The LiverSurgeryTrainer - Training of Computer-Based Planning in Liver Resection Surgery

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Abstract

Purpose The training of liver surgeons depends on local conditions such as the specialization of the clinic, the spectrum of cases, and the instructing surgeons. We present the LiverSurgeryTrainer, a software application to support the training of prospective surgeons in preoperative decision-making.

Methods The LiverSurgeryTrainer visualizes radiological images, volumetric information and interactive 3D models of patients' liver anatomy. In addition, it provides special interaction techniques and tools to perform individual resections on the training data. To assess the correctness of decisions made by the learner, comments and decisions from experienced liver surgeons are provided for each case. To complete the case, additional material concerning the actual surgery (e.g., videos, reports) is presented. The application workflow is derived from a scenario-based design process and is based on an instructional design model.

Results The LiverSurgeryTrainer was evaluated in several steps. A formative usability evaluation identified workflow and user interface flaws that were resolved in further development process. A summative evaluation shows the improvement of the LiverSurgeryTrainer in nearly all analyzed aspects. First results of a learning success evaluation show that learners experience a learning effect.

Conclusion Our training system allows surgeons to train procedures and interaction techniques for computer-based planning of liver interventions. The evaluations showed acceptance and usability.

Purpose

Conventional medical training in surgery strongly depends on available experts and the existing case spectrum. Besides training of surgical skills with medical simulators [1] the selection of an ideal treatment strategy and the training of surgery and treatment strategies play a major role. Until recently, the established method for the planning tumor interventions has been to select the most effective therapy on the basis of clinical data and 2D slice data. However, spatial conditions, especially the location of a tumor in relation to the complex vessel trees, are difficult to evaluate and create complications. Thus, computer-based planning systems are applied more frequently. Especially for the planning of treatments concerning the liver, 3D models of the liver, its vessels, and pathological structures are reconstructed from the slice data. Based on these models, different treatment possibilities can be assessed. More and more systems support these therapy decisions and pre-operative planning in liver surgery [2]. The application of such systems is not part of the medical education, and a training system is essential.

The LiverSurgeryTrainer enables training the required workflow, preoperative decisions, and interaction techniques for the planning of interventions (e.g., determination of virtual resection surfaces) on the basis of 2D slice data and 3D models. It does not aim to provide a simulation of the actual intervention to improve manual skills. Training with the system aims to enhance surgical competencies and acceptance of computer-based planning. To provide adequate information, we include expert comments and decisions. In addition, videos put the learner's planning decision in relation to expert recommendations.

Medical Background

The human liver has a complex vascular structure. Three vessel systems are responsible for the blood drainage (hepatic vein) and supply (hepatic artery and the portal vein) of the liver. The anatomical variations are manifold, so that it is necessary to identify individual anatomy for operation planning.

For the therapy decision in case of liver carcinoma and living liver donor transplantations (LDLT), consequences on vessel supply and drainage play a major role. In particular, the splitting of a liver for a LDLT is challenging, since both parts require working blood supply and drainage. An oncological resection should be performed with a safety margin around the tumor or metastasis to ensure that all tumor cells are removed. Long-term survival depends on the resection of all lesions and an adequate safety margin. There exist various types of resections regarding the extent and location of the resection surface. Typical anatomical resections include hemihepatectomy (removal of right or left lobe of the liver), extended hemihepatectomy (removal of right or left lobe of the liver and additional segments) and central resection (removal of central/middle segments).

After liver resection, the liver tissue can regenerate itself. That means that the liver grows to its original size several months after surgery. However, the postoperative residual liver volume should be at least 20% of the total estimated liver volume for normal parenchyma, 30-60% if the liver is injured by chemotherapy, steatosis, or hepatitis, or even 40-70% in the presence of cirrhosis [3].

Computer Assisted Planning and Training Systems

Conventionally, planning liver interventions is performed using contrast-enhanced CT data. One main task for radiologists and surgeons is to assess which volumes should be resected and which should be preserved. This is a challenging task, because the segments and the vessel anatomy vary strongly from patient to patient and are modified by tumor growth, previous surgeries, and regenerative growth.
Computer-based 3D reconstruction of the patient anatomy significantly enhances the accuracy of tumor localization and the accuracy of the planning of oncological interventions and LDLT [4]. Computer-assisted planning for liver cases has been clinically used for several years. Its usefulness in liver surgery has been validated for tumor surgery [4, 5, 6] and LDLT [7].

Existing e-learning systems are primarily interdisciplinary, case-based learning systems for medical students focused on diagnostics and medication-based treatment (e.g., Casus system, www.casus.eu, Campus system www.medicase.de). Most surgical training systems concentrate on non-patient-specific surgery simulation with deformable models [1, 8]. Furthermore, there are web-based surgical platforms which provide anatomical basics [9], videos, presentations of experts, information about surgical techniques and instruments as well as communication features (www.webop.de, www.websurg.com). There are no systems for training procedures and interaction techniques for computer-based planning of interventions on the liver.

In the following sections, we describe the development and evaluation process of the LiverSurgeryTrainer as well as the potential users, training steps, cases, and special features.

Methods

The development of the LiverSurgeryTrainer was carried out on the basis of a *scenario-based design* [10, 11]. In this context, scenarios are semi-informal methods to specify software design. Scenarios describe the situation or system which should be enhanced and the system that should be developed in natural language. This facilitates the communication between developers, physicians and prospective users [12].

Initially, the design ideas, content, and layout of the systems are included. They describe the learning content, learning goals of the training system as well as the training and planning processes. Before writing the first scenarios, we analyzed the clinical workflow in conversations with surgeons and observed their actions. Thus, the clinical practice for planning surgery and liver intervention was explored in depth.

In a step-wise improvement and specification during the development, the initial scenarios are adapted. Through discussions of the scenarios with surgeons, problems could be identified and resolved before implementation. The didactical concept of the LiverSurgeryTrainer is based on the Four-Component-Instructional-Design-Model [13], see section “Educational concept”. General user interface design principles [14, 15] such as consistency, aesthetic and minimalistic design, undo functions for interactions, and help functions were realized in an iterative process.

The implementation of the LiverSurgeryTrainer is based on MeVisLab and the Medical Exploration Toolkit (METK). MeVisLab is a graphical development environment for medical image processing and visualization. Existing modules supplemented by own developments can be freely combined in data-flow networks to build complex software prototypes [16]. The METK offers advanced visualization and exploration techniques as well as efficient case management (e.g., animations for smooth transitions between different viewpoints, interaction support of object selection) [17]. Detailed information about the used resection technique can be found in [18, 19].

Users of the LiverSurgeryTrainer

The target user groups for the LiverSurgeryTrainer are assistant surgeons specializing in abdominal surgery. They can be assumed to have a broad knowledge of liver anatomy and its diseases, but their experience in surgery, especially liver surgery, may vary. Furthermore, they may exhibit heterogeneous skills in computer usage and interaction with 3D models. Therefore, the LiverSurgeryTrainer provides support for several tasks but also enables a fluent workflow for more experienced users.

Learning goals

After training with the LiverSurgeryTrainer, the learner should be able to come to therapeutic decisions and planning independently. Furthermore, he/she should be more familiar using and interpreting 3D models. The training of therapeutic decisions involves, amongst others, the following aspects:

- Judgment and assessment of examinations (e.g., ultrasound, CT) and interpretation of the results from blood examinations
- Identification and assessment of anatomical variants and anomalies
- Determination of virtual resection surfaces that consider the remnant liver volume, the risk structures and the safety margin around the tumor
- Gain knowledge of possible complications and modifications of therapy proposal during the intervention

Resultant surgical questions for decision making in liver resection planning are for example:

- Is the patient resectable?
- Which segments have to be resected?
- Can lesions be resected with an appropriate safety margin?
- Is the estimated postoperative remnant liver volume sufficient?
- Is functionality of the vessel systems ensured after the resection?

The training should support the process of building mental rules for the planning workflow. Furthermore, the LiverSurgeryTrainer conveys interaction techniques for drawing resection lines in the 2D data and for exploration of the 3D model (zooming, rotating, and translating). Therefore, venous and arterial phase of the CT data are provided. Users have to deal with several anatomical variants of the vessel system and pathological structures, which they have to identify based on the slice data and the 3D model of the patient anatomy (first planning step).

Educational concept

In the framework of holistic case-based learning, users should acquire the knowledge and skills to make self-contained diagnosis and therapy decisions. We provide authentic learning cases and oriented the design of the training steps to the clinical workflow. This way of knowledge transfer imparts:

- Interdisciplinary knowledge instead of isolated factual knowledge
- Clinically applicable knowledge and strategies for problem solving

Furthermore, we used the *Four-Component-Instructional-Design-Model* [13, 20, 21] as basis for the didactical design. This model was specially developed for the design of training systems for complex skills. The application of its four components (learning tasks, part-task practice, supportive information, and just-in-time information) for the LiverSurgeryTrainer is described in the following.

The training cases are classified in *task classes* ranging from simple to complex. The complexity is determined by the number of skills that are necessary to accomplish the task (e.g., location and shape of the resection surface, number and type of the structures at risk). At the beginning, the single steps are described in detail and the learner receives detailed process instructions for the interaction (e.g., for drawing and editing the resection surface). During the advanced training of cases with equal complexity, the support is faded out and the learner receives only complex tips. The computer-based planning of surgical procedures includes the definition of cutting planes and the interaction with 3D models (e.g., rotation, zooming, and measurements). The accomplishment of these tasks is critical for the entire planning. Therefore, these subtasks should be trained separately in *part-task practices*. Thus, the best possible accuracy and increasing speed during the execution of these subtasks should be reached. Subtasks are presented at the beginning of each task class for which its execution is primarily needed. They follow a description of a simple example case (e.g., resection of a small, peripherally located tumor) to establish a connection to the whole task. The example case may be a commented expert video of a complete surgery planning. It clarifies the single training tasks and their application to the learner.

The learner receives *supportive information* in terms of relevant information concerning the medical aspects of the training case. Details are provided what to consider in each special case (e.g., variants of the vessels and tumor location with respect to major vessels). Examples of experts and their comments offer additional information regarding the medical background and specifics of computer-based planning. Furthermore, learners receive feedback about their planning result by using a comparison with expert recommendations. We included more than one expert recommendation for each case to convey different surgical courses.

In the context of the *just-in-time information,* the user receives support by planning and interacting with the 2D and 3D data. Different help modes offer different degrees of support. Rules and the necessary knowledge for the accomplishment of these rules are conveyed.

Training Workflow

The training steps of the LiverSurgeryTrainer (see Fig. 1) are guided by the clinical workflow and the training cases are based on anonymized real patient data to provide a holistic (problem-oriented) learning process. After choosing the training case (oncologic case or living donor liver transplantation), the learner receives all necessary information regarding the patient data, the anamnesis, and the accomplished examinations (ultrasound images and results, data of the blood examination). Afterwards, the CT slice data is presented to enable the user exploring the patient individual anatomy and pathology. The surgeon has to decide on an applicable therapy strategy based on all available information. Planning this therapy decision will be performed in subsequent training steps. For the planning process, the CT data and a 3D reconstructed model of the patient anatomy (liver, tumors, and vessels) are available. Resection surfaces can be placed, and the learner receives information about resected and remnant liver volumes. In the next step, the planning result is presented and compared to several expert recommendations. To complete the case, information regarding the OP protocol, pathology report, videos and photos of the real surgery and information about the post-operative process are presented to the learner.

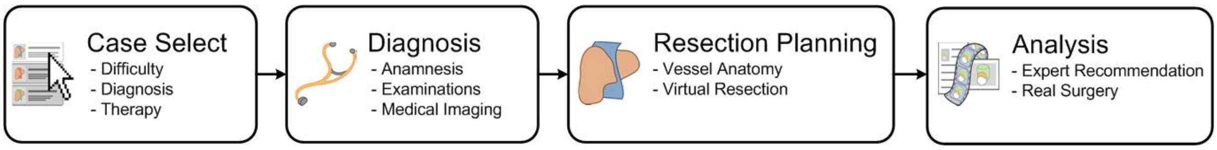

Fig. 1: Training steps of the LiverSurgeryTrainer oriented to the workflow of liver surgery planning.

Training Cases

The final version of the LiverSurgeryTrainer contains 13 training cases (11 oncological cases and 2 LDLT cases). Table 1 gives an overview of available cases and their difficulties. We differentiate between three degrees of difficulty (easy, medium, and hard), which depend on the location of the tumor, its distance to vessels at risk, and the degree of resection difficulty.

Three cases can be utilized to train the combination of several resections. In each case a hemihepatectomy and the removal of single segments or an atypical resection has to be planned. The case basis contains all important oncological surgery strategies. The number of cases roughly reflects the incidence in the clinical daily routine, albeit the low number of cases is not a representative ratio of the different surgical strategies.

For living liver donor transplantation, there are two training cases included (an adult donates for a child). The planning of these surgeries is not very challenging. The cases are suitable for an introduction to the training system. Until now, the case spectrum contains no donations for adults.

Resection	Number	Difficulty
Ext. Hemihepatectomy right	3	2 hard, 1 medium
Ext. Hemihepatectomy left	1	hard
Hemihepatectomy right	2	medium
Hemihepatectomy left	1	medium
Segmentectomy	4	1 hard, 2 medium, 1 easy
Atypical resection	3	1 hard, 2 medium
… thereof combined resections	3	1 hard, 2 medium
LDLT child	2	1 easy, 1 medium
LDLT adult	-	

Table 1 Training cases of the LiverSurgeryTrainer and their characteristics.

To ensure the quality of the program the cases were validated by experienced surgeons. Cases were reviewed regarding plausibility, correctness and relevance. Only cases, which all experts evaluated as correct and useful, were integrated into the LiverSurgeryTrainer.

Procedure of the Surgical Planning

The planning of the surgery or rather the intervention is divided into two steps:

- judgment of the vessel anatomy
- definition of the resection surface

The *assessment of the vessel anatomy* is essential for planning. In many cases, the vessels exhibit anatomical variations that especially affect resection planning. The assessment of the vessels is carried out on the basis of biphasic CT slice data. The user is guided through three steps in which the vessel anatomy of the three vessel systems (portal vein, hepatic artery, and hepatic vein) shall be characterized. For novice users, colored 2D overlays of all relevant structures are available. These overlays shall support users in detecting vascular structures in the slice data. Users can also select the 3D model of the patient for their evaluation. However, the standard for the assessment shall be the 2D data, because this is a well-established method in the clinical routine.

The *planning of the resection* is performed conventionally as well on the basis of the slice data. Therefore, the method for virtual resection planning described by Konrad-Verse et al. [18] is utilized. Learners are introduced in the 3D planning after doing the planning in 2D. They can switch to the 2D viewer at any time of the planning process. The presentation of the 3D model after the exploration of the 2D slices shall boost their reliance in the 3D models and the new way of planning. First, virtual resection lines are drawn on the slices (see Fig. 2). They have to be drawn approximately on each tenth slice. This depends on the positions of structures at risk. Second, resection lines in other slices are linearly interpolated. Third, the resection surface and remnant and resection volumes are calculated automatically. The user can modify the resection surface to improve planning by direct manipulation of the resection lines (e.g., if remnant volume is too small, vessels are cut or the safety margin is neglected). Fourth, the planning result is presented in the 3D model (see Fig. 3).

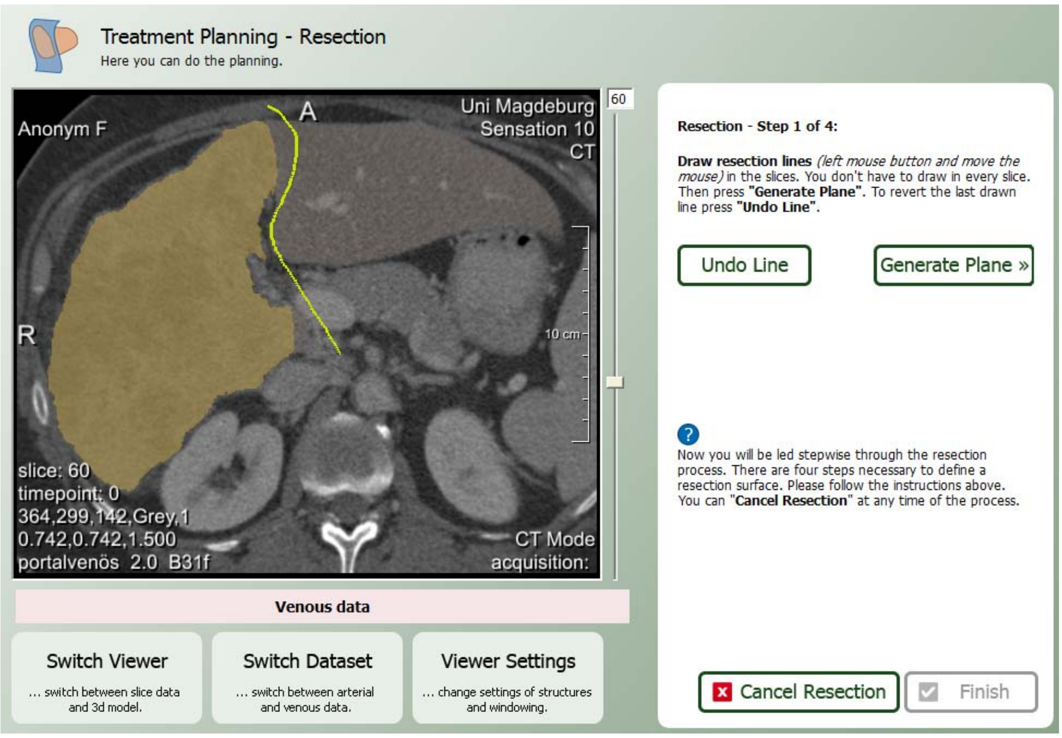

Fig. 2: Drawing the resection lines (yellow) in the slices. As support for novices, the tumor is presented with a colored overlay. In each step, the user receives support about the current task (bottom right).

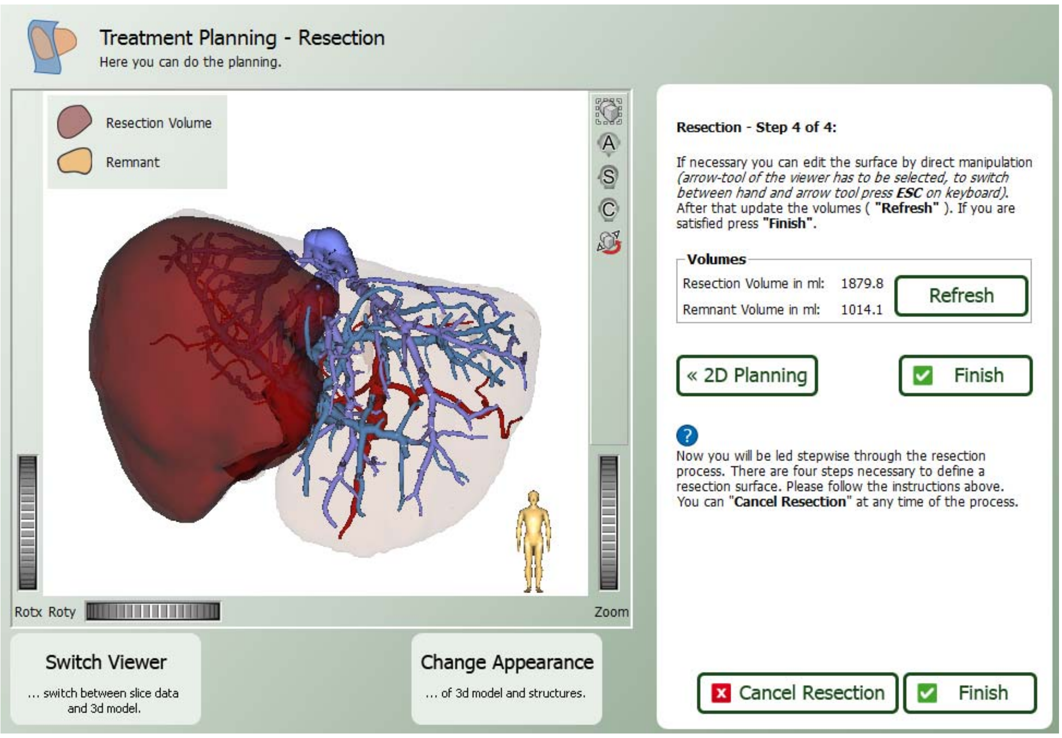

Fig. 3: After the 2D planning, the result is presented in 3D for validation (resection volume: red, veins: blue, hepatic artery: red). Quantitative volume information is presented on the right.

Analysis of the Planning

A quantitative comparison of the learner's result and expert's results is accomplished in terms of a self-regulating feedback. Learners can compare self-contained their resection planning with the planning of several experts. Because there is not only one correct resection strategy, we don´t integrate a direct assessment of the user´s planning. We want to convey that in clinical practice there are different approaches to remove a tumor. In visual analysis, the planning of the user and the expert recommendation are presented side by side in synchronized 2d and 3d viewers. This allows the user to inspect both planning's from same point of view. In addition, the comparison is presented textually (e.g. anatomical variants, number of resection surfaces, volume of remnant and resection liver parenchyma). The procedure and gives reasons for his decision are explained by the expert. Specifics or difficulties of this special case (e.g. cirrhosis, need of a vessel reconstruction) are pointed out.

Special Features

During the research for the LiverSurgeryTrainer, we developed and evaluated several features which enhanced the learning qualities of the system. In order to provide a stable release version, not all features described in this paper are available in the public DVD version.

Annotation techniques were developed to support learners during their exploration and evaluation of patient-specific liver anatomy. With the help of these techniques, segmented structures can be labeled automatically in the 2D slice data and the 3D model. Due to a lack of space for the labels, they are placed automatically in front of structures with low priority (e.g., the liver parenchyma), and nearby parts of one structure were grouped. Furthermore, a new interaction technique was developed to label and visualize hidden structures [22].

To familiarize learners with new cases and to support them during interactive exploration of the 3D data, we developed *3D animation techniques* for liver planning models. The developed syntax for the animation techniques is very abstract and based on a script language that can be used independently from the case and its geometry and topology [23].

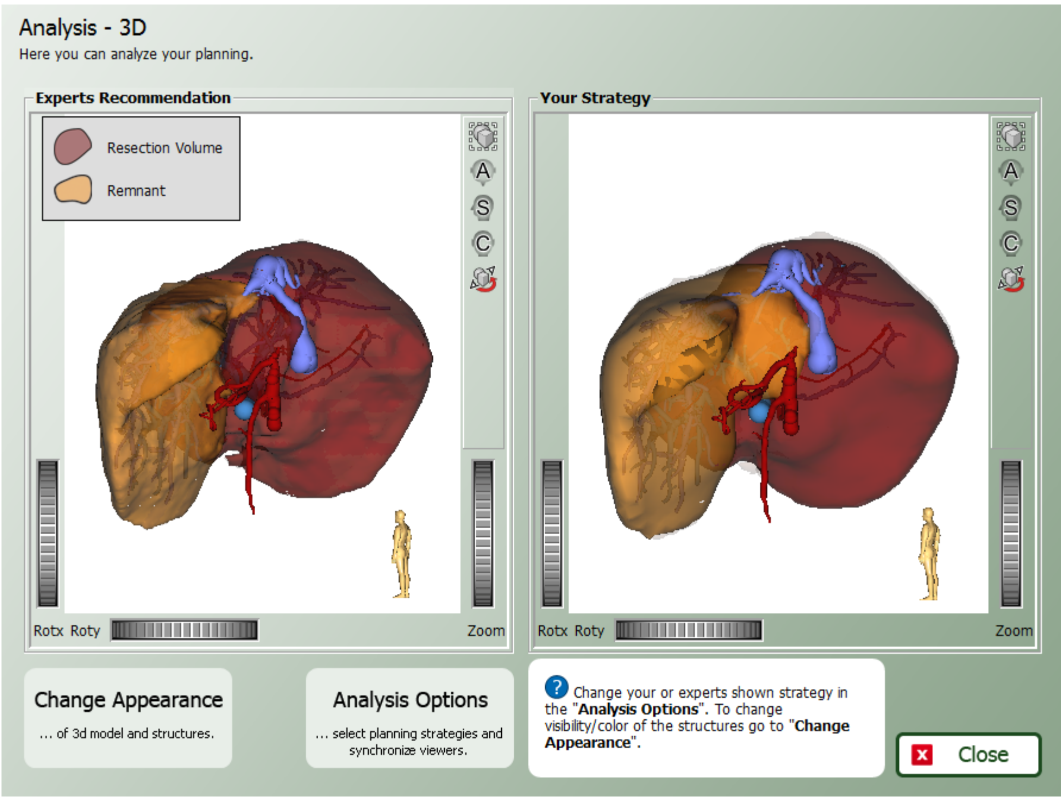

Fig. 4: Planning result of the user and the expert is presented in synchronized 3D viewers (resection volume: red, remnant: orange, hepatic vein: blue, hepatic artery: red)

Evaluation

The LiverSurgeryTrainer underwent different evaluations during the development process. At the beginning of our project, we performed a formative study with 11 surgeons (average age of 32 (30-44), 9 of them with more than 5 years professional experience) [24]. The participation was anonymous. An early-stage prototype of the training program was presented to the participants in order to identify workflow and other usability problems. In addition, priorities for the further development were determined. Feedback from questionnaires and oral discussions was collected. The feedback addressed the used terminology, conceptual errors, learnability, waiting times, and a general assessment of the system. The most important result of this study was that participants asked for more guidance and simpler interaction methods during the training process. It also turned out that attractive visual design is more than an optional feature but essential for the perceived usability and finally the acceptance of such a tool. Training steps should be made more fine-grained, and the advanced control elements should be displayed only on demand.

Based on these first results, the LiverSurgeryTrainer was subject of a fundamental redesign. The evaluation of the second prototype was based on the first study to guarantee comparability (evaluation form can be found on our website www.liversurgerytrainer.de). Analysis included whether the re-design of the LiverSurgeryTrainer resulted in better acceptance. 12 surgeons from our subject pool took part in this study (average age of 27 (25-63), 6 of them with more than 5 years professional experience). No test person confirmed a participation in the first test.

Assessment of the learning effect. In order to make a statement about the learning effect, a third study with so far 4 medical students and 2 assistant physicians was performed (average age of 26 (25-27), assistant physicians with 2 years surgical experience). After a short introduction in the handling of the system, each student was asked to perform the training with 5 oncological cases. The cases were selected by an experienced liver surgeon intending to provide cases with nearly equal difficulty. During the experiment, these cases were presented to the learners in random order. The experiments were recorded on video for post-experiment analysis (time measurements and comments of participants). After completion of each case, participants were asked how confident they feel with their planning. After completion of all cases, they filled out a questionnaire concerning the assessment of their subjective learning success.

Results

An overview of the results of the studies concerning the assessment of the LiverSurgeryTrainer is shown in Table 2, 3 and 4. In the second study nearly all evaluated aspects were rated within the positive sector of the scale. A positive trend between the first and the second version of the LiverSurgeryTrainer can be recognized. Best improvement took place in the general impression (average of 2.67 vs. 1.60) and the feedback to the user about the current state of the system (average of 3.38 vs. 1.78). The average of the temporal learning effort shows no improvement in the second version. It indicates that some time will be necessary to get used to the system and its functionality. This could be owing to the complexity of computer-based resection planning and/or the moderate experience of the surgeons with computers and 3d models.

The performed interviews regarding the subjective learning success in the third study show that participants enhanced their skills especially in the field of 3d interaction, comprehension of the general workflow of computer-based planning, and the definition of virtual resection surfaces (see Table 4).

Three participants stated that they improved their skills significantly in interaction with the slice data and choosing an appropriate window leveling. Another three participants indicated that they learned much about the interaction with the 3d models, especially the orientation/rotation of the models. The analysis of required times for each training step did not show any significant differences between the cases.

Usability aspect	**Average/ σ**	**Median**
Handling of the LiverSurgeryTrainer	3.23 (± 1.69)	3
Feedback of the program about its current state	3.38 (± 1.80)	3
Waiting times that arise during the training	3.69 (± 1.97)	4
Learnability of the handling	2.46 (± 1.45)	2
Temporal learning effort	3.31 (± 1.49)	3
Evaluation of the LiverSurgeryTrainer in general	2.67 (± 1.5)	2

Table 2 Results of the first usability study showing the median/average responses and standard deviation σ with response of 1 corresponding to "very good" and a response of 7 corresponding to "very bad".

Usability aspect	**Average/ σ**	**Median**
Handling of the LiverSurgeryTrainer	2.44 (± 0.73)	3
Feedback of the program about its current state	1.78 (± 0.83)	2
Waiting times that arise during the training	2.67 (± 0.87)	2

Learnability of the handling	2.67 (± 0.87)	3
Temporal learning effort	3.11 (± 1.90)	3
Evaluation of the LiverSurgeryTrainer in general	1.60 (± 0.70)	1.5

Table 3 Results of the second usability study showing the median/average responses and standard deviation σ with response of 1 corresponding to “very good” and a response of 7 corresponding to “very bad”.

Learning effect	**Average/ σ**	**Median**
Handling of 3d models (rotating, zooming, ...)	1.83 (± 0.75)	2
Handling of the CT data (windowing, slicing, ...)	3.50 (± 1.05)	3.5
Determination of vessel variations	5.00 (± 2.10)	5.5
Workflow of computer-based virtual resection	2.33 (± 1.37)	2
Definition of virtual resection surfaces	2.83 (± 2.56)	1.5

Table 4 Results of the assessment of the learning effect (third study) showing the median/average responses and standard deviation σ with response of 1 corresponding to “yes, I have learned” and a response of 7 corresponding to “no, I have not”.

Discussion

The LiverSurgeryTrainer is a system for the training of preoperative decision making and computer-based planning of liver resections (oncological and LDLT) [21, 25]. For more information visit our website www.liversurgerytrainer.de. The system is based on patient specific training cases to convey knowledge and planning skills as realistic as possible.

The LiverSurgeryTrainer includes a wide range of different clinical datasets. However, it is not possible to integrate own cases into the system in order to perform a planning. If this would be possible, the LiverSurgeryTrainer would be no longer a training system but a planning system. Therefore, robust methods for image registration and segmentation as well as medical certification would be necessary. In addition, the LiverSurgeryTrainer is not a surgical simulator which allows training of manual skills on the basis of deformable models. This is not the intention of our system and would suppose expensive input devices.

Training with the LiverSurgeryTrainer makes the learners aware of their own decisions. Based on expert recommendations learners should assess their planning by themselves. To intensify this process of mediate own decisions, the possibility to define more than one resection strategy is provided. The user could be asked additionally to rank his strategies concerning his confidence in each decision and give reasons for the ranking.

The first public prototype of the system is available on DVD but is has some limitations. It contains 11 oncological cases and 2 living liver donor transplantations for the training. The user is able to do the computer-based planning for these cases by drawing resection lines and testing different resection strategies. He gets feedback by the presentation of expert recommendations, which includes the resection surface and a short justification for his strategy. In this version the algorithm for the resection calculates the anatomical liver volume, not the functional volume. The described annotation and animation techniques are not available in the DVD version. It is available for independent review and can be ordered via our website.

We did only include cases in our database, which are eligible for a surgery, because the focus of the first version of the LiverSurgeryTrainer is the training of location and drawing of resection surfaces and not the decision making if a patient is eligible for a surgery or not. Cases which could not be resected would be finished after the initial steps. However, the integration of non-eligible patients would be a good extension of the learning goals of the LiverSurgeryTrainer. With these cases it would be possible to train the decision if a patient is operable and tumors/metastases are resectable. Therefore, patients which are not operable (e.g. bad general condition) and patients which are not resectable (e.g. cirrhosis of the liver – Child-Pugh-Score C, big central tumor) should be integrated.

In our opinion, no ground truth for a specific resection strategy in liver surgery exists. Therefore, we do not provide an objective score to the trainee. We use the self-regulating feedback and several expert recommendations to sensitize the user for the fact that there is not only one correct resection strategy. However, besides the self-regulating feedback, it seems to be reasonable to provide comparison values regarding the width of the safety margin around tumors, the amount of remnant liver volume, or the curvature of the resection surface. An interesting approach concerning the computer-based assessment of virtual resection surfaces is described by Demedts et al. [26]. Surgical quality properties are interactively computed and a single quality measure for a resection surface is generated. Thus, the evaluation of virtual resection surfaces is no subjective task. Another possibility to give the user reliable feedback of his planning could be a remote expert analysis. The learner could upload his planning results on a server and experts provide individual feedback.

The kind of feedback which is provided to the learner is an interesting point for discussion. In our work, the provided expert opinions include a detailed description of the decisions that the expert made to choose a resection strategy for the specific patient. Besides these subjective assessments, quantitative values such as the amount of functional liver volume after surgery could be beneficial from an educational point of view. This value could be very valuable for learners in addition to the expert opinions. From a technical point of view, the postoperative functional liver volume is hard to determine preoperatively because of regeneration processes in the liver which are not fully understood by now [27]. In our tool, the learners have to assess the potential functional volume after resection based on the 3D model of the hepatic vessels and the virtual resection surface. They have to learn that the planned resection volume is not equivalent to the postoperative functional liver volume. Nevertheless, an extension of the liver surgery trainer with a 3D visualization of vascular territories at risk from different vascular systems as described in [28] would be a valuable extension of our system. However, even with such visualization the real functional remaining liver volume after resection would be an estimation based on model assumptions.

The performed evaluations confirm that the LiverSurgeryTrainer is accepted by participants of the study. The usability of the training system was iteratively improved during the development process. This improvement was controlled by the first and second usability study as well as continuous feedback that we received from clinical partners. The third study showed that learners experience a learning effect when using the system. However, contrary to our initial expectations, learners did not get faster from case to case. One possible reason is that participants reported that the selected cases differed greatly in their difficulty (although experts selecting them considered them as roughly equally difficult). For example, more than one virtual resection surface was planned by the learners in several cases. We conclude that the complexity of a case is in the eye of the individual user, its intended strategy for the planning, and may vary depending on the surgical experience. Three participants indicated no learning success concerning vessel variations (they rated with 6 and 7 on a scale ranging from 1 corresponding to “yes, I have learned” to 7 corresponding to “no, I have not”). These answers, however, have to be considered carefully. The participants indicated no learning success regarding to vessel variations. Because this question is not formulated specifically, one interpretation may be that the participants knew everything about vessel variations in the liver. Another, likely probable, interpretation could be the liver surgery trainer does not convey knowledge regarding the vessel variations sufficiently.

In a follow-up project, a web-based interactive training tool for liver surgeons is currently developed. Diagnosis, surgical reports, patient specific 2d and 3d data of the liver, and self-assessment exercises shall procure liver anatomy and surgical basics. The training tool will be integrated in a Web 2.0 learning and cooperation platform where surgeons can upload, explore, and discuss interesting medical cases, techniques, surgical movies, and 3d visualizations.

To sum up, the methods proposed in this work contribute to the field of computer-assisted liver surgery and have the potential to improve the training of surgeons. Research in liver surgery training has not been completed by now. The development needs to be continued in the future in strong collaboration between radiologist, surgeons and scientists.

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