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Role of Liver Navigation in Surgery Planning and the Challenges

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Editorial

With continuous advancement of high dimensional imaging devices and the development of new image computing and visualization techniques, the world of interventional radiology and surgical care has achieved new heights. Computer vision and image processing plays an important role in health care, such as analysis, visualization, and exploration of medical image data. There are three crucial aspects of computer vision (CV), they are: 1) speed, 2) accuracy, and 3) urgency. Computer vision can visualize the diagnostic problems accurately and faster. For instance, artificial intelligence (AI), that uses CV, can process the input clinical data faster leading to benefits such as allowing the clinicians to attend to the other patients within the stipulated time, thus, reducing overall waiting time for the patients. Analyzing the data clinically might lead to false positive and false negative results, which impacts the patient safety adversely. This is one of the important areas, where computer vision is more effective due to the extensive data points, which artificial intelligence (AI) enabled computer vision (CV) uses. Lastly, in certain medical emergencies like brain hemorrhage, the medical images obtained are not optimum for localization of the defect and planning a treatment. Computer vision has brought about a paradigm shift in assisting clinicians during such difficult scenarios by enabling visualization of brain aneurysms, clipping or stenting them at the earliest.

Hepatic cancer is a leading cause of death worldwide and remains as the fifth most common malignancy both in men and women [1]. Hepatocellular carcinoma accounts for 12,000 deaths a year in USA alone [2]. There have been different types of treatments such as surgery, intervention, and radiation-based therapy; however, surgery has been mostly preferred because of its efficacy [3].

As the surgical treatments of liver cancer rely on the detailed knowledge of the vascular systems, high-resolution imaging such as computed tomography (CT) or magnetic resonance imaging (MRI) form an integral part of the preoperative planning for liver surgery. The most-commonly used imaging modality is contrast-enhanced multi-phase CT, where 2 or 3 datasets are acquired sequentially during the passage of the injected contrast agent through hepatic arteries, the portal veins and hepatic veins [4]. As this leads to a large amount of image data to be analyzed before the surgery, computerized virtual liver surgery planning tools have been proposed [3]. These tools mostly provide semi-automatic algorithms for the segmentation of anatomical structures within the liver [5-9]. Based on the vascular segmentations, patient-specific representations of the territories supplied by the branches of each vessel system can be calculated and a suitable surgical plan is defined. Clinically applicable surgical planning solutions are nowadays available from a few companies, such as, MeVis Distant Service AG (Bremen, GER), EDDA Technologies (Princetown, US), and Intrasense (Montpellier, FR). Extensive clinical studies have shown that highly accurate 3D planning enables better assessment of risk involved and therefore leads to a safer surgery. Using similar techniques with post-operative imaging data, it is also possible to monitor patient recovery and to detect possible disease recurrence. A look on the clinical routine shows however, that these virtual surgery planning tools are only used for the minority of cases as the cost and time required for such planning is too high. This in turn hinders the large-scale adaptation of liver surgery planning technology. Additionally, in order to provide an integrated and clinically relevant solution for computer-aided liver surgery, several challenges are being faced like:

1) *Lack of routinely applicable image analysis software enabling an efficient image analysis at modest costs*: As mentioned earlier, there have been several surgical planning solutions; for instance, MeVis provides a complete segmentations service, where image data is transferred from the hospitals to a segmentation expert team (including radiology assistants and surgeons), which analyzes the data, plans the surgery, and sends processed data back to the clinical sites. This approach has the advantage that trained users perform the segmentation but the time required for analysis (typically 3 days) is usually too long for hospitals workflows and the costs for each analysis can only be justified for very complex cases. The software tools by EDDA and Intrasense are installed at the clinical sites and are used directly by radiologists. This increases the flexibility of performing analyses and decreases costs when a large number of cases are analyzed. Nevertheless, these solutions couldn't find their way into clinical routine due to the time-intensive training of radiology staff required to handle the software and that relatively large investments are required for the purchase of the software solutions. Hence, low-cost, efficient software which can be handled by radiologists at different hospital sites is a fundamental requirement for further developments in the field of computer-aided liver surgery.

2) *Lack of standardization in liver segmenting process*: Liver segmentation is one of the most challenging tasks in preoperative planning and postoperative follow up owing to the anatomical variations, and complex geometry. In general, segmentation can be achieved manually, semi-automatically, or fully automatically. Whilst manual segmentation can be contemplated on a limited number of images, it represents a major bottleneck in today's clinical practice as complete manual segmentation is tedious, impractical and often involves large inter- and intra-observer variability. The fully automatic segmentation algorithms do not leave any scope for a surgeon to intervene and edit as per his/her desire [10-12]. Due to time and financial constraints, segmentation methods with reasonable user interaction (semi-automatic) are highly desirable. So far, the literature on medical image segmentation is rich, yet no method can claim to present a general solution for any segmentation requirements; rather we have a plethora of different techniques that can be used in specific applications.

3) *Lack of clinically applicable, versatile liver navigation systems with interfaces to different surgical planning data providers:* A good navigation system facilitates the planning, by providing the information about spatial relationship of the instrument and image data in real-time. Although a large number of surgical navigation approaches have been proposed by different research groups, only few of those have found their way into clinical routine because of several technical & non-technical reasons such as inadequate/unavailability of high-resolution machines/images, inadequate medical data for research, noise in medical data, and improper implementation (real-time, user friendly, etc.). Furthermore, this is due to high regulatory requirements for such devices and to missing interfaces for novel applications in devices which are already used in other surgical domains (such as neurosurgery or orthopedic surgery). The standardization of surgical planning data and the development of data transfer protocols is therefore a key requirement to enable the transfer of technological research results into the operating room. Research based on realistic assumptions is further hindered due to the lack of measurement systems which can be used in the operating room.

By developing a network-based data transfer protocol to an existing liver navigation system, real-time intra-operative measurement data can be transmitted to other computer and used for research on surgical navigation under realistic assumptions. The availability of an integrated and certified device for data acquisition further enables efficient development of surgical navigation solutions for other applications (such as kidney, pancreas, or prostate surgery). Most systems for surgical planning and navigation have been used in clinical feasibility studies at a single clinical site. A more extensive validation of proposed approaches is required to assess the benefits of the computer assisted surgery approach and to provide feedback and inputs for further research.

The objective of the research should probably be intended to conduct fundamental and translational research towards a second-generation computer assistance system for open liver surgery. The resulting technology could enable surgeons to optimally plan a resection strategy; transfer this surgical plan to the real situs; peri-operatively visualize the complex liver anatomy; identify structures at risk more precisely; and carry out surgery which is safe and reproducible.

In order to quantitatively assess the quality of a resection and optimize the chosen strategy towards minimally invasive and safe surgery, anatomical and functional parameters need to be calculated [13]. The most important parameter in such an evaluation is the tumor resection margin which indicates if a tumor is resected with a sufficient safety margin. In general, a margin of 1 cm is chosen in order to make sure that no microscopic tumor invasion remains in the non-resected liver tissue. Additional parameters include the resected and remnant volumes and functional perfusion parameters. Depending on the disease stage, a hepatic resection of up to 80% of the liver can be tolerated [14]. However, in cases of damaged liver tissue (due to chemo therapy or cirrhosis), only a smaller percentage of volume loss can be tolerated. Hence, it is of vital importance that accurate volume estimates are performed during the surgical planning process. Several parameters need to be calculated in order to enable quantitative assessment and optimization of resection strategies, such as calculation of the overall liver volume, calculation of resection and remnant volumes based in resection planes, calculation of resection margins based in resection planes, calculation of perfusion areas for portal and hepatic veins, etc. These calculations should be performed automatically based on the liver (tumor) segmentation and surgical planning methods. During the surgical treatment itself, interaction with the visualization and navigation devices should be reduced to a minimum in order to avoid distracting the surgeon from the usual workflow. This would provide the required surgical information in compact representation and in an intuitive format. The segmented data could probably be color-coded according to a definition established in collaboration with surgeons. Critical structures such as vessels close to resection planes could be highlighted and the use of additional warnings during the resection process is initiated. The surgical guidance information incorporated using the navigation information from the real-time interface could provide the following functionality [15-17]: 1) visual guidance for the alignment of resection instruments to resection planes, 2) real-time feedback on deviation from planned resection planes, 3) warnings when resection instruments are moved towards critical structures, 4) real-time updates on tumor resection margins.

In addition to the guidance information, suitable strategies for the placement of the virtual camera in the 3D scenes could probably be investigated in order to display the structures of interest for resection automatically. The resection planes could be used in the surgical navigation framework defining the surgery-specific visualization strategies.

Finally, the general efficacy and usability of the entire surgical planning solution could also be assessed. The purpose should be to evaluate the solution from the end-user perspective, namely the radiologists and surgeons. Since it would involve a lot of technical parameters, the following parameters need to be checked carefully:

- Time requirements for segmentation of liver, tumors, and vessels
- Number of segmentation errors requiring manual editing
- Time requirements for the defining a plane of resection
- Number of modifications performed on the resection plane
- Rating of the obtained surgical plan (resection strategy and functional evaluation)
- Overall time required for the surgical planning process
- Number of interventions required by the technical team
- Comments for possible improvements of the software.

In addition to the evaluation of average time required and usability, learning curves could be analyzed in order to draw conclusions on the required training efforts for further software deployment.

It has been proven that virtual surgery planning leads to a better evaluation of the risks involved in a surgery [18,19]. On one hand, an effective surgical planning helps in planning for difficult surgeries which seemed impossible earlier, on the other hand, it is plausible that a detailed risk analysis might make a procedure appear too risky to perform. Better pre-operative surgery planning is also expected to provide benefits during the actual surgery. Through the detailed understanding of the anatomical structural variations, intra-operative changes in the surgical strategy might be required less frequently and the better understanding of risk structures might lead to decreased complications during resection and an overall better outcome in terms of complete resection.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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