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and Other Interventional Techniques

Laparoscopic ultrasound navigation in liver surgery: technical aspects and accuracy

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Abstract
The functional–anatomic structure of the liver according to Couinaud classification based on the intrahepatical course of the vascular structures is the basis of all modern liver surgery. Consequently, the use of intraoperative ultrasound is an undisputed requirement for every liver resection. Exact following of the planned resection plane can be realized only with the application of permanent online navigation based on intraoperative ultrasound during the dissection of the hepatical tissue. Now that the authors have established ultrasound navigated resection in open liver surgery using a navigated parenchymal dissecting instrument, they intend to transfer this technique from open to laparoscopic liver surgery. A special adapter was developed to connect an ultrasound-based navigation system to laparoscopic instruments. The authors present the first results in terms of technical aspects and feasibility.

Key words: Laparoscopic surgery — Laparoscopic ultrasound — Liver — Navigation

Despite recent advances in laparoscopic techniques and instrumentation, laparoscopic liver surgery still is limited to a select patient population. One major reason may be the lack of tactile sensation and orientation during dissection of the liver parenchyma. Laparoscopic fenestration of solitary giant liver cysts has been reported [4]. Laparoscopic resections are feasible and safe for selected patients with left-sided or right peripheral lesions requiring limited resection [2] (Table 1).

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Although laparoscopic resection of metastatic liver disease seems feasible, this approach still is debated [7]. The safe anterolateral segments according Couinaud classification are shown in Fig. 1. However, direct translation of the information received sonographically into the resection procedure can cause difficulties, especially with segment/sector ectomies. After the course of the vessels has been projected onto the liver capsule in accordance with the ultrasound picture, dissection of the hepatic tissue itself is performed currently without the support of pictures. As a result, there could be significant deviations in the planned resection plane (Fig. 2). Exact following of the planned resection plane can be realized only by application of a permanent online navigation based on intraoperative ultrasound during dissection of the hepatic tissue.

Now that we have established an ultrasound-navigated system for open liver surgery with online navigation of the dissection instrument, we will use this technique also in laparoscopic surgery to navigate under laparoscopic ultrasound control (e.g., during interventional ablation procedures or liver resections).

Materials and methods

The US-Guide 2000 is an independent navigation system compatible with all ultrasound machines. It is based on an electromagnetic tracking system with six degrees of freedom [5]. On the system monitor, the ultrasound B-picture, overlaid by the navigation data in real time received from the ultrasound and transferred into the navigation system, is displayed. The position finding necessary for the navigation is based on a calculation of distance and angle in accordance with the common satellite navigation. A newly developed adapter allows the navigation system to be combined with a laparoscopic ultrasound probe (B-K Medical 8566, Denmark, Fig. 3a and b). The computer is connected to a transmitter and two magnetic sensors. The weak magnetic field created by the transmitter has to cover the abdominal part in which the intervention is performed. At the same time, the sensors fixed to the head of the laparoscopic ultrasound probe, the interventional or dissection instrument, must remain within the magnetic field throughout the whole procedure. The navigation system

Table 1. Literature overview of laparoscopic liver surgery

Author	Patients (n)	Duration (min)	Conversion rate (%)	Complication rate (%)	Hospital duration (days)
Rau 1998 [10]	17	183.5	5.9	11.8	7.8
Cherqui 2000 [2]	30	214	6.6	20	9.6
Mouiel 2000 [9]	30	79	10	20	—
Fong 2000 [6]	11	248	55	40	9.2
Berends 2001 [1]	10	180	20	0	6
Tang 2002 [11]	11	190	9	9	11.3
Gigot 2002 [7]	37	—	13.5	22	7
Descottes 2003 [3]	87	—	10	5	5

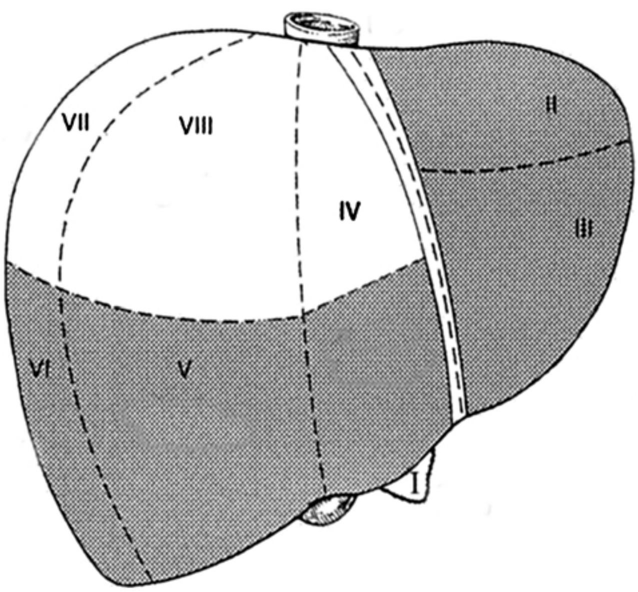

Fig. 1. Anterolateral segments II, III, IVb, V, and VI (shaded grey) according to Couinaud classification. Adapted from Gigot et al. [8].

recognizes the position and anterograde orientation of the needle in relation to the laparoscopic ultrasound head and target structure, then projects this virtually onto the ultrasound picture. Additional functions of the ultrasound machine (e.g., duplex sonography) are available during the intervention and can be used to recognize and avoid vessels.

First, the adapter is placed at the head of the laparoscopic ultrasound probe to connect the electromagnetic tracker to the adapter. The nearer the adapter can be placed to the tip of the instrument, the higher the accuracy of the system. For calibration with an ultrasound phantom, the distance between the adapter and the ultrasound probe must be determined and calibrated with the software of the navigation system. Then the other tracker is placed at a laparoscopic dissection instrument built for laser dissection and calibrated as mentioned earlier. In phantom testing and in a liver organ model, the virtual resection line then is overlaid to the laparoscopic ultrasound B-mode picture, offering the possibility of navigated ablation or resection. Second, the system is integrated in a liver organ model to detect disturbances attributable to trocar and camera instruments.

Results

For transmission of the ultrasound picture data, the ultrasound machine and the navigation system must be connected by an interface. For correct calculation and display of the course followed by the resection line, it is necessary to define the length of the hepatic dissection instrument (i.e., distance from the instrument tip to the sensor position). For the navigated resection, the US-Guide 2000 is positioned close to the area of intervention. The two magnetic sensors, connected by cable to the navigation system, are then attached to the laparoscopic ultrasound head with special adapters. The transformer adapter that takes on the transformer sensor is a small plastic mount connected to the ultrasound head. The transformer sensor is attached to it in the same manner as a connecting clamp. The ultrasound B-mode picture is then presented with the overlaid navigation data (Fig. 4a). We used metal trocars up to 25 mm in size to bring the system into the abdominal cavity (Fig. 4b).

Laparoscopic navigation under ultrasound guidance is technically feasible in this model. Even when the tip of the ultrasound probe was angulated, no disturbances of the navigation system were obvious, due to the close approximation of the laparoscopic ultrasound head and electromagnetic sensor. Anatomic landmarks in liver tissue could be safely reached. No interaction of the electromagnetic tracking system and the laparoscopic equipment (e.g., trocar and laparoscopic camera) could be seen.

Conclusion

In this report, we describe the use of a laparoscopic navigation system with permanent sonographically guidance. Therefore, the exact following of a planned resection level can be transferred online to the liver organ. This improves the precision of laparoscopic liver dissection and may lead to an improvement in the quality of the operation. Laparoscopic navigation under ultrasound guidance offers a new technique and tool for the visceral surgeon. Especially in laparoscopic surgery, this method may improve orientation in interventions or resections in liver surgery. Our preliminary results show the feasibility of this technique in the field of laparoscopic surgery. To date, the size of the electromagnetic sensors are limiting the minimally invasive use of navigation because the sensors in our studies still measure 8 × 8 × 6 mm. Further studies investigating accuracy and reproducibility in the laparoscopic operation field are necessary for evaluation of this new technique.

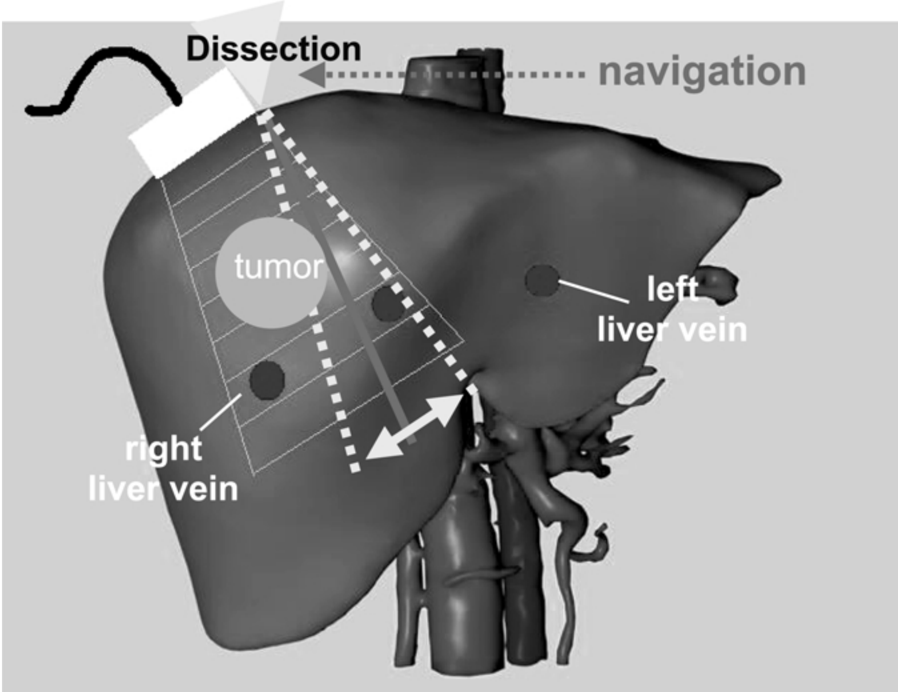

Fig. 2. Deviation of planned (*red line*) vs real (*yellow lines*) resection line without navigation.

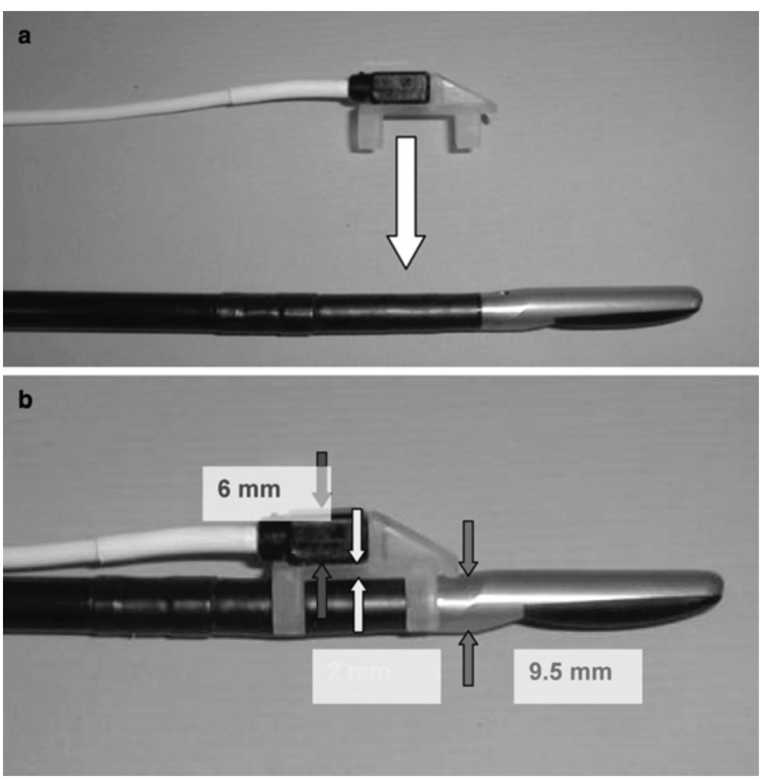

Fig. 3. **a** Adapter with mounted tracking sensor placed as near as possible to the tip of the laparoscopic ultrasound probe. **b** Adapter with mounted tracking sensor at the head of the laparoscopic ultrasound probe. The total diameter of the system is 17.5 mm.

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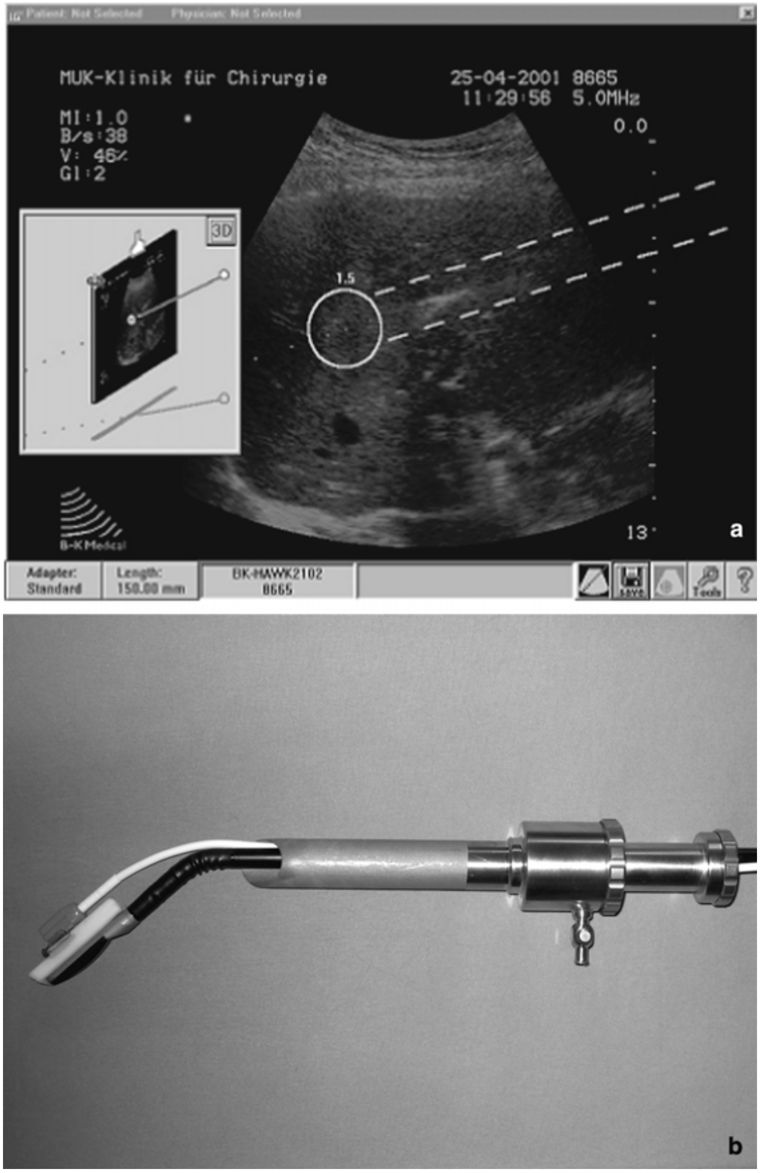

Fig. 4. **a** Ultrasound B-mode picture of the liver with the navigation line (*trajectory*) of the dissection instrument. The yellow circle indicates the point at which the dissection line intersects with the B-mode picture plane (out-of-plane function). **b** Laparoscopic ultrasound probe (B-K Medical 8566) connected to the navigation system through a 22 mm trocar in an experimental environment. Problems of sterilization are not yet solved.

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