A new measure to assess the difficulty of liver resection

S. Beller a, S. Eulenstein a, T. Lange a, M. Niederstrasser a, M. Hünerbein b, P.M. Schlag b,c,*

a Surgical Research Unit OP 2000, Campus Berlin Buch, Charité Universitätsmedizin, Berlin, Germany
b Klinik für Chirurgie und Chirurgische Onkologie, Robert-Rössle Klinik, Berlin-Buch, Berlin, Germany
c Charité Comprehensive Cancer Center, Charité Campus Mitte, Universitätsmedizin Berlin, Invalidenstrasse 80, 10117 Berlin, Germany

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Abstract

Background: There is no valid measure to assess surgical difficulty and feasibility of a planned liver resection. It is the objective of this study to evaluate a mathematical measure from a 3D graphical analysis.

Methods: Eleven different 3D models of hepatic tumours were evaluated by experts for resectability and analysed with Amira® graphic software taking into consideration the portal and hepatic venous vascular relationships. Virtual resection volumes with increasing resection margins from 1 to 30 mm were determined separately for portal veins, hepatic veins, their intersections and volume unions. The integral of the increasing resection volumes was defined as risk coefficient. The risk coefficients from this volumetric analysis were compared with the expert opinion.

Results: The risk coefficient based on the integral of portal venous and hepatic venous volume unions reproduced the expert opinion highly significantly (correlation coefficient 0.9, \( p < 0.05 \)) and more accurately than volumetric analysis of the planned resection margin.

Conclusion: With automated volumetric analysis, anatomically problematic situations in liver surgery can be reproduced and scaled. The risk coefficient obtained is a suitable objective measure for defining risk areas in liver surgery.

Keywords: Liver; Surgery; Risk; 3D; Volumetry

Introduction

Liver surgery has made enormous progress in recent decades. Preconditions for this were optimised anaesthesiological management, improved anatomical knowledge of liver segmentation, refined diagnostics and the development of better techniques of tissue dissection and haemostasis.1–5 However, correct preoperative risk assessment and operation planning are crucial for patient safety.6,7

In addition to the site of a lesion, there are many patient factors and liver factors like liver function, presence or absence of liver cirrhosis or fatty change and patient’s body build, that determine the difficulty and risk of liver resection. Central segments, in particular those close to the hilum, are problematic areas in liver surgery. Critical situations can arise due to small volume of postoperative residual parenchyma and impaired liver function.8,9 But imminent dangerous moments for major liver resections can be assessed relatively well using volumetry of preoperative 3D models and functional tests.10–13 Less centrally located tumours present variable degrees of surgical difficulty and feasibility as well, depending on their size and position relative to the vascular tree. Such tumours can face the surgeon with different risk and surgical challenge regarding the achievement of an R0 resection while sparing central structures.

Intraoperative ultrasound and the use of modern navigation technique are definitely helpful to achieve R0 resection while sparing as much parenchyma as possible at the same time.14,15 However, for better planning of liver resections, a differentiated and objective measure of the difficulty of tumour resections is desirable. Scaling of problem areas in liver surgery must take into account particularly the position relative to the portal and hepatic veins. On the basis of preoperative 3D models, we have developed a mathematical algorithm to define and scale problem areas in liver surgery for solitary hepatic lesions and have tested its usefulness through comparison with an expert opinion.
Methods

Material selection

The selection of 3D models had to meet two preconditions. The selection should execute a large variance of tumour locations and it should be possible for the experts to evaluate the number of models within a reasonable time. Preliminary tests in evaluating 3D models demonstrated, that with much more than 10 models and multiple examples of each position, obtaining a subjective expert opinion of high quality is not viable. Thus particular attention was paid to a good cross-sectional case selection of tumours and to different size of tumours with various positional relations to vessels. Eleven preoperative 3D models of solitary hepatic tumours with different degrees of difficulty as estimated subjectively were selected from our own patients for this analysis. For an optimised selection range the localization of the tumour was virtually changed in four of these cases. The tumours were distributed in all problem areas and liver segments and are shown in Fig. 1. The tumours had a median diameter of 4.8 cm (1.3–9.7).

Production of such 3D models has already been described in detail elsewhere and is based on data from 64-slice multidetector computed tomography (LightSpeed VCT; General Electric Medical Systems, Milwaukee, WI).14,16,17

Obtaining the expert opinion

The 11 3D models labelled A–K together with the Amira® visualisation software (Mercury Computer Systems Inc., USA) were made available to 15 experienced surgeons specialised on hepatobiliary surgery. Using this software, they were able to rotate and view the models on their personal computer as they wished. The surgeons were asked to classify and rank the liver models according to the feasibility of resection from position 1 (very easy) to position 11 (most difficult). A resection proposal (local excision, segment-guided resection, left/right hemihepatectomy, anatomical/expanded) had to be documented.

Mathematical algorithm to determine the degree of difficulty

The Amira® graphics and visualisation software (Mercury Computer Systems Inc., USA) were used for this analysis. Special modules were developed in this system for automatic calculation of all required variables.

For each case, the vascular-dependent and virtually omitted volume of the resected liver parenchyma were calculated in steps of 1 mm with an increasing resection margin from 1 mm to 30 mm. For each voxel of the liver parenchyma, the geometric relationship to the dependent vascular structure was determined separately and in the virtual resection impairment of the portal vascular supply and the venous drainage (hepatic veins and vena cava) was classified correspondingly. The portal and hepatic veins were resected virtually when the segmental vessel margin was reached at the site corresponding to the selected resection margin. The vena cava was resected virtually with the assumption of a possible wall excision of the vessel according to a separate standard. Only when the vessel midline of the vena cava was reached this was analysed as a total perfusion deficit of the liver.

Besides the virtual resection volume depending on the portal vascular supply (RVpv) and the venous drainage (RVhv), the intersection (RVpv ∩ RVhv) and volume unions (RVpv ∪ RVhv) were calculated. All volumes were stated as a percentage of the total liver volume.

The risk coefficient (rC) was defined as a measure of the degree of difficulty of a potential liver resection. It was calculated as integral of the different virtual resection volumes from 1 mm to 30 mm resection margin (RM) and was scaled according to the following formula to the maximum variant (loss of the entire liver parenchyma with just 1 mm virtual resection margin):

\[ rC = \int_{1}^{30} f(RM)d(RM)/30 \]

Data analysis

The order of the models resulting from the expert opinion was compared with the variables from the mathematical calculation. The correlation was analysed using the non-parametric Kendall Tau-b test.

Results

The expert opinion

The experts’ classification according to the degree of difficulty (feasibility) and the recommended types of resection are shown in Table 1. The variance of the classification (range of ranking) was five steps for cases B and F, and at least four steps for cases A, I and K. The planned types of the surgical procedures also varied considerably.

The mathematical determination of the degree of difficulty

The time required to analyse the corresponding volumes and risk coefficients was 8–9 min for each 3D model.

The risk coefficients obtained with the mathematical algorithm are listed in Fig. 2 and compared to the ranking of the models from the expert opinion. Fig. 2 also includes the volume unions RVPV ∪ RVhv for liver models A–K shown graphically.

The correlation of the risk coefficients with the expert opinion was not significant for the volume calculation based
on the portal veins. For all other virtual resection volumes (calculations based on the hepatic veins and the intersection and volume unions depending on the portal and hepatic veins), the correlation was highly significant. The data and the correlation analyses, along with a comparison with the tumour volume and tumour diameter, are shown in Table 2. Contrary to expectation, the hepatic vein-dependent analysis showed a higher correlation than the combined volume.

Table 1
Expert opinion of various liver models with solitary liver tumours

<table>
<thead>
<tr>
<th>Liver model</th>
<th>Ranking (degree of difficulty)</th>
<th>Frequency of recommended type of resection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Average</td>
</tr>
<tr>
<td>C</td>
<td>1–1</td>
<td>1.0</td>
</tr>
<tr>
<td>E</td>
<td>2–3</td>
<td>2.3</td>
</tr>
<tr>
<td>G</td>
<td>1–4</td>
<td>2.7</td>
</tr>
<tr>
<td>J</td>
<td>3–5</td>
<td>4.2</td>
</tr>
<tr>
<td>A</td>
<td>4–7</td>
<td>5.0</td>
</tr>
<tr>
<td>F</td>
<td>5–9</td>
<td>7.0</td>
</tr>
<tr>
<td>K</td>
<td>6–9</td>
<td>7.0</td>
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<tr>
<td>I</td>
<td>6–9</td>
<td>7.5</td>
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<tr>
<td>B</td>
<td>6–10</td>
<td>8.2</td>
</tr>
<tr>
<td>D</td>
<td>10–11</td>
<td>10.3</td>
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<tr>
<td>H</td>
<td>11–11</td>
<td>11.0</td>
</tr>
</tbody>
</table>

The ranking classifies the degree of surgical difficulty.
Abbreviations for the resection proposal: E — local excision, S — segment-guided resection, HR(E) — right hemihepatectomy (expanded), +p.C — potentially (partial) resection of vena cava, and INOP — case is inoperable.
However, by omitting the cases B, D and H with a high proportion of hepatic veins the correlation for the combined volume (RVPV ∩ HV) was clearly superior. The overall data list of the resection volume unions RVPV ∩ HV for resection margins of 1–30 mm was further analysed. For each resection margin, the correlation with the expert opinion was analysed separately (correlation coefficient) and then contrasted with the risk coefficient. This analysis confirmed that the risk coefficient determined from the volume unions with the described mathematical algorithm (rC = \( \int_{\text{RM}}^{30} f'(\text{RM})d(\text{RM})/30 \)) is the best measure for illustrating risk regions and a better measure than the analysis of the actually planned resection margin.

### Discussion

Problem situations in liver surgery exist especially in central tumours extending to large vessels and small tumours which are difficult for the surgeon to localise and palpate intraoperatively. When resection is too cautious,
there is a danger of an inadequate safety margin resulting in histopathological R1 situation and an increased risk of recurrence. However, with an extensive resection, the patient can be endangered by impaired postoperative liver function. In addition, centrally located tumours raise the problem of balancing the necessity of central vessel resection and reconstruction with all its risks against the increased risk due to a marginal resection.

Clinical preoperative risk assessment for liver resection

Preoperative liver function can be measured objectively by functional tests or scoring systems and the functional residual volume can be estimated with scintigraphy or volumetry. Additionally a transfusion risk score was developed for predicting perioperative blood transfusion in liver surgery. This risk score could lead to substantial saving by improving the cost-effectiveness of the autologous blood donation programme. However, these parameters have ultimately been disappointing. Only the maximum limits, which the surgeon will and can expect from the patient, are worked out. Ultimately the individual estimation of the anatomical degree of difficulty is made intuitively and is always a relative assessment.

Assessment of tumours according to the tumour size and peripheral or central location only is certainly not sufficient for a differentiated consideration. Assignment of tumours to more easily accessible segments (II, III, IVb, V, VI) and those that are more difficult (I, IVa, VII, VIII) enables additional classification. But the combination of these tumour characters is difficult to assess and to measure objectively.

Preoperative risk assessment is usually based on the surgeon’s experience and his attention during imaging study. However, the difficulty and demands of a surgical procedure can be more or less evident. Apart from the tumour size, the position (liver segment/central or peripheral location) and the residual functional liver parenchyma, there is currently no objective measure available for the anatomical degree of difficulty of a liver resection. Ultimately all available factors are very difficult to estimate jointly. An exact definition of the different degrees of difficulty is, therefore, not possible using the previous measurement parameters. The size and relation of the tumour to the individual vascular tree relative to the total volume of the liver are decisive for the anatomical degree of difficulty of a liver resection.

Volumetric preoperative risk assessment for liver resection

Volumetric methods have proven especially when planning liver transplants and for determining the functional residual volume for large liver resections. Using volumetry to determine a risk coefficient that reflects the expected degree of surgical difficulty is an obvious possibility.

With the aid of the mathematical algorithm presented, based on the diminishing functional residual parenchyma with increasing safety margin, variables were analysed that scale the anatomical degree of difficulty and the surgical challenge. Measurement parameters were validated through a comparison with an expert opinion. They reproduced the expert opinion on a limited number of models of liver tumours. However, the mathematical software algorithm is favourable as this is an objective reproducible measure, whereas the experts’ opinions have a high variability. The presented analysis shows that the risk coefficient is best illustrated by the hepatic vein-dependent resection volume and the volume union of portal perfusion deficit and hepatovenous drainage deficit. There was no correlation with the portal vein-dependent perfusion deficit in our analysis. This effect can only be explained by a biased case selection. Although the liver is supplied only by one portal vein but three hepatic veins, the selection included three tumours (case B, D and H) which are in a variable but close relation with the hepatic vein star. In these cases even a resection margin of a few millimetres leads to total impairment of venous outflow from the liver. In contrast, the main portal vein is affected in only two cases (F, K) and only within a resection margin of 30 mm.

Because of this imbalance in the case selection, the surprisingly high correlation of the hepatic vein-dependent analysis and the lack of correlation for the portal vein-dependent analysis are explicable. An analysis performed without liver models B, D and H shows a corresponding change in the correlation coefficients (Table 2) and thus confirms the superiority of the volume unions (RV$_{PV}$ U HV) as a basis for calculation. A mathematically exact proof for this would be possible either through a second series or by randomisation. An increase in the number of cases is hardly feasible according to our experience because of the difficulty of obtaining an experts opinion. Thus arranging a greater number of cases is not feasible due to the massive increase in time needed to obtain a qualitatively equivalent expert opinion.

In the expert opinion, assessment of tumours of medium degree of difficulty is very variable. Liver models A, F, K, I and B vary in the hierarchy by up to five steps. In general estimation of the distance of a tumour from vessels is sometimes difficult even on a 3D image. A more precise analysis of these cases suggests that the 3D models were often not considered perfectly from all the necessary angles despite the limited number of cases. As a consequence vascular relations were occasionally estimated incorrectly. This may also explain the sometimes different resection plans. Probably the expert results may also be skewed, since most centers do not routinely use such 3D models in assessing resectability.

Conclusion

Computer-derived risk analysis does not out-weigh clinical judgement and experience, but it is a helpful tool. It is
with medium degrees of difficulty, that automated measurement with the aid of a risk coefficient has advantages. When the graphics software is programmed accordingly, the additional time needed to determine this objective measure is negligible, since preoperative 3D simulation is often included in the preoperative planning anyway.

The presented analysis shows that the risk coefficient obtained of the resection volume union can help in objectively assessing the degree of difficulty of liver tumour surgery. This measure can also be used for an objective comparison of groups in studies. In addition there are advantages for objectivising the indications for intraoperative use of 2D, 3D and/or contrast-assisted ultrasound and of more complex intraoperative aids such as navigation equipment.

Whether these volumetric variables have clinical relevance and can predict a complicated postoperative course must be investigated in a larger group of patients. Validation of this algorithm for multiple metastases is also necessary. However, particularly desirable is a tumour-specific risk score that can be included into the clinical routine.

**Conflict of interest**

The authors have no conflict of interest to disclose.

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**Reference**

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