Impact of Virtual Tumor Resection and Computer-Assisted Risk Analysis on Operation Planning and Intraoperative Strategy in Major Hepatic Resection

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Hypothesis: Currently, standard planning for hepatic resection is based on the schematic description of the functional anatomy of the liver according to Couinaud, and on the evaluation of 2-dimensional computed tomographic imaging of the liver. Recent developments in image-based computer assistance allow patients' individual functional liver anatomy to be computed from mathematical analysis of standard multidetector computed tomographic scans. An intended resection can be performed virtually under realistic anatomic conditions, and the influence of different resection planes on blood supply and drainage within the remaining liver parenchyma can be calculated by a computer-assisted risk analysis. We evaluated the impact of computer-assisted risk analysis on operation planning for major hepatectomies, in particular on extent of resection or need for vascular reconstruction.

Design: Prospective cohort study.

Setting: Academic tertiary care referral center.

Patients: Twenty-five consecutive patients admitted to the hospital for major hepatectomy, of whom 4 had tumors deemed unresectable by both methods.

Interventions: Two-dimensional computed tomography was used to calculate the volume of the future liver remnant with the intended resection line manually determined, and then the volume of the future liver remnant was calculated again by computer-assisted risk analysis as the remaining liver volume not being devascularized but having both portal venous blood supply and hepatic venous drainage.

Main Outcome Measures: The difference between the remaining functional liver volumes calculated by the 2 methods.

Results: The deviation between liver volumes determined by 2-dimensional computed tomography and by computer-assisted risk analysis was less than 20% in 14 of 21 patients, between 20% and 30% in 3, between 30% and 40% in 2, and 41% and 43% in 1 patient each. The most extensive deviations were found in extended left hepatectomy or when left hepatectomy was combined with additional wedge resection in the right lobe. In 7 cases, all with a deviation greater than 20%, the results of computer-assisted risk analysis led to a change of operation planning with regard to the extent of resection (n=3) or the need for vascular reconstruction (n=4), although in 1 of these cases resection was not performed because of peritoneal carcinomatosis.

Conclusions: Image-based computer assistance allows for areas at risk for devascularization or venous congestion to be identified and precisely calculated before resection. In selected cases with small liver remnants, operation planning may be improved substantially by preoperative computer-assisted risk analysis.

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Since its theoretical introduction, computer-aided diagnosis and intervention planning has gained increasing interest. Particularly in liver surgery, preoperative imaging plays an important role in the assessment of resectability and the choice of operative strategy, ie, regarding the extent of resection or the need for vascular reconstruction. In oncologic liver surgery, complete tumor removal together with an adequate safety margin and maintenance of a sufficient amount of liver tissue to sustain hepatic function are priorities. Because the reasons for liver failure after hepatic resection are multifactorial, such as underlying liver disease, intraoperative blood loss, or postoperative septic complications, the mini-

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Classification of liver resections refers to the functional anatomy of the liver, with Couinaud first describing 8 independent portal venous segments and 4 hepatic venous segments. This model is schematically based on a regular portal venous and hepatic venous distribution, which, as shown in several anatomic studies, does not exist without exception. In contrast, the number and size of independent portal segments and hepatic venous segments, as well as their distribution on the liver surface, show great variations.3,11,12

Currently, planning of liver resection is mainly based on ultrasound, computed tomography (CT), and/or magnetic resonance imaging. Although these imaging methods provide excellent visualization of intrahepatic vascular branches, neither the number and distribution nor the extent of liver territories can be determined distinctly. Hence, in oncologic tumor resection, where the achievement of a certain safety margin may require the dissection of major intrahepatic vascular structures, areas at risk for devascularization can be identified only vaguely. Thus, prediction of the remaining and fully vascularized liver parenchyma is imprecise.

Recently developed software tools dedicated to image-based computer assistance in liver surgery, however, are based on a mathematical analysis of preoperatively obtained multidetector CT images incorporating the patient’s individual liver anatomy into the process of intervention planning.13-18 This new software enables the surgeon to perform liver resections virtually under realistic anatomic conditions, followed by an automatic calculation of the resection’s impact on blood supply and drainage in the remaining liver tissue. The areas at risk for devascularization can be assessed for each dissected branch separately, and the necessity for its reconstruction may be considered. The final result provides the remaining vascularized liver volume, taking into account the branches designated for reconstruction.

In a consecutive series of 25 patients, we prospectively evaluated the impact of computer-assisted risk analysis on operation planning for major hepatectomies.

METHODS

PATIENTS

In 25 consecutive patients (11 female, 14 male; median age, 52 years) admitted to our department for major hepatectomy, the potential value of computer-assisted operation planning was assessed. Underlying tumors were hepatocellular carcinoma (n = 7), cholangiocellular carcinoma (n = 7), adenoma (n = 1), focal nodular hyperplasia (n = 1), and metastases of colorectal cancer (n = 5), gastrointestinal stroma tumor (n = 2), anal carcinoma (n = 1), and hypernephroma (n = 1).

CT PROTOCOL

The CT imaging was performed with a 16-row multidetector CT scanner (SOMATOM Sensation 16; Siemens Medical Solutions, Erlangen, Germany). The multidetector CT protocol consisted of 3 image sets (arterial, portal venous, and hepatic venous phases) of the liver that were collected in succession with the following variables: 120 KV (peak); 140 to 170 mA seconds; section thickness/collimation, 5/0.75 mm; feed/rotation, 12 mm; rotation time, 0.5 second; reconstruction increment, 1 mm for the arterial scan and 2 mm for the venous scans. Computed tomographic angiography was performed to display the arterial hepatic anatomy. For the display of the portal and hepatic venous anatomy, second and third CT image sets were acquired 10 and 40 seconds after the arterial phase.

IMAGE EVALUATION AND INTERVENTION PLANNING

The software assistants HepaVision and InterventionPlanner were used to accomplish the volumetric risk analysis to determine liver parenchyma with postoperatively impaired blood flow. These tools are stand-alone applications dedicated to research on image-based computer assistance in liver surgery and were developed on the prototyping platform at the Center for Medical Diagnostic Systems and Visualization at the University of Bremen, Bremen, Germany.13-18 The prototypes offer a standardized workflow for computation of functional liver anatomy and volumetric risk analysis based on the standard 2-dimensional CT images (2D-CT) described in the preceding paragraph with processing times of 2 hours (expert user) on a standard desktop personal computer. The overall computations included the following steps.

Step 1: Image Analysis

All relevant structures (liver, portal vein, hepatic veins, hepatic artery, and tumors) were extracted (segmented) from the original image data. The intrahepatic vessels were transformed into a hierarchical tree representation and the direction of blood flow was noted within each vascular system. Major branches were identified from this hierarchical model and labeled with different colors to allow the user to identify them. Any subtree of interest can be selected and explored by the user. This is shown for the main branches of portal vein and the hepatic veins for patient 17 in Figure 1A and B.

The results of the vascular analysis and the liver segmentation were combined to calculate the individual vascular territories of the patient for any vascular system in this context, the term territory (not segment) always represents a part of the liver that is supplied or drained by a certain vascular branch, ie, an individual functional unit. The calculated territories of the portal venous supply and the hepatic venous drainage for patient 17 are shown in Figure 1C and D.

Step 2: Virtual Resection

To properly evaluate the impact of computer-assisted risk analysis on intervention planning, we defined virtual lines of dissection within several axial sections of the CT image data (portal venous phase) without knowledge about functional liver anatomy (as computed in step 1) and according to conventional planning criteria (Figure 2A-C). The virtual lines of dissection were interpolated then for all sections and the corresponding 3-dimensional liver split was calculated, giving the volumes for remaining and resected liver tissue (Figure 2D). This step provides the value for “remaining functional liver volume determined by 2D-CT” (rFLV2).

Step 3: Risk Analysis

In this final step, the results of the resection planning in step 2 were combined with the functional data calculated from the
patient's individual anatomy in step 1. Vascular branches subjected to dissection were identified fully automatically and the territories of the remnant liver supplied or drained by these branches were calculated. This provided the volumes of the remnant with an impaired blood flow and therefore with an impaired function, yielding the “remaining functional liver volume after computer-assisted risk analysis” (rFLV3) (Figure 3).

OPERATION PLANNING, SURGICAL STRATEGY, AND INTRAOPERATIVE TECHNIQUE

Without knowledge of the results of computer-assisted risk analysis, standard surgery planning was performed with the use of axial 2D-CT, assessing resectability and determining the line of dissection and the extent of resection (Figure 2A-C). The line of dissection was determined as follows.

The tumor had to be removed completely with a certain safety margin; whenever possible, a standard resection was planned. In right or left hepatectomies (removal of Couinaud segments V-VIII with or without I, or II-IV with or without I), the line of dissection was adjusted along the vena cava–gallbladder line. In extended right hepatectomies (removal of Couinaud segments IV-VIII with or without I), the line of dissection was oriented along the falciform ligament and umbilical fissure. In extended left hepatectomies (removal of Couinaud segments II-V and VIII with or without I), margins smaller than 1 cm were also accepted.

Total liver volume and functional liver volume (FLV), which was defined as total liver volume minus tumor volume, were measured. The volume of the future liver remnant (rFLV2) was calculated according to the determined resection line on 2D-CT (Figure 2D).

Thereafter, on the basis of the intended resection line manually determined previously on 2D-CT, the volume of rFLV3 was calculated. It was defined as the future liver volume not at risk for devascularization, but having both portal venous blood supply and hepatic venous drainage (Figure 3A-E).

Preoperative surgery planning based on 2D-CT was compared with the results of the computer-assisted risk analysis. In cases with significant differences between rFLV2 and rFLV3 (deviation of [(rFLV2−rFLV3)/rFLV2], >15%), an extended risk analysis was performed by separately calculating the impact of each dissected vascular branch causing devasculariza-
tion within the remaining liver tissue. According to the findings of the risk analysis, operation planning based on 2D-CT was reevaluated with special regard to the extent of resection or the need for vascular reconstruction. Changes in resection planning were assigned only to cases with large areas of devascularized tissue, with a difference between rFLV2 and rFLV3 of 20% being selected as the cutoff point.

Operation planning was performed by the same 2 investigators (H.L. and A.R.). Surgical exploration and liver resections were all performed by the same surgeon (H.L.).

### RESULTS

#### RESECTABILITY, OPERATIVE DATA, AND OUTCOME

There was no contradictory assessment of resectability between conventional planning in 2D-CT and planning with computer-assisted risk analysis. In 4 patients, tumors were assessed to be unresectable according to both methods. Overall, 21 patients underwent explorative laparotomy, and in 17 of these patients liver resection was possible (resectability rate, 81%). In 2 patients, the liver tumors were not resected because of intra-abdominal peritoneal tumor spread, and in a third patient there was disseminated multifocal tumor in the entire liver (which had not been diagnosed at laparoscopy 2 weeks before admission). In another case, although technically possible, planned extended left hepatectomy was not performed in a 75-year-old woman because of extremely fragile liver parenchyma after preoperative chemotherapy. The extent of the 17 performed resections is listed in Table 1.

In 16 of the 17 resections, complete tumor removal was achieved (R0 resection). The achieved safety margins ranged from 1 mm (metastasis of gastrointestinal stroma tumor) to 4 cm, with a median of 0.8 cm. There was 1 R1 resection. In this case there was microscopic tumor at the cutting margin of the right hepatic artery (due to perineural invasion) after extended right hepatectomy (segments I and IV-VIII, including hilar resection and resection plus reconstruction of the inferior vena cava and portal vein).

#### VOLUMETRY

Segmental volumetry was performed only in patients undergoing surgery (n=21). The deviation of remaining functional liver tissue with 2D-CT planning from that with

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*Figure 2. Resection planning in 2-dimensional computed tomography (patient 17). A-C, Drawing lines of dissection manually (freehand mode) within several axial computed tomographic sections of the portal venous phase. D, Areas of resected (red) and remnant (green) liver parenchyma according to the manually defined lines of dissection over all sections (only 1 section shown here). Remaining liver volume after resection planning in 2-dimensional computed tomography, 780 mL.*
computer-assisted risk analysis, \((rFLV2−rFLV3)/rFLV2\), was less than 10% in 11 patients, between 10% and 20% in 3, between 20% and 30% in 3, between 30% and 40% in 2, and 41% and 43% in 1 case each (Table 1).

In the 7 cases with a deviation of \((rFLV2−rFLV3)/rFLV2\) greater than 15%, the underlying anatomic reasons were as follows: In 3 cases computer-assisted risk analysis showed little impairment of portal blood supply (≤5% of the liver remnant achieved according to 2D-CT planning) and in 4 cases the impairment of portal blood supply ranged between 5% and 8%. Regarding the hepatic veins, computer-assisted risk analysis showed an impairment of venous outflow ranging from 18% up to 41% (Table 2).

In all planned extended right hepatectomies (resection line along the falciform ligament), the deviation was less than 10% (Figure 4). For planned right hepatectomies, the deviation ranged between 6% and 12%, and for left hepatectomies, between 11% and 23%. The most extensive deviations were noted in cases of extended left hepatectomy or when left hepatectomy was combined with an additional wedge resection in the right lobe (Table 1).

### EVALUATION OF OPERATION PLANNING AND INTRAOPERATIVE STRATEGY

In 7 patients, the results of computer-assisted risk analysis made us change our surgical strategy with regard to the

### Table 1. Differences in Remaining Functional Volume by Method of Resection Planning and Type of Hepatic Resection

<table>
<thead>
<tr>
<th>Planned Resection</th>
<th>Deviation of ((rFLV2−rFLV3)/rFLV2)*</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0%-10%</td>
</tr>
<tr>
<td>Extended right hepatectomy</td>
<td>8 (2)</td>
</tr>
<tr>
<td>Right hepatectomy</td>
<td></td>
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<tr>
<td>Left hepatectomy</td>
<td></td>
</tr>
<tr>
<td>Left hepatectomy plus segmentectomy in right lobe</td>
<td></td>
</tr>
<tr>
<td>Central hepatic resection</td>
<td>2</td>
</tr>
<tr>
<td>Extended left hepatectomy</td>
<td></td>
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Abbreviations: rFLV2, remaining functional liver volume after resection planning with 2-dimensional computed tomography; rFLV3, remaining functional liver volume after computer-assisted risk analysis.

*Data are given as number of patients. In 4 cases (shown in parentheses) tumors were not resectable (see “Results” section).
extent of resection (n=3) or the need for vascular reconstruction (n=4). In these cases, the difference in remaining functional liver volume in 2D-CT operation planning compared with planning with computer-assisted risk analysis was more than 20%. These cases all consisted of extended left hepatectomies, left hepatectomies, or central resections (Table 1 and Table 2). In 1 case resection was not performed because of peritoneal carcinomatosis, but in 6 patients, changes in operation planning could be realized intraoperatively. Volumetric data for these 6 cases are listed in detail in Table 2. Two cases are described individually.

In all resections, intraoperative ultrasound was used routinely to visualize the intrahepatic vascular anatomy. If vascular reconstruction was planned, the intrahepatic vessel in question was identified selectively by intraoperative ultrasound. In cases in which the extent of resection was enlarged because of impaired venous outflow, the corresponding vein was also visualized by intraoperative ultrasound, and the area in question was respected according to the knowledge of its extent after computation of the patient’s individual liver anatomy.

Case 1

In a 62-year-old man with an 8-cm hepatocellular carcinoma, resectability assessed by 2D-CT suggested left hepatectomy plus partial resection of segments V and VIII. The calculated FLV and rFLV2 were 1357 mL and 720 mL, respectively. Computer-assisted risk analysis with respect to hepatic venous drainage showed that segment VI was not drained via the right hepatic vein but almost entirely by a large tributary into the middle hepatic vein. Since resection of the middle hepatic vein was required, rFLV3 would have decreased to 442 mL, corresponding to 33% of FLV (Figure 5A). Therefore, preoperative operation planning was changed to include reconstruction of this hepatic venous branch. At operation, the vein draining segment VI was visualized by intraoperative ultrasound and carefully freed. Temporary closure of this vein with a vascular clamp led to venous congestion of the liver tissue drained by it. Interposition of a venous allograft between this vein and the vena cava provided sufficient hepatic venous outflow of the entire liver remnant (Figure 5B).

Case 2

In a 41-year-old woman with 2 metastases of anal carcinoma in segment VII and in the left lobe (segments III and IV) infiltrating the left portal vein, operation planning with 2D-CT suggested left hepatectomy (segments II-IV) and subsegmentectomy of segment VII with a calculated rFLV2 of 798 mL. Computer-assisted risk analysis showed that segments V and VI were entirely drained by the middle hepatic vein. According to 2D-CT planning, the middle hepatic vein had to be dissected centrally within the liver. Thus, segments V and VI would have been without venous drainage, resulting in an rFLV3 of only 471 mL (Figure 6A-E). At operation, a subsegmentectomy of segment VII was performed. Thereafter, during left hepatectomy, the middle hepatic vein was localized with intraoperative ultrasound. The venous wall was partially resected and then carefully reconstructed with a small vascular patch harvested from the dissected left hepatic vein. In this way, venous drainage of segments V and VI could be preserved completely (Figure 6F).
The aim of our study was to determine the extent to which computer-assisted risk analysis can influence the operation planning of liver resections in comparison with standard 2D-CT. Our preoperative analysis included volume measurements of vascular liver territories as well as an exact evaluation of localization and extent of liver tumors with respect to intrahepatic vessels. For each dissection line manually selected on 2D-CT, we were able to perform a risk analysis for both the portal vein and the hepatic venous system to calculate the liver volume at risk for devascularization.

The most interesting finding of our study was that in one third of the resections planned with 2D-CT, computer-assisted risk analysis showed an amount of devascularized liver tissue greater than 20% and up to 43%, mainly due to venous congestion and only slightly due to impaired portal venous perfusion. This is valuable information because the importance of optimal venous outflow for sufficient liver function has become more and more evident with the development of right-lobe living-donor liver transplantation.20,21 Although hepatic circulation in segmental liver transplantation and partial hepatectomy varies (ie, due to different underlying pathophysiologic pathways such as cold or warm ischemic time or hemodynamic alterations in the splanchnic system in cirrhosis), it is likely that venous congestion might also lead to impairment of liver function after hepatic resection.

There are several reports in the literature addressing the management of resected hepatic veins in partial hepatectomy for liver malignancies.22-27 In all of these articles, reconstruction of liver veins was based on the knowledge of the typical hepatic venous anatomy. However, in none of these reports had exact visualization and calculation of the involved liver tissue been performed before operation. In contrast, the method of computer-assisted risk analysis presented in this study allowed us to calculate precisely the amount of the corresponding area when dissecting a certain hepatic vein. To our knowledge, this is the first report in which the decision for hepatic venous reconstruction was supported by and derived from an exact volumetric analysis of potentially devascularized hepatic parenchyma.

Figure 4. A, Resection planning and volumetry in 2-dimensional computed tomography for a large cholangiocellular carcinoma requiring extended right hepatectomy. Red indicates area to be resected; green, remnant liver parenchyma. Remaining liver volume after resection planning in 2-dimensional computed tomography, 619 mL. B, Computer-assisted risk analysis showing a remaining functional liver volume after computer-assisted risk analysis of 607 mL, indicating a difference between methods of only 2%.

Figure 5. A, Liver with a centrally located hepatocellular carcinoma. Computer-assisted risk analysis with respect to hepatic veins shows that the right hepatic vein (blue) is draining segments VII and VIII, whereas segment VI is almost completely drained via the middle hepatic vein (yellow). This area (red bordered) would be without venous outflow in case of removing the middle hepatic vein. B, Operative site after reconstruction of the biliary tract with a hepaticojejunostomy and after interposition of an allogeneic venous graft between segment VI vein and vena cava. The remaining liver tissue, in particular the inferior part, is homogeneous without signs of venous congestion.
In resections in which computer-assisted risk analysis showed a deviation of rFLV2 from rFLV3 of more than 20%, the intrahepatic course and distribution pattern of the right and middle hepatic vein differed by far from the regular hepatic venous anatomy as described by Couinaud. In all of these cases, the right hepatic vein was relatively small while the middle hepatic vein drained a very large area of the right liver lobe. In particular, the inferior lateral portion of the right liver lobe—corresponding to Couinaud segment VI—was more or less completely drained via the middle hepatic vein rather than right hepatic vein. Without knowledge of this variation but following the standard operation planning based only on 2D-CT, large amounts of the remaining liver parenchyma would have been left without venous drainage. Although the sequelae of impaired venous outflow are not known with certainty, it is likely that venous congestion would result in functional impairment or even necrosis, predisposing to biliary and infectious complications. Therefore, our strategy was to minimize these potential risks. Because there is always a certain amount of necrosis at the resection surface, we changed our operation planning only in cases in which more than 20% of the remaining liver tissue was at risk for impaired blood flow.

The decision whether to resect areas with venous congestion or to reconstruct the venous outflow depended on the entire volume of remaining functional liver parenchyma. We restored the hepatic venous outflow to preserve liver tissue in cases with a small volume of remaining functional liver parenchyma (rFLV3/FLV, <0.4) and when the risk of postoperative liver insufficiency seemed to be increased. The latter was especially true in extended left hepatectomies with very large raw surfaces or when major hepatic surgery was combined with additional gastrointestinal surgery, such as biliary anastomosis. In cases in which the remaining liver tissue seemed large enough for adequate function, we preferred to resect the areas with venous congestion to avoid the potential risks of vascular reconstruction.

In the series presented herein, the portal and hepatic venous anatomy of the left lateral liver lobe (Couinaud segments II and III) was nearly uniform, with the umbilical fissure being almost exactly the anatomic border between segments II/III and IV. This is already known from segmental liver transplantation of the left lateral lobe. Accordingly, computer-assisted risk analysis did not give decisive additional information in any of these cases, and we did not change any of the planned extended right hepatectomies. In addition, computation and visualization of the patient's individual functional liver anatomy also confirmed the vena cava–gallbladder line to be the border between the left and the right portal venous system. However, when the liver was dissected along this line, computer-assisted risk analysis predicted an impairment of the venous outflow of the remnant, a phenomenon that is already well known from living-donor liver transplantation. The vascular impairment within the right liver lobe ranged from little venous congestion...
to major congestion of the anteromedial sector (23% of the entire remaining liver tissue).

The most extensive differences were noted in extended left hepatectomies or when left hepatectomies were combined with wedge resections of the right lobe. This can be explained by anatomic factors. First, the vascular anatomy of the right lobe, in particular the distribution of the right and middle hepatic veins, shows great variability. Second, on the right liver side there are no surface landmarks outlining the segmental borders (ie, like the umbilical fissure on the left side). Therefore, in contrast to extended right hepatectomies, we consider computer-assisted risk analysis to be very useful in the operation planning of extended left hepatectomies because it may help to identify larger areas at risk for devascularization, thus showing the need for either performing vascular reconstruction or changing the planned line of transection. Consistently, in central hepatectomies computer-assisted risk analysis is helpful only with regard to the dissection line within the right liver lobe.

Intraoperative use of the findings based on the process of computer-assisted risk analysis is hampered by the fact that there are no markers on the liver surface representing the intrahepatic vascular territories. Intraoperative application is currently based on intraoperative ultrasound and the surgeon’s ability to transduce the preoperative figures into the operative site. Therefore, the development of intraoperative navigation systems is one of the most exciting and promising issues in the field of computer-assisted hepatic surgery.

The necessity to transduce the preoperative findings of computer-assisted risk analysis into the operative site was the reason why operation planning and hepatic resections were done by the same surgeon in all cases in our study. This seemed to be the best way to ensure the intraoperative realization of the preoperatively planned reconstructions, although this carries the risk of a bias. Therefore, future studies are warranted in which operation planning will be investigated by several independent surgeons to avoid a potential systematic mistake.

In our study only the portal venous and hepatic venous system were analyzed, but the same considerations are true for the hepatic artery and to some extent also for the biliary tree. Therefore, ongoing progress in computer assistance and imaging operation planning will have to include the hepatic venous system as well as the entire Glisson Trias.

We have focused on first liver resections only. The potential use of computer-assisted risk analysis will probably be even greater in repeated liver resections because of the altered vascular system. In particular, repeated liver resection after left or right hepatectomy is often hampered by having only one remaining major hepatic vein.

In conclusion, computer-assisted risk analysis provides a reliable preoperative view of the number and extent of portal venous segments as well as their relation to hepatic veins. Thus, areas at risk for either devascularization or venous congestion may be identified and precisely calculated before resection. In selected cases, this information may influence operation planning with regard to the extent of resection or the need for vascular reconstructions. This is especially important in cases of small liver remnants or marginal hepatic function, where minor complications such as partial hepatic necrosis, infectious complication, or bile leakage may have fatal consequences. Because of the great variability of the right intrahepatic vascular system, in particular of the right and middle hepatic veins, operation planning for resections that go deeply into the right lobe, ie, extended left hepatectomies or central liver resections, may be improved substantially by preoperative computer-assisted risk analysis.

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Patient selection and operative planning for hepatic resection are based in large part on tomographic imaging provided by computed tomography and, to a lesser extent, magnetic resonance imaging. Information provided by these studies allows identification of the number and location of tumor sites within the liver. On this basis, operative resection decisions are made, including the type and extent of resection (anatomic vs nonanatomic). In most circumstances information provided by a standard preoperative contrast-enhanced image is sufficient for operative planning purposes, without the need for specialized image processing.

More recently the use of preoperative imaging has played a greater role in liver surgery, particularly with extended hepatic resections, where a small remnant liver volume may be insufficient for postoperative recovery. The use of computer-aided software now allows the clinician to define the remnant liver volume, and this can be used to calculate the volume of the expected remaining hepatic parenchyma. This technique is used at most liver surgery centers for extended hepatic resection for tumors, but it also plays an important role in operative planning for live-donor liver transplantation.

In the current report, Lang et al introduce an important innovation for preoperative image analysis before hepatic resection. Their technique defines the functional liver remnant after major hepatectomy on the basis of maintenance of portal venous inflow as well as hepatic venous outflow. The authors identified a subset of patients at risk for significant areas of nonfunctional remnant liver (ie, compromised vascular supply) and, on this basis, modified their planned operative procedures with the intent of improving patient outcomes. In cases where the remnant liver volume was large, portions of the at-risk liver were resected to eliminate a remaining ischemic segment. In circumstances where the remnant liver volume was borderline or small, vascular reconstruction was performed to allow adequate perfusion of such segments. Resections most likely to leave large “at-risk” segments included left hepatectomy and extended left hepatectomy, clinical circumstances where operative results have always been associated with the highest complications rates. Interestingly, the results for extended right hepatectomy did not require modification in this series, perhaps relating to the more predictable portal venous inflow and hepatic venous drainage based on the anatomic landmark of the falciform ligament.

As is the case with all important developments in the field of surgery, this article introduces new questions that will need to be answered during the coming years. While impairment of portal venous or hepatic venous blood supply to the remnant liver is important, does impairment of either one of these areas of vascular supply result in complete elimination of the involved segment from the parenchymal volumetric calculation? The authors have not provided details regarding the assessment of the biliary tract or hepatic arterial assessment to the remnant liver, and clearly these must play an important role. While operative planning in marginal cases using virtual resection techniques appears to be of assistance to the operating surgeon, techniques to ensure that the planned plane of resection is accurate have yet to become clinically available. From this standpoint, the development of image-guidance techniques in liver surgery may allow liver surgeons to more precisely execute preplanned operative procedures.

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