Any surgical intervention on the liver, be that a classical resection or a complex split for living donor liver transplantation requires an in-depth three-dimensional (3D) understanding of the organ’s internal vascular and biliary anatomy in order to preserve adequate organ function after the treatment. This means that vascular in- and outflow need to be adequately maintained and the bile collection system uninjured after the surgical procedure. Due to these challenges, liver resections, ablations and transplantations have only become possible relatively late in surgical history and even nowadays remain a challenging procedure.

The introduction of surgical planning based on pre-operative 3D imaging data from computer tomography (CT) or magnetic resonance imaging (MRI) enables a better understanding of surgical strategies and a quantitative assessment of the risk factors. Furthermore, surgical strategies can be evaluated and optimized prior to surgery, using the available planning data. Clinically applicable surgical planning solutions are nowadays available from companies such as MeVis Distant Service AG (Bremen, Germany) (Figure 1). Extensive clinical studies have shown that highly accurate 3D planning enables better assessment of risk situations and therefore leads to safer surgery. Using similar techniques on post-operative image data, it is also possible to monitor patient recovery and to detect eventual disease recurrence.

The missing link between virtual surgery planning and evaluation is intra-operative support for the reproduction of a planned surgical treatment, leading to an increase in the precision of the resection and / or the ablation treatments. This in turn should be reflected in improved R0 resections and / or more precise, safe tumor ablations, even for cancer deposits at critical, inaccessible locations. The ultimate goal is to thus increase the chances of a curative treatment for the affected patients. The development of such navigation systems for Computer Aided Liver Surgery (CALS is topic of ongoing research since the late 1990’s when first clinical trials appeared. Technological developments in combination with improvements in computational power have led to increased accuracy and usability of such systems3-5.

Clinical indications
While the exact clinical indications for and application of CALS still need to be defined and are likely to change and expand as the technology behind CALS is subject to continuous improvements, current use includes complex liver resections, combined resections / ablations or donor hepectomy in living donor liver transplantation.
In patients with extensive bilobar disease or with tumor deposits lying within the caval confluence, surgical resection or other ablation techniques (such as microwave or radiofrequency ablation) may be deemed impossible owing to a high operative risk, and in the case of extensive removal / destruction of parenchyma, postoperative liver failure. While careful preoperative planning is of course always essential in hepatic resections, this can prove life-saving in particularly complex surgical settings, where a fine line often needs to be drawn between complete oncological (R0) resection and not endangering the patient’s immediate postoperative outcome. It is in these settings, that the use of computer aided 3D imaging with preoperative computer-assisted risk analyses and volumetrics as well as the use of intraoperative guided resections may substantially change the surgical approach and with it, potentially also the patient’s outcome.

Other settings include resection of liver tumours which are not anymore visible, as improved chemotherapy regimes result in radiological „complete response“ and surgeons are faced with the problem of carrying out surgery on non-visualizable, non-palpable lesions. The advantage of CALS thus lies in fusing pre- and post-chemotherapy CT images and permitting image-guided, stereotactically navigated resection of normal-looking parenchyma. With radiological-clinical response rates not always equaling pathological, the patient’s immediate postoperative outcome. It is in these settings, that the use of computer aided 3D imaging with preoperative computer-assisted risk analyses and volumetrics as well as the use of intraoperative guided resections may substantially change the surgical approach and with it, potentially also the patient’s outcome.

The aim of any new technological development such as CALS is to provide maximal support with minimal changes in the routine workflow and operative processes.

Developers of intra-operative support systems for surgery on soft tissues are always faced with a trade-off between the attainable accuracy and the required procedural effort to obtain adequate deformation handling. Based on the clinical setting (living donor liver transplantation, intraoperative tumor ablation or complex liver resections), adequate technological support needs to be chosen and assumptions regarding the deformation need to be made. Finally, the general constraints of the intraoperative setting (workflow, workspace, interferences, sterility requirements) have to be taken into consideration in order to determine an adequate approach for CALS (Figure 3).

The aim of any new technological development such as CALS is to provide maximal support with minimal changes in the routine workflow and operative processes.

Current applications and Future Outlook

At the Inselspital Bern as well as in other hospitals in Germany, CALS is already in use in on-going clinical trials. Patients requiring liver resection (+/- ablation) for benign or malignant diseases are currently being recruited and initial results evaluating feasibility and accuracy have generated promising results. The main problem with computer navigated surgery of the liver inherently lies with the organ itself. The soft, parenchymatous liver tissue is subject to constant, albeit usually relatively subtle movements. One of the main issues are the nearly unavoidable breathing artifacts due to the attachments of the liver to the diaphragm. Once the surgeon has mobilized the liver by partially or completely freeing the liver from these attachments, breathing artifacts may be slightly reduced but now the entire organ is subject to increased movement. While the anesthetist may aid the process of intraoperative navigation by controlled apnea and the surgeon by packing swabs around the organ after mobilization, thus „stabilizing“ the liver, the extent of deformation caused by further surgical manipulations or respiratory movements can only be minimized and never completely abrogated.

Future improvements may be achieved with the use of a frame or „cage“ (Figure 4), employed to maximize registration accuracy as artifacts due to respiration or surgical manipulation are minimized. The „cage“, which is made of biocompatible material, is fabricated from patient specific preoperative images with the surgical instruments then being navigated relative to the target using dedicated openings in the template. A virtual three-dimensional liver cover mesh is calculated based on the segmentation of the liver surface and spherical markers integrated into the mesh, thus allowing for the mesh and hence the liver surface to be tracked by an optical navigation system (Peterhans et al, work in progress). Once the „cage“ is placed around the liver, further major deformations are avoided and the registration process is rendered significantly more accurate. While such frames are still in the pilot phase, they may help revolutionize CALS in the future.

![Figure 3: Intraoperative setting. Visible are the stereo camera system using infrared light and the computer screen showing the current intraoperative situs of the liver, the vessels and the location of the tumors. The screen is covered with a sterile plastic cover, allowing the surgeons to touch the screen and select the image of choice while also being able to flip the image, improving the 3D understanding during the resection.](image1)

![Figure 4a - b: a. Screenshot of the liver mesh after reconstruction from a patient prior to resection b. Liver template in biocompatible material with attached markers for tracking and guiding holes for ablation needles.](image2)