transection of the parenchyma is performed in an anterior-to-posterior direction until the vena cava is reached. The right side of the vena cava is then dissected, and the right hepatic vein and the inferior hepatic veins are ligated. The triangular ligament and the retroperitoneal attachments are transected, and the specimen is removed.

THE CIRRHOTIC PATIENT

Cirrhotic patients, by definition, have reduced hepatic functional capacity and reserve. Accordingly, these patients are at higher risk from hepatectomy and require careful assessment of liver function, appropriate selection for surgery and choice of operation, and greater attention to perioperative care.

Operative Planning

Selection of patients Hepatic failure is the major cause of hospital death and long-term morbidity after hepatic resection in cirrhotic patients. Consequently, determination of a cirrhotic patient’s candidacy for hepatectomy is based on preoperative assessment of baseline liver function. A variety of tests have been proposed for assessment of hepatic reserve, including measurement of clearance of various dyes and metabolic substrates (e.g., indocyanine green and aminopyrine). Measurement of the urea-nitrogen synthesis rate has also been suggested as a way of predicting outcome after resection. Another functional test involves administering lidocaine and measuring levels of monethylglycinexylidide (a metabolite of lidocaine that is generated mostly through the cytochrome P-450 enzyme system in the liver) as a gauge of liver function. Measurement of the hepatic portal venous pressure gradient via invasive radiologic techniques has been found to predict postoperative hepatic failure. Assessment of portal venous hemodynamics by means of noninvasive Doppler ultrasonography has also been found to predict outcome after hepatectomy.

Currently, none of these functional tests are routinely done at most major liver resection centers. In practice, the Child-Pugh score [see 5:3 Jaundice] is the most commonly employed clinical tool for selection of surgical candidates. A Child-Pugh score higher than 8 is generally accepted as a contraindication to major hepatic resection.

Choice of procedure The appropriate extent of resection for cirrhotic patients may be quite different from that for noncirrhotic
patients. In cirrhotic patients, the majority of hepatectomies are performed to eradicate HCC. A prime consideration in such resections is the margin needed to ensure tumor clearance. Most clinicians aim for a tumor-free margin of 1 cm. A 1989 study, however, found that in cirrhotic patients with HCC, as long as the tumor margin was microscopically clear of cancer, the exact size of the margin was not correlated with the incidence of recurrence. In fact, the acceptance of limited margins, coupled with the acceptance of nonanatomic resections aimed at preserving as much functional parenchyma as possible, is the single change in technical practice that is most responsible for the great improvements in the safety of hepatic resection observed worldwide in cirrhotic patients.

The guiding principle for hepatectomy in cirrhotic patients is that limited resections should be favored, with as much functional parenchyma spared as possible. In general, even for patients with well-compensated Child’s grade A cirrhosis, we try to limit resections to less than two segments of functional liver. Patients with large tumors are more likely to tolerate a major resection because little functional parenchyma must be removed along with the tumor. Major hepatic resections involving removal of at least one hemiliver are now reported to carry an operative mortality of less than 10% in cirrhotic patients. Such procedures are usually performed in cirrhotic patients who have large tumors replacing most of one hemiliver, acceptable liver function, and no atrophy of the uninvolved hemiliver. Small tumors are often more difficult to manage. For patients with small, deeply placed tumors whose resection would necessitate removal of a large amount of functional parenchyma, an ablative alternative or even transplantation might be more suitable.

In an attempt to preserve as much functional liver as possible, many surgeons resort to more technically challenging operations. Most will perform multiple limited resections in order to avoid performing a full hemihepatectomy. Some go so far as to reconstruct the right hepatic vein for the purpose of preserving venous outflow in segments 5 and 6 after resection of segments 7 and 8.

Operative Technique

Hepatic resection in cirrhotic patients is associated with certain specific technical difficulties that substantially increase the complexity of the operation. The liver parenchyma is hard, which makes retraction of the liver difficult. In addition, anatomic landmarks are distorted and difficult to find as a consequence of fibrosis and atrophy-hypertrophy. Finally, portal hypertension and tissue friability contribute to increased blood loss during mobilization and parenchymal transection.

Exposure and mobilization Trifurcated incisions and thoracoabdominal incisions should be avoided in cirrhotic patients because of the potential for ascitic leakage externally or into the chest. The increased firmness of the cirrhotic liver and the consequent difficulty of retraction can lead to significant blood loss from retroperitoneal or phrenic collateral vessels during mobilization. To prevent such bleeding, it may be preferable to use an anterior approach in which the liver parenchyma is split within the principal scissura down to the anterior surface of the vena cava before the right hemiliver is mobilized off the retroperitoneum. The right hemiliver is then mobilized in a medial-to-lateral direction, and the right hepatic vein is secured during mobilization of the right hemiliver off the vena cava.

Inflow control At one time, it was widely doubted whether the Pringle maneuver was safe in cirrhotic patients. Subsequently, however, many studies verified that this maneuver can be performed for extended periods in cirrhotic patients without increasing either morbidity or mortality. Nevertheless, it is advisable to employ the Pringle maneuver sparingly in this population so as
to minimize ischemic stress. Our practice is to clamp the portal triad with a vessel loop tourniquet for 10-minute periods with 5-minute breaks in between. We have not found additional protective maneuvers (e.g., topical cooling) to be necessary.

**Parenchymal transection** In patients with normal liver parenchyma, most experienced hepatic surgeons use blunt dissection, with either the clamp-crushing technique or the finger-fracture technique, to transect the liver tissue. In patients with cirrhosis, however, the firmness of the parenchyma makes the clamp-crushing technique less than ideal: because the parenchyma is often harder than the underlying vasculature and biliary radicles, blunt dissection is likely to tear these vessels. Accordingly, ultrasonic dissectors that coagulate and seal vessels during dissection are more suitable for parenchymal transection in this population.

**Closure and drainage** Because of the likelihood of postoperative ascites, the abdominal wall is closed with a heavy continuous absorbable monofilament suture to create a watertight closure. To prevent major fluid and protein losses and ascending infections, abdominal drains generally are not used. Reports specifically examining the role of drainage in cirrhotic patients documented a much lower incidence of postoperative complications and a shorter hospital stay for patients in whom no drains were placed.

**Postoperative Care**

The focus of postoperative care in cirrhotic patients is on management of cirrhosis and portal hypertension [see 5:10 Portal Hypertension]. In most such patients who undergo hepatic resection, transient hepatic insufficiency develops postoperatively, with hyperbilirubinemia, ascites formation, hypoalbuminemia, edema, and worsening of the baseline coagulopathy.

In the first 24 hours after the procedure, crystalloid must be administered at a level sufficient to maintain adequate portal perfusion. If patients are stable after the first 24 hours, they are subjected to water and sodium restriction and receive liberal amounts of salt-poor albumin for volume expansion if needed. Spironolactone is started in all patients as soon as oral diet is resumed, and furosemide is added as needed. On rare occasions, a peritoneovenous shunt may have to be employed to control postoperative ascites, but this measure is usually unnecessary if patients were properly selected. The PT is checked twice daily during the immediate postoperative period; a PT longer than 17 seconds is corrected by administering fresh frozen plasma.

**CHEMOTHERAPY-ASSOCIATED STEATOHEPATITIS**

One of the most important advances in the treatment of metastatic colon cancer over the past few years has been the development and approval of a number of newer chemotherapeutic agents, such as irinotecan, oxaliplatin, cetuximab (C225), and bevacizumab (Avastin). These agents target the cancer cell cycle, paracrine growth factors, and angiogenic factors, and they have led to substantial improvements in survival for patients with hepatic colorectal metastases. They are currently being used not only to allow effective palliative treatment to be provided in cases where resection is not feasible but also, by downstaging certain hepatic tumors, to allow surgical treatment to be provided for a percentage of patients who were previously thought to have unresectable disease. Consequently, it is now common for patients to be subjected to a number of chemotherapies before being considered for hepatectomy. Along with the benefits of these advances in chemotherapy, however, has come the challenge posed by postoperative management of the hepatic damage that can result from the use of these newer agents.

The hepatic surgeon must therefore be vigilant for the condition commonly known as chemotherapy-associated steatohepatitis (CASH). This disease is associated with a characteristic clinical triad consisting of (1) hepatic steatosis, (2) splenomegaly, and (3) thrombocytopenia. Fatty infiltration of the liver can be assumed if hepatic attenuation is found to be lower than splenic attenuation. Splenomegaly is a sign of portal hypertension, as is refractory consumptive thrombocytopenia that is not related to bone marrow suppression and therefore is not corrected even when chemotherapy is stopped.

When CASH is documented, patients should be selected for hepatectomy according to the same criteria used for patients with early cirrhosis. Consideration should also be given to preoperative portal vein embolization (PVE) (see below) before hepatectomy to increase the size of the hepatic remnant.

**PREOPERATIVE PORTAL VEIN EMBOLIZATION**

Most liver surgeons would be reluctant to resect more than the equivalent of two segments of functional liver in a patient with documented cirrhosis. Consequently, many cirrhotic patients with technically resectable tumors are relegated to noncurative ablative therapy out of concern over possible postoperative hepatic failure. The situation may be changing, however, with the growing use of preoperative PVE, which may extend surgeons’ ability to resect tumor in cirrhotic patients.

In PVE, access to the portal vein on the side of the liver to be resected is gained via a percutaneous transhepatic approach. The vein is embolized approximately 1 month before the planned resection so as to produce ipsilateral atrophy along with compensatory hypertrophy of the contralateral future hepatic remnant. The degree of compensatory hypertrophy can be dramatic [see Figure 17] and may modulate postoperative hepatic dysfunction. PVE is also employed in patients with normal parenchyma in whom extensive resection may result in a very small hepatic remnant. In patients undergoing right trisectionectomy, particularly those with congenitally small left lateral sections, the entire area of the extended right hepatectomy, including the main right portal vein and the segmental branches supplying segment 4, can be embolized.

There is substantial evidence that preoperative PVE can be successfully used in patients with cirrhotic livers or impaired hepatic function and that such use is generally well tolerated. One immediate benefit of PVE is that it may act as a kind of stress test for the liver, allowing preoperative determination of the likelihood of liver regeneration. If no compensatory hypertrophy is seen 4 weeks after PVE, the decision to perform a major hepatectomy should be reconsidered.

**Repeat Hepatic Resection**

Since 1984, when one of the first reports of repeat hepatic resection was published, a number of reports from around the world have demonstrated that repeat resection can be done safely and with good long-term results even for recurrent malignancies. The morbidities and mortalities reported after repeat hepatectomy for metastatic colorectal cancer and hepatocellular carcinoma are comparable to those reported after initial hepatectomy. Extended survival has been demonstrated, and in selected cases, survival is equivalent to or even better than that observed after initial resection. In the following section, we concentrate on the key technical aspects of repeat hepatic resection;
discussions of indications, patient selection, and outcome are available in other sources.106,113,120,126 Repeat hepatic resection poses certain technical difficulties that are not commonly encountered during initial resection.105,127,128 First, adhesions at the previous line of parenchymal transection can make reexposure of the liver difficult. Mobilizing the liver off the vena cava and reexposing the porta hepatis and the hepatic veins can be extremely hazardous if dissection was previously done in these areas. Second, liver regeneration and systemic chemotherapy can induce accumulation of fat within the liver, thereby rendering it more friable106; the increased friability further increases the difficulties of reexposure and predisposes to tearing of Glisson’s capsule.127 Third, regeneration alters the normal anatomic configuration of the portal structures [see Figure 18].129 For example, after a right hepatectomy, the porta hepatis is rotated posteriorly and to the right. The normal anatomic relations among the portal structures are altered, with the bile duct displaced posteriorly and the portal vein displaced anteriorly.

Preoperative imaging is even more important for repeat resections than for primary resections; the reason is that scarring limits access to the liver for intraoperative assessment via palpation or ultrasonography. Before embarking on a repeat resection, it is essential to know the exact number and locations of the lesions to be treated within the regenerated parenchyma. Preoperative imaging also facilitates operative planning by accurately delineating the vasculature within the regenerated liver.

In a repeat resection after a previous major right hepatectomy, it is important to be prepared to convert the incision into a thoracoabdominal incision if necessary. Access through the right chest may be required for mobilization of the liver because of adherence of the previous resection margin to the diaphragm, or it may be required for access to the rotated CBD and portal vasculature at the porta hepatis.

In the dissection of the right upper quadrant after a previous right hepatectomy, three landmarks are particularly helpful in defining the anatomic structures within the regenerated left hemiliver. The first landmark is the remnants of the ligamentum teres, which defines the demarcation between the left lateral section (segments 2 and 3) and the left medial section (segment 4); these should be found early on. The ligamentum teres may be followed to the base of the umbilical fissure to define the location of the left hepatic artery. Whether this artery arises from the common hepatic artery or from the left gastric artery, it passes into the liver parenchyma at the base of the umbilical fissure. The second landmark is the caudate lobe. The lesser omentum should be opened early on to reveal this lobe. An index finger should then be passed in front of the caudate toward the obliterated foramen of Winslow to define the porta hepatis and the location of the portal vein. The third landmark is the vena cava. Performing the Kocher maneuver to mobilize the duodenum off the vena cava allows this vessel to be dissected, thus further
Laparoscopic Hepatic Resection

In addition to revolutionizing treatment of gallstone disease, laparoscopic techniques are increasingly used for fenestration of benign cysts of the liver and for staging of hepatobiliary malignancies to prevent unnecessary laparotomies. Until comparatively recently, however, laparoscopic resection of liver tumors was described only in case reports or small series. Perhaps the main reason for the strong resistance to laparoscopic hepatic resection has been fear of catastrophic bleeding. If inadvertent damage to a major hepatic vein or the vena cava occurs during an open operation, the bleeding can be controlled with direct manual compression until the vessel is repaired; however, if such damage occurs during a laparoscopic operation, control of the bleeding is considerably more difficult. In addition, damage to a hepatic vein or the vena cava during a laparoscopic procedure can theoretically result in CO₂ embolism. Another concern is that the loss of tactile sensation characteristic of laparoscopic surgery may lead to inadequate tumor clearance. Finally, whereas there are many liver retractors designed to hold the liver in one position, there is no good retractor for repeatedly moving the liver from side to side, as would be necessary during a laparoscopic hepatectomy. The human hand is still the best tool for this purpose.

Laparoscopic hepatic resection has been greatly facilitated by several recent technologic advances, including laparoscopic staplers and ultrasonic dissectors, which can be used for ligation of the hepatic vasculature and transection of liver parenchyma. The most important advance, however, is the hand access port, a small port through which one hand can be introduced into the abdomen for a hand-assisted laparoscopic resection. With this approach, the surgeon not only regains a measure of tactile sensation but also is able to employ the best liver retractor available. Moreover, direct manual compression of any bleeding vessels is once again possible, and the incision made for extraction of the resected specimen.

Appropriate patient selection is essential for safe laparoscopic resection of liver tumors. Resection of any two segments along the lower edge of the liver is easily accomplished laparoscopically. At defining the portocaval plane. Definition of this plane leads to the correct plane for dissection and mobilization of the liver off the vena cava; it also allows isolation of the hepatoduodenal ligament for application of the Pringle maneuver and for extrhepatic dissection of the inflow vessels.

In a repeat resection after a previous left hepatectomy, the main concern with regard to mobilization of the liver is the anterior position of the portal vasculature after right-side hypertrophy. It is therefore prudent to mobilize the right hemiliver, perform a Kocher maneuver, and follow the vena cava caudally to identify the portal vein from the right. The stomach and the colon usually are adherent to the edge of the previous resection and must be carefully dissected free to allow access to the liver. If the middle hepatic vein was preserved in the earlier left hepatectomy, it will lie immediately deep to the plane of the stomach or the colon and thus may be a source of hemorrhage during dissection.

Control of the inflow or outflow vasculature may be compromised by the scarring resulting from the previous operation. If extensive extrhepatic dissection was performed for control of inflow vasculature in the earlier procedure, control of these vessels in the repeat resection is more safely accomplished via intrhepatic pedicle ligation [see Operative Technique, Right Hepatectomy, Step 6—Alternative (Intrahepatic Pedicle Ligation), above].

A major concern with repeat hepatectomy is that it is sometimes necessary to perform more limited resections than would otherwise be indicated. Normally, for removal of liver tumors, we avoid wedge excisions because these nonanatomic resections are more often associated with greater blood loss and positive margins than anatomic resections are. In a repeat hepatectomy, however, anatomic considerations arising in the regenerated liver may make a wedge resection the best choice.

With appropriate patient selection and careful operative planning, very favorable perioperative and long-term results can be achieved after repeat hepatic resection. It is noteworthy that studies addressing repeat resection have not documented any substantial increases in blood loss, duration of operation, or rate of complications in comparison with the initial resection.

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**Figure 19** Laparoscopic hepatic resection: hand-assisted. Introduction of the hand within the abdomen restores tactile sensation to the surgeon and facilitates resection of the liver. The hand is the best liver retractor available and can be used to dissect the parenchyma. The specimen can be extracted through the hand access port.
MSKCC, we have laparoscopically resected lesions from all segments. In the following section, we provide a general overview of laparoscopic hepatic resection; more in-depth discussions of the technical aspects of these procedures and the results reported from various centers are available elsewhere.

**OPERATIVE TECHNIQUE**

The patient is placed on the operating table in the supine position, with the arm on the side of the resection out from the body at a 60° angle and the contralateral arm tucked. The patient is securely strapped down to allow for rotation of the table. For a right hepatectomy or resection of segments 7 and 8 (bisegmentectomy 7, 8), the patient may be positioned in the left lateral decubitus position. The surgeon stands on the side opposite the side of the resection.

A left lateral sectionectomy typically requires the placement of five ports. Pneumoperitoneum is achieved via an initial port placed at the umbilicus; to prevent gas embolism during liver transection, it is maintained at the lowest pressure possible (typically 10 to 12 mm Hg). Subsequent ports are then placed along the subcostal line. A second 5–12 mm port is placed at the intersection of the subcostal and midclavicular lines to permit dissection of the triangular ligament, the hepatic vein, and the inferior vena cava. A third 5–12 mm port is placed between the previous two ports to permit dissection of the porta hepatis. The fourth 5–12 mm port is placed in the right midclavicular line to permit the introduction of an endovascular stapler for division of the portal structures and liver parenchyma. We prefer using 5–12 mm ports in the beginning, so that the camera and the staplers can be passed through any of the ports. If a 5 mm camera is available, 5 mm trocars can be placed at certain spots, usually at the most lateral positions. This step frees up the 12 mm ports that are used to pass the endoscopic GIA stapler. We generally use the 45 mm rotating articulated stapler loaded with the white 2.5 mm cartridge.

Some situations call for the use of a hand access port, which can be of great help in several ways. First, the hand access port allows the surgeon to retract and compress the liver manually if bleeding is encountered, thereby increasing the overall speed of the procedure. Second, large resected liver specimens can be removed through the hand access port, without any need for a separate extraction site. Third, if intracorporeal suturing is required to manage bleeding or bile leakage, the surgeon can use the right hand to place the suture and the left hand, placed through the hand access port, to tie the knots. A disadvantage of the hand access port, however, is that it may get in the way of the other trocars, especially in a small patient. Hence, knowing when and where to place the hand access port requires a measure of experience. For a left-side resection, the hand access port should be placed through a transverse incision in the left upper quadrant. Alternatively, the port may be placed in the upper midline; traction is then provided by the hand used to retract the left hemiliver medially while the triangular ligament provides countertraction.

The procedure starts with the placement of a 10 mm port, usually in the right or left upper quadrant on the side opposite that on which the hand access port will be placed. After staging is performed to confirm that the lesion is resectable, a 5 to 6 cm incision is made for placement of the hand access port. The port site should be chosen so as to allow manual retraction of the part of the liver to be resected, with the falciform and triangular ligaments used to provide countertraction. Once the access port is in place, the abdomen is fully palpated under laparoscopic vision. A laparotomy sponge is placed into the abdomen to facilitate retraction and absorb blood, and a long bulldog clamp is inserted for use in the Pringle maneuver. A long umbilical tape is tied to the bulldog clamp beforehand so that the instrument can be easily located throughout the procedure. Additional ports are then placed as necessary for introduction of the staple or the ultrasonic scalpel.

![Figure 20](image-url) Shown are the recommended port placements for (a) laparoscopic left lateral sectionectomy and (b) hand-assisted laparoscopic right hepatectomy.
The area to be resected is outlined with the electrocautery. The liver is manually retracted, intermittent application of the Pringle maneuver is initiated, and the parenchyma is transected. Liver resection is performed with the ultrasonic dissector or by electrocautery. The laparoscopic approach is suitable for both minor and major hepatic resections. At present, however, it remains unclear whether this approach constitutes a significant advance in liver surgery. To clarify this issue, further study of laparoscopic hepatic resection with respect to perioperative outcome, quality of life, and long-term survival is required.

References


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