Vascular and Biliary Variants in the Liver: Implications for Liver Surgery

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Accurate preoperative assessment of the hepatic vascular and biliary anatomy is essential to ensure safe and successful hepatic surgery. Such surgical procedures range from the more complex, like tumor resection and partial hepatectomy for living donor liver transplantation, to others performed more routinely, like laparoscopic cholecystectomy. Modern noninvasive diagnostic imaging techniques, such as multidetector computed tomography (CT) and magnetic resonance (MR) imaging performed with liver-specific contrast agents with biliary excretion, have replaced conventional angiography and endoscopic cholangiography for evaluation of the hepatic vascular and biliary anatomy. These techniques help determine the best hepatectomy plane and help identify patients in whom additional surgical steps will be required. Preoperative knowledge of hepatic vascular and biliary anatomic variants is mandatory for surgical planning and to help reduce postoperative complications. Multidetector CT and MR imaging, with the added value of image postprocessing, allow accurate identification of areas at risk for venous congestion or devascularization. This information may influence surgical planning with regard to the extent of hepatic resection or the need for vascular reconstruction.
Introduction

With the increasing complexity and prevalence of hepatobiliary surgery (e.g., transplantation surgery and hepatic resection), a detailed preoperative evaluation of hepatic vascular and biliary anatomy is mandatory. The goals are to choose the best therapeutic approach, to reduce complications, and to identify the anatomy requiring special attention at surgery. Diagnostic imaging with multidetector computed tomography (CT) and magnetic resonance (MR) imaging allows accurate and noninvasive preoperative evaluation of the hepatobiliary anatomy (Figs 1, 2) (1,2).

In transplantation surgery, a road map of the biliary and arterial vascularity of the donor and recipient is a prerequisite for the procedure. Especially when there are arterial variants, accurate surgical planning and close monitoring of hepatic arterial patency are required.

Anatomic variants of the biliary and hepatic arterial anatomy are common, with the classic anatomy being found in only 58% and 55% of the population, respectively. Variant hepatic arterial anatomy not only dictates the surgical technique but may also predict the risk of hepatic arterial complications and of subsequent biliary strictures and liver abscesses. Unanticipated anatomic variants may necessitate additional anastomoses, increasing graft ischemia time and the risk of postoperative graft dysfunction (3).

In laparoscopic cholecystectomy, although the complication rate is less than 1%, some anatomic variants increase the risk of biliary or arterial injuries if unrecognized by the surgeon.

Multidetector CT and MR imaging, especially when hepatobiliary contrast agents are used such as mangafodipir trisodium or gadolinium benzyloxypropionictetraacetate (BOPTA) for MR imaging, clearly depict both biliary and arterial anatomic variants, with a high degree of correlation with digital subtraction angiography and with intraoperative cholangiography.

Imaging Techniques

Multidetector CT

Multidetector CT, performed with intravenous injection of iodinated contrast medium, permits
single-breath-hold volumetric data acquisition during multiphase imaging. This allows angio-
graphic and parenchymal evaluation of the liver. Thin-section scanning of large anatomic areas can
be performed at speeds three to seven times faster than possible with single-detector helical CT
scanners.

Multidetector CT angiography, a noninvasive technique, has demonstrated excellent correlation
with conventional angiography results, but it is devoid of some of the negative aspects of conven-
tional angiography, and it reduces both the costs and the radiation burden (1,2,4–7).

Despite the challenge related to the small cali-
ber of normal bile ducts, multidetector CT can
also be used for noninvasive evaluation of the bili-
ary tract in potential living liver donors. Multide-
tector CT cholangiography is performed as fol-
lows: After intravenous infusion of 25 mg of di-
phenhydramine (Benadryl; Pfizer, New York,
NY) to reduce the risk of allergic reactions, 20
mL of the cholangiographic contrast agent iodip-
amide meglumine 52% (Cholografin; Bracco Di-
gnostics, Princeton, NJ) diluted in 80 mL of
normal saline is administered as a 30–60-minute
infusion. Fifteen minutes after completion of the
infusion, multidetector CT of the liver is per-
formed with 2.5-mm collimation; images are re-
constructed at 1.25-mm intervals with a reduced
field of view.

It has been demonstrated that multidetector
CT cholangiography, owing to its higher spatial
resolution, allows better visualization of second-
order bile ducts than conventional MR cholan-
giography and mangafodipir-enhanced excretory
MR cholangiography, either alone or in combina-
tion (8).

Our multidetector CT angiography protocol
is as follows: Imaging is performed after injec-
tion of a maximum of 150 mL of nonionic iodin-
ated contrast material (iodine concentration, 300
mg/mL) through an 18–20-gauge antecubital in-
travenous cannula at a rate of 5–7 mL/sec. The
multidetector CT angiography technique is sum-
marized in Table 1.

## MR Imaging

MR imaging is an accurate and noninvasive tech-
nique for evaluating the hepatic vascular and biliary
anatomy that is devoid of ionizing radiation and
safe for patients who are allergic to iodinated
contrast agents.

Improvements in contrast agents, with the de-
velopment of hepatocyte-specific contrast agents
with biliary excretion, like mangafodipir triso-
dium (Teslascan; Nycomed, Princeton, NJ) and
gadobenate dimeglumine (MultiHance; Bracco,
Milan, Italy), coupled with advancements in gra-
dient performance, coil design, and MR angiogra-
phy software, permit faster imaging with im-
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The MR imaging protocol at our institution
involves a 1.5-T system (Signa; GE Healthcare,
Waukesha, Wis) with a phased-array torso coil.

For MR angiography, 40 mL of gadopentetate
dimeglumine (Magnevist; Berlex, Montville, NJ)
is injected intravenously with a power injector
(Medrad; Indianola, Pa) at a rate of 2 mL/sec.

For MR cholangiography with mangafodipir
trisodium, a 5 µmol/kg dose (0.1 mL/kg, up to a
maximum of 15 mL) is administered intrave-
nously by means of slow injection over 1–2 min-
utes, followed by a 10-mL saline flush. The pa-
tient is imaged 15–30 minutes after the injection
to obtain T1-weighted manganese-enhanced MR
cholangiopancreatography images.

For MR cholangiography with gadobenate
dimeglumine, a 0.05 mmol/kg dose (0.1 mL/kg,
up to a maximum of 15 mL) is administered intravenously by means of a power injector at a rate of 2 mL/sec, followed by a 20-mL saline flush. During intravenous administration, dynamic vascular images are acquired, with the same imaging delay and parameters used for the MR angiography protocol, as specified in Table 2. At 30–60 minutes after injection, the patient is again imaged to take advantage of the biliary excretion and to obtain T1-weighted gadolinium-enhanced MR cholangiopancreatography images.

The sequences used for MR angiography are listed in Table 2; those used for biliary MR imaging are listed in Table 3.

### Image Postprocessing

The raw imaging data obtained from multidetector CT or MR imaging are processed on a commercially available workstation (ADW 4; GE Healthcare) for multiplanar reformation as well as 3D reconstruction with maximum intensity projection (MIP) and volume rendering. The most useful planes for looking at the relevant anatomic variants on postprocessing views are listed in Table 4.
Vascular and Biliary Anatomy

Hepatic Arterial Anatomy
The classic hepatic arterial anatomy, with the proper hepatic artery dividing into right and left hepatic arteries, is observed in approximately 55% of the population (Fig 3). The Michel classification of hepatic arterial variant anatomy is shown in Table 5 (1).

Hepatic Venous Anatomy
In the classic hepatic venous anatomy, three main hepatic veins drain into the inferior vena cava (IVC). The left hepatic vein drains segments II and III, the middle hepatic vein drains segments IV, V, and VIII, and the right hepatic vein drains segments V–VII. In approximately 60% of the population, the middle and left hepatic veins join to form a common trunk, which drains separately into the IVC (1,10,11) (Fig 4).

Portal Venous Anatomy
The normal portal venous anatomy consists of the main portal trunk branching, at the porta hepatis, into the right and left portal veins, with the right portal vein subsequently dividing into anterior and posterior branches (12,13) (Fig 5).

Table 5
Hepatic Arterial Variants according to the Michel Classification

<table>
<thead>
<tr>
<th>Type</th>
<th>Frequency (%)</th>
<th>Description*</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>55</td>
<td>RHA, MHA, and LHA arise from the CHA</td>
</tr>
<tr>
<td>II</td>
<td>10</td>
<td>RHA, MHA, and LHA arise from the CHA; replaced LHA from the LGA</td>
</tr>
<tr>
<td>III</td>
<td>11</td>
<td>RHA and MHA arise from the CHA; replaced LHA from the SMA</td>
</tr>
<tr>
<td>IV</td>
<td>1</td>
<td>Replaced RHA and LHA</td>
</tr>
<tr>
<td>V</td>
<td>8</td>
<td>RHA, MHA, and LHA arise from the CHA; accessory LHA from the LGA</td>
</tr>
<tr>
<td>VI</td>
<td>7</td>
<td>RHA, MHA, and LHA arise from the CHA; accessory RHA</td>
</tr>
<tr>
<td>VII</td>
<td>1</td>
<td>Accessory RHA and LHA</td>
</tr>
<tr>
<td>VIII</td>
<td>4</td>
<td>Replaced RHA and accessory LHA or replaced LHA and accessory RHA</td>
</tr>
<tr>
<td>IX</td>
<td>4.5</td>
<td>Entire hepatic trunk arises from the SMA</td>
</tr>
<tr>
<td>X</td>
<td>0.5</td>
<td>Entire hepatic trunk arises from the LGA</td>
</tr>
</tbody>
</table>

*CHA = common hepatic artery, LGA = left gastric artery, LHA = left hepatic artery, MHA = middle hepatic artery, RHA = right hepatic artery, SMA = superior mesenteric artery.

Figure 3. Normal hepatic arterial anatomy in a 36-year-old living donor for liver transplantation. Axial MIP image shows the normal anatomy of the hepatic artery. CHA = common hepatic artery, LHA = left hepatic artery, RHA = right hepatic artery, SA = splenic artery, Seg IV HA = segment IV hepatic artery.

Figure 4. Hepatic venous confluence in a 47-year-old liver donor. Coronal MIP image from multidetector CT shows the confluence of the left hepatic vein (LHV), middle hepatic vein (MHV), and right hepatic vein (RHV).
Biliary Anatomy

The classic biliary anatomy appears in about 58% of the population and consists of the right hepatic duct and left hepatic duct draining the right and left lobes of the liver, respectively (Fig 6). The right duct branches into the right posterior hepatic duct, draining posterior segments VI and VII, and the right anterior hepatic duct, draining anterior segments V and VIII. The right posterior duct, which has a horizontal course, usually runs posterior to the right anterior duct, which is more vertically oriented, and fuses with it from a medial approach to constitute a short right hepatic duct. Segmental tributaries draining segments II–IV form the left hepatic duct. The fusion of the right and left hepatic ducts gives rise to the common hepatic duct. The caudate lobe usually drains to the origin of the left hepatic duct, or to the right hepatic duct. The cystic duct usually drains into the lateral aspect of the common hepatic duct below its origin (14).

Surgical Considerations

The most important concept to be kept in mind in the preoperative evaluation of a potential donor for living liver transplantation is the course of the hemihepatectomy plane. The incision is performed along a relatively avascular plane that separates the left and right lobes of the liver and runs 1 cm to the right of the middle hepatic vein, connecting the gallbladder fossa and IVC, close to the so-called Cantlie line (Fig 7).
The left lobe of the liver is left in the donor, while the right lobe is harvested for transplantation into the recipient; attention must be paid to ensure adequate metabolic vitality to both of them. Therefore, major vessels traversing the hepatectomy plane must be preoperatively identified to avoid damage with subsequent ischemic injury to the graft or the donor liver. Some of these anomalies may require modification of the surgical procedure or may even contraindicate the surgery to avoid irreversible damage to the donor liver; examples are provided later (15).

Hepatic tumor resection, mainly performed to treat hepatic metastasis, is another growing surgical field in which preoperative evaluation of vascular and biliary anatomy is of compelling importance.

About 50% of patients with colorectal cancer, the third most common malignancy in Western countries, develop hepatic metastases. Liver metastases are responsible for death in at least two-thirds of colorectal cancer patients with liver metastases. The only potentially curative treatment for these patients is liver resection, after which the 5-year overall survival rate, in selected patients, is 37%–58% (16).

The combination of advancements in diagnostic imaging, with more accurate preoperative staging, and of improvements in surgical techniques, has allowed increasingly complex liver surgeries to be performed with resultant reduction in the number of patients undergoing nontherapeutic laparotomy (17).

Preoperative selection of patients with colorectal metastases relies heavily on diagnostic imaging, since the treatment strategy depends not only on distinguishing patients with or without liver metastases but also on assessing the number, size, location, and surgical margin of the liver metastases (Fig 8). The anticipated remaining liver needs to be evaluated in order to assess the ability to preserve sufficient remnant liver (>20% in a healthy liver), adequate vascular inflow and outflow as well as biliary drainage, and two contiguous hepatic segments (18,19).

Multidetector CT and MR imaging, with the added value of postprocessed images, may allow accurate identification of areas at risk for venous congestion or devascularization, potentially influencing surgical planning with regard to the extent of hepatic resection or the need for vascular reconstructions.

The value of diagnostic imaging is even greater in cases of small residual liver volume or in patients with compromised hepatic function (eg, in hepatic cirrhosis), where minor complications such as partial hepatic necrosis or bile leakage may be fatal.

Owing to the greater variability of the right intrahepatic vascular anatomy, resections extensively involving the right hepatic lobe rely heavily on preoperative assessment of the liver with diagnostic imaging to detect vascular and biliary anatomic variants (20).

Another emerging surgical and radiologic field is intraarterial chemotherapy treatment of hepatic metastasis. After hepatic resection for colorectal cancer metastases, a combination of hepatic intraarterial chemotherapy and systemic chemotherapy is useful to treat micrometastases in the remaining liver and to prevent extrahepatic spread of malignancy.

Hepatic intraarterial chemotherapy plus systemic chemotherapy has been compared with systemic therapy alone, and the combination has been demonstrated to decrease the rate of hepatic recurrence and to improve 2-year overall survival. Intraarterial chemotherapy infusion relies on the fact that hepatic metastases derive most of their blood supply from the hepatic artery, whereas

**Figure 8.** Hepatectomy for a liver neoplasm requires complete tumor resection with tumor-free margins (arrowheads). In addition, the vascular supply and drainage of the residual liver need to be preserved.
normal liver tissue is mainly perfused by the portal vein (21). Therefore, hepatic arterial infusion pumps (HAIPs) allow delivery of maximum doses of chemotherapeutic agents to hepatic malignancies and reduced amounts to normal liver tissue and other organs, minimizing chemotherapeutic toxicity (1).

The success of hepatic arterial chemotherapy relies on accurate patient selection and surgical expertise in HAIP placement. The catheter must be inserted so as to ensure adequate and homogeneous distribution of the chemotherapy to the liver without perfusion of extrahepatic tissues. In order to preserve the long-term patency of the catheter and of the cannulated artery, the catheter tip must not create turbulence in the hepatic artery (Fig 9) (22,23).
Hepatic Arterial Variants

Because of the considerable variability of hepatic arterial anatomy (Fig 10), assessment of this anatomy is crucial in the preoperative evaluation of potential living liver donors (24). Not all the anatomic variants have the same level of importance. It varies depending on whether the variants are found in the donor or in the recipient. A replaced or accessory left hepatic artery from the left gastric artery is not important in a donor, whose left lobe is going to be left in place, but it is relevant in a recipient because, during native liver removal, extra steps are required to ligate it at the origin (Fig 11). A variant origin of the artery to the medial segment of the left hepatic lobe (segment IV) is not important in the recipient, but it is extremely relevant in the donor because the heptectomy plane would cut the arterial supply of this segment. Other variants, such as a replaced right hepatic artery from the superior mesenteric artery, require extra surgical steps in both the donor and the recipient (Fig 12) (25).

Arterial variants relevant in donors and in recipients are summarized in Table 6 (Fig 13).

### Table 6

<table>
<thead>
<tr>
<th>Hepatic Arterial Variants and Liver Transplantation</th>
</tr>
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<tbody>
<tr>
<td>Arterial Variants</td>
</tr>
<tr>
<td>Variants relevant in donors</td>
</tr>
<tr>
<td>MHA from the RHA</td>
</tr>
<tr>
<td>CHA trifurcation into the RHA, LHA, and GDA</td>
</tr>
<tr>
<td>RHA or LHA from the CHA before origin of the GDA</td>
</tr>
<tr>
<td>Variants relevant in recipients</td>
</tr>
<tr>
<td>Short RHA</td>
</tr>
<tr>
<td>Celiac artery stenosis</td>
</tr>
<tr>
<td>Replaced or accessory LHA (Michel types II and V)</td>
</tr>
<tr>
<td>Replaced hepatic trunk arising from the SMA (Michel type IX)</td>
</tr>
<tr>
<td>Variants relevant in recipients</td>
</tr>
<tr>
<td>Short RHA</td>
</tr>
<tr>
<td>Celiac artery stenosis</td>
</tr>
<tr>
<td>Replaced or accessory LHA (Michel types II and V)</td>
</tr>
<tr>
<td>Replaced hepatic trunk arising from the SMA (Michel type IX)</td>
</tr>
<tr>
<td>Note.—CHA = common hepatic artery, GDA = gastroduodenal artery, LHA = left hepatic artery, MHA = middle hepatic artery, RHA = right hepatic artery, SMA = superior mesenteric artery.</td>
</tr>
</tbody>
</table>

### Figure 13

Early branching of the left hepatic artery in a living donor for liver transplantation. CT angiogram shows early branching of the left hepatic artery (arrow) from the common hepatic artery (CHA) before takeoff of the gastroduodenal artery (GDA).

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**Vascular and Biliary Variants Relevant to Surgery**

**Hepatic Arterial Variants**

Because of the considerable variability of hepatic arterial anatomy (Fig 10), assessment of this anatomy is crucial in the preoperative evaluation of hepatic arterial variants.

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**Teaching Point**

Not all hepatic vascular variants are surgically relevant in hepatic tumor resection. The level of importance and influence on surgical technique mainly depend on the spatial relationship of the arterial variant to the tumor, to prevent injury to aberrant hepatic vessels and consequently to the hepatic parenchyma secondary to liver and biliary ischemia and to ensure complete tumor-free resection margins. Although vascular and biliary
anatomic variants need to be evaluated on a case-by-case basis, Table 7 summarizes some of the most important variants relevant to hepatic tumor surgery, according to which liver lobe contains the tumor.

### Hepatic Venous Variants

A key point to successful living donor liver transplantation is to maintain the balance between the blood supply and venous drainage of the graft. Venous congestion can seriously damage the graft, causing its failure; therefore, even small hepatic venous branches, which run along the parenchymal dissection plane, need to be left intact or reconstructed (26).

Information relevant for the surgeon concerns the pattern of venous drainage into the IVC and around the hemihepatectomy plane. The branching pattern of the middle hepatic vein needs to be carefully scrutinized because it affects the location of the heptectomy plane. Hepatic venous branches draining segments VIII and V may empty into the middle hepatic vein (Fig 14). A branch draining the right superior anterior segment (segment VIII) into the middle hepatic vein may be present in 9% of the population and has important implications, requiring extra surgical steps to avoid venous congestion of the segment (known as medial sector venous congestion) and segmental necrosis and atrophy (Fig 15) (25,26).

A venous anomaly relevant in donors is an accessory inferior right hepatic vein draining directly into the IVC, usually draining segment VI.

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### Table 7

<table>
<thead>
<tr>
<th>Arterial Variants*</th>
<th>Michel Type</th>
<th>Left Lobe Resection</th>
<th>Right Lobe Resection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replaced LHA from the LGA</td>
<td>II</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Replaced RHA from the SMA</td>
<td>III</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Replaced RHA and LHA</td>
<td>IV</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Accessory LHA from the LGA</td>
<td>V</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Accessory RHA</td>
<td>VI</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Accessory RHA and LHA</td>
<td>VII</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Replaced RHA and accessory LHA or replaced LHA and accessory RHA</td>
<td>VIII</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Entire hepatic trunk from the SMA</td>
<td>IX</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Entire hepatic trunk from the LGA</td>
<td>X</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* LGA = left gastric artery, LHA = left hepatic artery, RHA = right hepatic artery, SMA = superior mesenteric artery.

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### Table 8

<table>
<thead>
<tr>
<th>Venous Variants*</th>
<th>Implications for Surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variants relevant in donors</td>
<td></td>
</tr>
<tr>
<td>Accessory inferior RHV &gt; 3 mm</td>
<td>Increases surgical complexity, and the surgical technique must be modified</td>
</tr>
<tr>
<td>Variants relevant in recipients</td>
<td></td>
</tr>
<tr>
<td>Accessory inferior RHV draining into the IVC &gt; 3 cm from the main hepatic venous confluence with the IVC</td>
<td>Increases surgical complexity, and the surgical technique must be modified</td>
</tr>
<tr>
<td>Early branching of the segment VIII vein</td>
<td>Increases surgical complexity, and the surgical technique must be modified</td>
</tr>
<tr>
<td>Anomalous drainage of segments V and VII into the MHV</td>
<td>Risk of medial sector congestion and atrophy</td>
</tr>
<tr>
<td>Early confluence of the hepatic veins</td>
<td>Increases surgical complexity, and the surgical technique must be modified</td>
</tr>
</tbody>
</table>

*MHV = middle hepatic vein, RHV = right hepatic vein.*
or VII, rarely segment V. The anomaly may be seen in as many as 47% of cases. Sometimes more than one vessel may be found. In preoperative planning, it is important to highlight not only the presence and number of these accessory veins but also their size and their distance from the main hepatic venous drainage site along the IVC. When this distance is more than 40 mm, it may be technically difficult to implant both veins into the recipient’s IVC (25).

Venous variants relevant in donors and in recipients are summarized in Table 8.

**Figure 14.** Segment V drainage into the middle hepatic vein. Color-coded 3D image shows the drainage of segmental liver anatomy from middle hepatic vein tributaries along the surgical plane (Cantlie line) for right hepatectomy. The image was created from multidetector CT data by using dedicated software (MeVis; MeVis Technology, Bremen, Germany). Drainage of segment V (single arrow) is into the middle hepatic vein (double arrows). The volume of the segment V drainage (light brown region) is about 80 mL; therefore, the vitality of this segment needs to be preserved despite the increased surgical difficulties.

**Figure 15.** Segment VIII drainage into the middle hepatic vein. (a) Axial T1-weighted MR image of a 46-year-old living donor for liver transplantation shows a tributary vein (arrow) draining segment VIII into the middle hepatic vein. The hemihepatectomy plane (white line) intersects the accessory vein before its confluence with the IVC. (b) Postoperative axial T1-weighted MR image of the recipient shows atrophy of the corresponding liver segment (arrows). (c) On a corresponding photograph obtained during the surgical procedure, the hepatic parenchyma drained by the accessory hepatic vein appears congested (arrows).
Not all hepatic venous variants are surgically relevant in hepatic tumor resection. The level of importance and influence they exert on surgical technique mainly depend on their spatial relationship to the tumor, to prevent injury to aberrant hepatic vessels and to hepatic parenchyma (ischemia and venous congestion) and to ensure complete tumor-free resection margins (Figs 16, 17). In the case of a right lobe hepatic tumor, accessory inferior hepatic veins, which usually drain segments V and VI directly into the IVC, require additional surgical steps to be clamped or ligated. This increases the time required for the surgery and its complexity. In the case of left hepatectomy, if a large tributary vein drains segment VIII into the MHV, resection of the MHV may result in impairment of segment VIII venous drainage, with subsequent congestion, ischemia, and atrophy; therefore, extra surgical steps may be required and must be planned in advance.

Depending on the location of the tumor, vascular variants can sometimes be useful to perform unusual partial hepatectomies, providing suffi-
cient hepatic tissue to ensure tumor-free resection margins without impairing vascular drainage and supply to the remainder of the liver. For example, a tumor located in segment VII, in a patient with an accessory right inferior hepatic vein, draining more than 40 mm from the confluence of the main right hepatic vein with the IVC, can be safely resected without taking away the posterior-inferior segment (Fig 18).

**Figure 17.** Extended hepatectomy for a right lobe metastasis in a 72-year-old woman with colorectal cancer. (a) Preoperative coronal CT image shows a tumor (black arrow) in the superior segments of the right hepatic lobe; the tumor compresses the IVC and middle hepatic vein (white arrows). Therefore, an extended right hepatectomy was performed that included the middle hepatic vein and a portion of segment IV to achieve tumor-free resection margins. (b) Postoperative axial CT image shows a perfused residual lobe, indicating that the extended right hepatectomy was successful.

**Figure 18.** Unusual partial hepatectomy for tumor resection in a patient with a vascular variant. Image shows a tumor (white oval) in liver segment VII. The patient has an accessory inferior right hepatic vein (arrow) that drains into the IVC more than 40 mm from the confluence with the main right hepatic vein. Owing to this vascular variant, an unusual partial hepatectomy (white line) was performed, which allowed safe resection without loss of the posterior-inferior segment.

**Figure 19.** Portal vein trifurcation in a 52-year-old man undergoing right hepatectomy for hepatocellular carcinoma. Three-dimensional volume-rendered image (inferior oblique view) from CT angiography shows trifurcation of the portal vein into the right anterior portal vein (RAPV), right posterior portal vein (RPPV), and left portal vein (LPV).

A summary of some of the most important venous variants relevant to surgery, according to which lobe of the liver contains the tumor, is provided in Table 9.

**Portal Venous Variants**

Portal vein trifurcation is found in 10%–16% of patients (Fig 19). Although this variant does not
represent a contraindication to surgery, it needs to be known before the operation because extra surgical steps are necessary for isolation of portal vein branches.

The distance between the bifurcation of the left portal vein and that of the right portal vein must be ascertained preoperatively because of its implications for the surgical technique (25,27).

Table 10 summarizes portal venous variants relevant in donors and in recipients.

In patients with complex anatomy, multiplanar images and 3D reconstructions may be useful to clarify the relationships of the tumor to the vascular anatomy, helping the surgical planning (1). Portal variants relevant for tumor resection surgery are reported in Table 11.

### Biliary Variants

Biliary complications, occurring in 7%–10% of donors, represent the most common cause of morbidity in living donor liver transplantation; they include bile leakage and bile duct stricture. Postoperative bile leakage can occur in different locations, but mainly occurs at the caudate branches in the hilar plate. Bile leakage may also occur at the repair site of the hepatic duct and rarely along the parenchymal transection surface of the liver.

<table>
<thead>
<tr>
<th>Table 10</th>
<th>Portal Venous Variants and Liver Transplantation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Portal Venous Variants</strong></td>
<td><strong>Implications for Surgery</strong></td>
</tr>
<tr>
<td>Variants relevant in donors</td>
<td>Surgical planning must be modified because of lack of a portal segment to clamp during surgery, as well as to prevent bleeding in the donor and difficult anastomosis in the recipient</td>
</tr>
<tr>
<td>Trifurcation of the portal vein</td>
<td></td>
</tr>
<tr>
<td>Portal venules to segment V</td>
<td>Surgical planning must be modified to avoid bleeding and ischemia</td>
</tr>
<tr>
<td>Variants relevant in recipients</td>
<td></td>
</tr>
<tr>
<td>Dorsal branch of segment VII supplying the posterior-superior area of the right lobe</td>
<td>Surgical planning must be modified to prevent ischemia in the recipient</td>
</tr>
<tr>
<td>Trifurcation of the portal vein</td>
<td>Surgical planning must be modified because of lack of a portal segment to clamp during surgery, as well as to prevent bleeding in the donor and difficult anastomosis in the recipient</td>
</tr>
<tr>
<td>Acute angle of portal vein branching</td>
<td>During regeneration, the liver may engulf the veins and reduce blood supply, causing ischemia in the graft</td>
</tr>
<tr>
<td>Short length of the portal vein</td>
<td>May cause allograft failure</td>
</tr>
</tbody>
</table>

<table>
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<th>Table 11</th>
<th>Portal Venous Variants and Relevance for Tumor Resection</th>
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<tr>
<td><strong>Portal Venous Variant</strong></td>
<td><strong>Left Lobe Resection</strong></td>
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<tr>
<td>Trifurcation of the portal vein</td>
<td>Yes</td>
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<tr>
<td>Right and left portal vein branches supplying segment VIII</td>
<td>No</td>
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</table>

*Figure 20.* Normal and variant bile duct anatomy. *L* = left hepatic duct, *RA* = right anterior hepatic duct, *RP* = right posterior hepatic duct. Drawings show the normal anatomy (*A*), trifurcation (*B*), a short right hepatic duct (*C*), continuation of the right anterior hepatic duct into the common hepatic duct (*D*), drainage of the right posterior hepatic duct into the left hepatic duct (*E*), and drainage of the right anterior hepatic duct into the left hepatic duct (*F*).
It has been demonstrated that detailed preoperative evaluation of biliary anatomic variants with CT cholangiography or MR cholangiopancreatography is useful for preventing this type of complication, helping the surgeons safely perform hepatectomy in the donor and biliary reconstruction in the recipient (Fig 20) (28,29). In the setting of preoperative evaluation of the liver, T2-weighted MR cholangiopancreatography may be inadequate for identification of the intrahepatic biliary ducts and of biliary variants.

Mangafodipir trisodium (manganese dipyridoxyl diphosphate [Mn-DPDP]) and gadolinium-BOPTA are hepatospecific MR contrast agents, excreted into the biliary system, that produce T1 shortening of the bile. Mn-DPDP–enhanced 3D MR cholangiopancreatography has been demonstrated to be both sensitive and specific in identifying variants of the intrahepatic bile ducts (9,29).

One of the most common bile duct variants, found in 15.6% of cases in one series, is the right posterior hepatic duct draining into the left hepatic duct. This variant can lead to inadvertent biliary tract injury in the donor. Other common clinically relevant anatomic variants of the biliary tract that may complicate transplantation surgery include a posterior-inferior branch of the right hepatic duct draining into the left hepatic duct and biliary trifurcation (Fig 21). In some centers, biliary trifurcation may preclude graft harvesting because of the increase in the postoperative complication rate.

However, it has been demonstrated that accurate presurgical assessment of biliary anatomy variants, performed with multidetector CT cholangiography (Fig 22) or MR
cholangiopancreatography (Fig 23), allows surgeons to plan their approach before beginning the procedure and helps prevent biliary tract injuries, resulting in a low biliary complication rate of 1.9% in one series (28,30,31).

Biliary complications are also an important cause of major morbidity in hepatic tumor resection, with a prevalence of 3.6%–8.1% and high associated risks for liver failure (35.7%) and surgical mortality (39.3%). One of the most serious biliary complications is bile leakage, which has been demonstrated to increase when the resection is extended to segment I or IV. Anatomic factors, like the complexity of bile duct confluence and the variability of the left intrahepatic bile ducts, account for the higher prevalence of biliary complications after left-sided hepatectomy.

Despite advancements in hepatic resection surgical techniques, like use of an ultrasonic dissector, the prevalence of biliary complications has not substantially changed. Therefore, to delineate possible anatomic variants in the biliary tract, preoperative biliary diagnostic imaging is recommended before left-sided hepatic resection, particularly if extended hepatectomy or trisegmentectomy needs to be performed (32,33).

A summary of bile duct variants relevant in donors and in recipients is shown in Table 12, and a summary of relevant bile duct variants in partial hepatic resection for tumor treatment is shown in Table 13.

Bile duct injuries can occur after either open or laparoscopic cholecystectomy. Today, laparoscopic surgery is the standard of care for treatment of cholelithiasis, but the risks of bile duct injuries associated with this technique are increased compared with open surgery. Variant biliary anatomy is one of the factors that may contribute to the occurrence of bile duct injury after laparoscopic cholecystectomy (34).

An aberrant right hepatic duct, which occurs in 3.2%–18.0% of patients, drains part of the right lobe of the liver directly into the extrahepatic biliary tree. Being close to the cystohepatic angle (formed by the cystic duct and gallbladder below, the right lobe of the liver above, and the common hepatic duct medially), the aberrant duct may undergo accidental transection or ligation during cholecystectomy and therefore complications may ensue. These complications include formation of a biliary fistula, biloma, sepsis, pain, and repetitive episodes of cholangitis. If the volume of parenchyma drained by the ligated duct is not small, biliary atrophy with resultant jaundice may occur (35).

In about 10% of the population, the cystic duct runs for a long length paralleling the common hepatic duct, within a common fibrous sheath. This variant anatomy, if not recognized, may
cause postcholecystectomy complications. The common bile duct may be misinterpreted as the cystic duct, with resultant inadvertent ligation or transection of the extrahepatic bile duct. The extrahepatic bile duct may also undergo stricture if the long parallel cystic duct is ligated too close to the common hepatic duct.

Another potential complication is an excessively long cystic duct remnant after surgery, which constitutes the anatomic basis for calculus formation and postcholecystectomy syndrome.

Multidetector CT cholangiography and MR cholangiography allow clear anatomic delineation of the variant biliary and cystic duct anatomy; therefore, they may be used to preoperatively identify those anatomic variants that require special attention by the surgeon (36,37).

### Table 12
**Biliary Duct Variants and Liver Transplantation**

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<th>Variants relevant in donors</th>
<th>Prevalence (%)</th>
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<td>Trifurcation†</td>
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<td>RPHD draining directly into the CHD</td>
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<td>Accessory hepatic ducts</td>
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<td>Variants relevant in recipients</td>
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<td>LHD draining into the RAHD</td>
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<td>Trifurcation†</td>
<td>11</td>
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<tr>
<td>Cystic duct draining into the RHD</td>
<td>~0 (very unusual)</td>
</tr>
<tr>
<td>Accessory hepatic ducts</td>
<td>2</td>
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</tbody>
</table>

*CHD = common hepatic duct, LHD = left hepatic duct, RAHD = right anterior hepatic duct, RHD = right hepatic duct, RPHD = right posterior hepatic duct.
†Simultaneous emptying of the RAHD, RPHD, and LHD into the CHD.

### Table 13
**Biliary Duct Variants and Relevance for Tumor Resection**

<table>
<thead>
<tr>
<th>Biliary Variant*</th>
<th>Left Lobe Resection</th>
<th>Right Lobe Resection</th>
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<td>Yes</td>
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<tr>
<td>Trifurcation†</td>
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*CHD = common hepatic duct, LHD = left hepatic duct, RAHD = right anterior hepatic duct, RHD = right hepatic duct, RPHD = right posterior hepatic duct.
†Simultaneous emptying of the RAHD, RPHD, and LHD into the CHD.

### Placement of Intra-arterial Chemotherapy Pumps

In intraarterial chemotherapy pump placement, preoperative mapping of the hepatic arterial anatomy is mandatory because it aids in deciding whether the patient is suitable for the procedure itself and whether modifications of the technique are required. It is important to place the intraarterial infusion pump within the dominant hepatic artery, as proximal as possible but distal to the origin of the gastroduodenal artery. In patients with normal arterial anatomy, the chemotherapy pump is placed in the proper hepatic artery after the origin of the gastroduodenal artery (Fig 9).
patients with variant vascular anatomy, the location of the pump varies according to the origin of the gastroduodenal artery and to the relationships between the dominant artery perfusing the liver and accessory hepatic arteries (Fig 24).

Hepatic lobar arteries are not end arteries. After occlusion of a variant hepatic artery, flow to the contralateral hepatic lobe is rapidly restored through collateral vessels. Therefore, in cases of variant hepatic arterial anatomy, the variant artery can be ligated, and the restored flow through the remaining dominant hepatic artery eliminates the need to implant separate infusion pumps.

In some patients with arterial vascular variants, like replaced right and left hepatic arteries (Michel types II and IV), modification of the technique may be required. In patients whose lesion is in the right hepatic lobe and who have a Michel type III vascular variant, a pump placed in the main hepatic artery would supply chemotherapeutic agent only to the left lobe and middle hepatic artery, leaving the lesion untreated (1).

It has been demonstrated that patients with variant arterial anatomy are more likely to experience HAIP complications if they undergo cannulation of a vessel other than the gastroduodenal artery. Moreover, in the setting of multiple variant vessels, patients experience increased pump-related complications compared to patients with a single artery variant (22,23). Complications of intraarterial pump placement like extrahepatic misperfusion and chemotoxic effects on normal hepatic tissue can be minimized by preoperative evaluation of the hepatic and extrahepatic vascular anatomy. Small duodenal arteries originating between the tip of the infusion catheter and the junction of the gastroduodenal artery and proper hepatic artery must be preoperatively detected to reduce the risks of chemical cholangitis, bleeding, and duodenitis (1).

Conclusions
Multidetector CT and MR imaging with MR cholangiopancreatography, with image postprocessing, provide excellent delineation of hepatic vascular and biliary anatomy relevant to surgery. They help determine the best heptectomy plane to avoid transecting major venous branches and identify patients in whom additional surgical steps will be required. Preoperative knowledge of hepatic vascular and biliary anatomic variants is mandatory for surgical planning and to help reduce postoperative complications in both the donor and the recipient. Multidetector CT and MR imaging, with the added value of postprocessed...
images, allow accurate identification of areas at risk for venous congestion or devascularization. This information, in some anatomic variants, may influence surgical planning with regard to the extent of hepatic resection or the need for vascular reconstructions.

In cases of small liver remnants or compromised hepatic function (eg, in hepatic cirrhosis), where minor complications such as partial hepatic necrosis or bile leakage may have fatal consequences, this information is invaluable.

References


Vascular and Biliary Variants in the Liver: Implications for Liver Surgery

Onofrio A. Catalano, MD, et al

RadioGraphics 2008; 28:359–378 • Published online 10.1148/rg.282075099 • Content Codes: CT GI MR

Page 364
The most important concept to be kept in mind in the preoperative evaluation of a potential donor for living liver transplantation is the course of the hemihepatectomy plane. The incision is performed along a relatively avascular plane that separates the left and right lobes of the liver and runs 1 cm to the right of the middle hepatic vein, connecting the gallbladder fossa and IVC, close to the so-called Cantlie line (Fig 7).

Page 367
Not all the anatomic variants have the same level of importance. It varies depending on whether the variants are found in the donor or in the recipient.

Page 367
Not all hepatic vascular variants are surgically relevant in hepatic tumor resection. The level of importance and influence on surgical technique mainly depend on the spatial relationship of the arterial variant to the tumor, to prevent injury to aberrant hepatic vessels and consequently to the hepatic parenchyma secondary to liver and biliary ischemia and to ensure complete tumor-free resection margins.

Page 368
A key point to successful living donor liver transplantation is to maintain the balance between the blood supply and venous drainage of the graft. Venous congestion can seriously damage the graft, causing its failure; therefore, even small hepatic venous branches, which run along the parenchymal dissection plane, need to be left intact or reconstructed (26).

Page 372
Biliary complications, occurring in 7%–10% of donors, represent the most common cause of morbidity in living donor liver transplantation; they include bile leakage and bile duct stricture.
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