Abstract Image-guided surgery and navigation have resulted from convergent developments in radiology, teletransmission, and computer science. Patient selection and preoperative planning in hepatobiliary-pancreatic (HBP) surgery rely on preoperative imaging. The operative procedure is finally led by the fusion of additional information gained by the palpating hand and intraoperative ultrasound. Despite advances in reducing morbidity and mortality, decisions are often hardly quantifiable and are restricted to super-specialists in HBP surgery. New developments in computed tomography (CT) and magnetic resonance imaging (MRI) technology have led to the possibility of the volumetric prediction of liver resections. These data can be shared via telemedicine and used for simulation and training. Three-dimensional (3D) reconstructions have led to a better topologic understanding of tumor-vascular tree relations in the individual patient. With the increasing use of ablative procedures and laparoscopy, intraoperative imaging and navigation will hold increasing significance for the HBP surgeon. Flat screen monitors adjacent to the surgical field present computer-generated 3D virtual liver resection proposals which can be transferred into the real liver. The main obstacles in HBP navigation are the flexibility and mobility of the target organ. Intrahepatic and surface markers seem to be mandatory for computer-navigated surgery. The first feasibility studies are promising.

Key words Navigation · Image-guided · Surgery · Liver · HBP · Virtual · Telemedicine

Computer meets medicine

Surgery requires a significant amount of cognitive analysis and integration of patient data. Decisions often have to be made quickly and depend solely on physical examination. Due to the natural limitations of the surgeon’s eyes, hands, and three-dimensional (3D) imagination, procedures classically have to be performed through large incisions to get adequate exposure. These limitations may be overcome by introducing high-performance computing.

Konrad Zuse from Berlin Kreuzberg earns the merit of creating and inventing the first working free-programmable computer, “Z3” in 1941. At this time he also designed the first programming language “Plankalkül”. The term “virtuality” was introduced by Jaron Lanier in 1989, although its development dates back to the early 1960s, when the first graphic computers were built. Since then, computers have been infiltrating all parts of modern medicine, such as administration, monitoring, controlling, teaching, simulation, robotics, and others. Three-dimensional (3D) reconstructions of computed tomography (CT) and magnetic resonance imaging (MRI) scans provide a detailed roadmap. Surgical access trauma can be minimized by highly sophisticated instruments. This article gives an overview of emerging technologies with the focus on their impact on hepatobiliary-pancreatic (HBP) surgery. The convergence of radiology, telephone, computers, and surgery has mounted in 3D presentations, simulations, and operation planning. The road towards completely navigated soft-tissue surgery is still the object of desire. It is being approached step by step in order to utilize images (CT, MRI, or positron emission tomography [PET]) in the operating room with the utmost precision.

Telemedicine

In 1864, the German Natural Sciences Congress stated their amusement at a new invention by Johann Philipp Reiss, which, they felt, would not be suitable for any serious task. It was Alexander Graham Bell who then patented this invention as the telephone, in 1876, and led it to general acceptance. The first telemedicine
application dates back to the Apollo program, where all physiologic functions of the astronauts were monitored at Houston Control Center, about 240,000 miles away.

Telemedicine has been established in terms of teleconference systems in the clinical routine. The first transatlantic teleoperation was performed by Marescaux et al. in 2001. They performed a laparoscopic cholecystectomy by manipulating a telematic robot.

**To make the real world virtual**

Sight, sound, touch, and smell are the typical four senses used by surgeons for decision-making (the fifth sense, taste, has only historical relevance in medicine).

**Visual immersion**

Visual information provides approximately 70% of our sensory input and obviously is the most important for a surgeon. Thus, the first requirement for virtual reality is an image source. Marescaux used the Data Set of the Visible Human Project funded by the National Library of Medicine to reconstruct a virtual hepatobiliary reality. This data set, derived from serial whole-body sections of an executed man, has been used for multiple medical applications, such as teaching, training, and simulation. But these images are static, atlas-like, and not applicable for the individual patient. Especially in the HBP region, individual anatomy is highly variable, due to variants from the anatomical norm, tumors, regenerative growth, and preceding operations.

Multislice CT scans and MRI do provide patient-specific data of such high quality that they can be used for 3D reconstruction.

**Segmentation**

Before visualization of organ structures can be done, the images have to undergo a segmentation process. That means that the organ structures have to be detected within the primary image slices. This step is not standardized and is performed either manually, semi-automatically, or completely automatically. Only radiologically validated segmentation results should be visualized. Inaccuracy during the segmentation process will place the patient at risk. Therefore, some systems with volume rendering use fuzzy 3D visualizations of tumors.

**Visualization**

Surface rendering represents the surface borders of the organ structures. These surfaces are represented in the computer as a mesh of polygons. For visualization, these polygons are filled with a color so that smooth surfaces result. Volume rendering realizes every voxel of a given organ and defines translucidity and reflexivity. Surface-rendering visualization is faster than volume rendering, due to the dramatically decreased volumes of data which have to be handled by the graphic computers, and is used typically for interactive applications.

Classical computer screens in combination with shutter glasses can be used to generate 3D vision. But head-mounted displays with tracking systems for head movements give better 3D impressions. The virtual retinal display is a new device developed at the Human Interface Technology Laboratory (HIT) in Seattle. A low-power laser projects an image directly on the retina. Clinical studies on the impact of 3D visualizations on operation planning have shown a significant improvement in precision, of up to 21%, compared with 2D visualizations. These trials used classical 2D displays. Studies on realistic 3D displays are underway.

Nevertheless, manual capacities are impaired when displays are used instead of direct vision. Task efficiency and knot strength were evaluated under standardized conditions using direct vision and electronic imaging with 2D and 3D systems. Median task efficiency (defined as the time to complete the knot) was 35.0 s for direct vision and 53.0 s and 53.5 s for 2D and 3D imaging, respectively ($P < 0.05$). With respect to direct vision, this represented an overall degradation of task efficiency compared with the use of electronic imaging of 52%, with no detectable difference between 2D and 3D imaging. The knot strength, representing the degree of tightening, was weaker with electronic imaging, but the difference was not significant, largely due to variation between the three individuals carrying out the task.

**Haptic immersion**

Touch provides only about 5% of the overall sensory input, but it is the second most important sense in surgery. Through force-feedback devices, one can truly feel a virtual object. These haptic devices compensate for the distance which will result from the use of robotic surgery and are used in simulators such as cholecystectomy trainers.

**Sound**

Acoustic feedback devices have been introduced in neuromonitoring systems in head and neck surgery. These devices have not yet been introduced in HBP surgery.