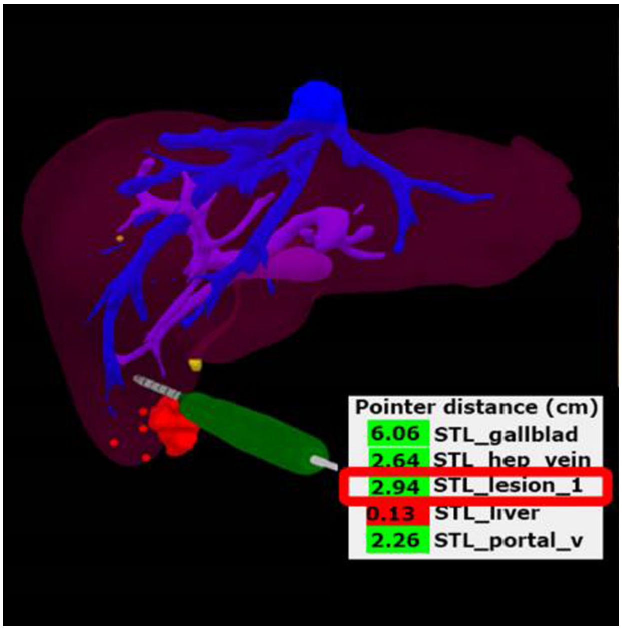

Fig. 1 Sample screen shot from the navigation software during open liver surgery

Results

A detailed description of the clinical workflow developed in the first stage of the study is provided in Table 1, while Fig. 2 illustrates the final design of the OR table. After development of the clinical workflow, a total of 14 navigated procedures with pathology–verified accuracy measurements were performed. The median surgical overhead time of the procedures was 32 min. This includes placement of the EM-sensor and surgical clips on the surface of the liver (8.5 min), sterile intraoperative contrast-enhanced CBCT scan (14 min), registration of the 3D model with a real-time situation and all navigation-related measurements (9 min). The navigation technology resulted in an accurate and intuitive real-time visualization of liver anatomy and tumor's location (Fig. 1), confirmed by intraoperative checks on visible anatomical landmarks. Additionally, surgeons indicated that the system aided in better anatomical insight, and helped to localize the lesion throughout the procedure. Based on 43 accuracy measurement verified by pathology (e.g., three to four locations per patient), the average accuracy of the system was 13 mm. Although pathology is the "gold" standard for resection margins assessment, this method is ultimately affected by inter-observer variation of pathologists and tissue deformation of *ex vivo* liver samples. Therefore, the accuracy of the navigation system may improve, if the current "gold" standard (i.e., pathology) for accuracy measurements will be replaced with an intraoperative imaging modality (e.g., ultrasound or CBCT).

Fig. 2 Adjusted operating table (OR) that combines X-ray "transparency" of carbon OR tables and electromagnetic (EM) tracking with NDI Tabletop Feld generator (left image). This is a combination of the Magnus carbon system (MAQUET, Germany) and a custom-made Perspex sleeve for positioning of the EM field generator

Conclusion

We successfully developed and implemented EM navigation for open liver surgery. This was done by combining a preoperative 3D liver model, intraoperative CBCT imaging and EM tracking of the liver and a sterile EM-pointer. Achieved accuracy shows that the assumption of locally rigid organ registration allows for accurate detection of critical anatomical structures within the resection area.

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An intraoperative ultrasound based navigation method for laparoscopic ablation of liver tumors

I. Paolucci[1], M. Schwalbe[1], G. A. Prevost[2], A. Lachenmayer[2], D. Candinas[2], S. Weber[1], P. Tinguely[2]

[1]University of Bern, ARTORG Center for Biomedical Engineering Research, Bern, Switzerland

[2]University Hospital of Bern, Department of Visceral Surgery and Medicine, Bern, Switzerland

Keywords Image-guided liver surgery · Ablation · Laparoscopy · 3d ultrasound

Purpose

Local thermal ablation is a tissue sparing treatment option for selected malignant liver lesions. The laparoscopic access represents a minimally invasive approach suitable for patients with liver lesions not amenable to percutaneous ablation or if a combined treatment of ablation and resection is performed. For successful laparoscopic ablation, an ablation probe has to be accurately placed in the tumor while avoiding the injury of important intrahepatic structures at the same time. The ablation probe placement is conventionally performed under laparoscopic ultrasound (LUS) guidance, which requires significant experience and is challenging due to limited access and long probe trajectories [1]. Additionally, conventional LUS provides only limited feedback of technical success regarding the placement of the ablation probe prior to applying the ablative treatment. We therefore propose a navigation approach based on electromagnetically (EM) tracked laparoscopic ultrasound for intraoperative guidance of the ablation probe using 2D US, and validation of the probe placement using 3D US. While other navigation techniques rely on complex and time consuming registration processes relying on preoperative imaging [2], the proposed approach does not involve a registration process, potentially reducing intraoperative complexity.

In this study we aimed to evaluate positional accuracy and procedural efficiency of this technique in a laparoscopic model and compare it to the conventional approach for laparoscopic targeting of liver lesions.

Methods

A commercially available navigation system (CAS-One, CAScination AG, Switzerland) for liver surgery based on optical tracking was adapted for EM tracking. For tracking of the LUS probe (FlexFocus 800, BK Medical, Denmark) an EM sensor was attached to the flexible head of the LUS probe using a uniquely fitting adapter and was calibrated using a Z-wire phantom. For guidance of the ablation probe, an EM sensor (Pointershell, Fiagon GmbH, Germany) which can be reproducibly attached to a trocar, was used. The axis and entry point of this trocar were calibrated which allows to accurately measure the direction of the trajectory and the distance to the target. Both instruments were calibrated preoperatively to reduce the intraoperative setup time. Additionally, a workflow for placement of an ablation probe and validation of this placement by measuring the target positioning error (TPE) was implemented. This workflow consisted of the following steps (Fig. 1):

(A) Localization and selection of the tumor
(B) Placement of the ablation probe using a cross-hair viewer (Fig. 1)
(C) Acquisition of a 3D US scan of the tumor and the ablation probe
(D) Measurement of the resulting TPE on the 3D US scan

To evaluate the proposed technique, three surgeons with experience in laparoscopic ablation of liver tumors were asked to perform 10 targetings using the navigation and 10 using the conventional non-navigated approach. For targeting, a laparoscopic model consisting of a plastic torso and an agar liver phantom with intrahepatic tumors was used. The surgeons were allowed to reposition the ablation probe if they could not hit the tumor on the first targeting attempt. For each placement, the number of probe repositionings, the TPE, and the time for probe placement (step B) were measured.

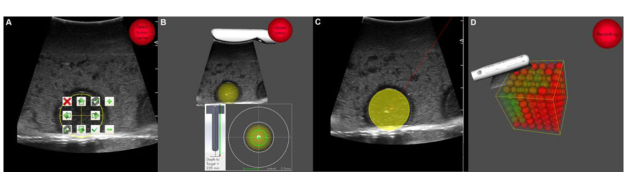

Fig. 1 Workflow for navigated laparoscopic placement of an ablation probe and acquisition of a 3D US scan for validation of the probe placement [3]

Results

Using the proposed navigated approach for targeting, the tumor was hit without requiring to repositioning the ablation probe in 30 out of 30 targetings. Contrarily, when using the non-navigated approach in 17 out of 30 (59%) targetings up to five repositionings were required (Fig. 2). Median TPE for targeting using the navigated and non-navigated approach were 4.2 mm (IQR 2.9–5.3 mm) and 6 mm (IQR 4.7–7.5 mm), respectively ($p < 0.01$). Median time for navigated and non-navigated targeting was 39 s (IQR 24–47 s) and 76 s (IQR 47–121 s) ($p < 0.01$). However, no difference in targeting accuracy and targeting time was found between the surgeons ($p = 0.32$ and $p = 0.27$). During navigation, the median time for localization and selection of the tumor (step A) was 49 s.

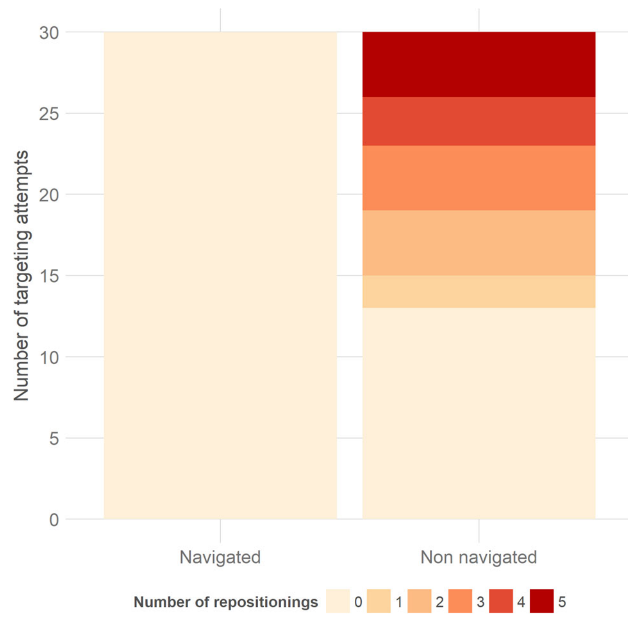

Fig. 2 Ablation probes repositionings required to hit the tumor [3]

Conclusion

Overall, the navigation approach allowed to accurately place the ablation probe into the tumor on the first attempt, compared to required repositionings of the ablation probe in 59% when using non-navigated targeting. This potentially reduces the risk of bleeding and seeding of tumor cells when using multiple repositionings. The evaluated accuracy of 4.2 mm is sufficient when considering an intended 5–10 mm ablation margin, as used in clinical practice. Also, the surgeons could perform the placement of the ablation probe significantly faster using the navigation compared to the conventional approach.

The evaluated navigation approach avoids potential inaccuracies caused by intraoperative registration due to the pneumoperitoneum and intraoperative tissue manipulation. These factors might be significantly reduced, as the trajectory is planned based on intraoperative imaging acquired after pneumoperitoneum and liver mobilization. As this navigation approach assumes a static environment for only a short time (mean 39 s) and could thus be applied during an extended end-expiration phase or using high frequency jet ventilation, organ motion compensation was not included in this study. In case of significant organ deformation, the method allows to quickly adapt the planned trajectory (mean 49 s). Additionally, the 3D US based validation method allows to assess the accuracy of the ablation probe placement intraoperatively, with the possibility of repositioning if needed.

To conclude, the proposed navigation method allows accurate and efficient placement of ablation probes using EM tracked US in a laparoscopic model. As this method relies only on real-time intraoperative imaging, it avoids potential inaccuracies caused by organ deformation during the procedure.

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Peripheral nerve block support system guided by ultrasonic image

N. Takahashi[1], A. Hanafusa[1], H. Hayashi[2]

[1]Shibaura Institute of Technology, Bio-science and Engineering, Saitama, Japan

[2]Osaka Minami Medical Ccenter, Osaka, Japan

Keywords Peripheral nerve block · Ultrasonic image · Stereo camera · Needle guidance

Purpose

A peripheral nerve block (PNB) is a type of anesthesia that involves the injection of anesthetic around the peripheral nerve to block pain transmission. Ultrasound-guided PNB is a PNB method that can visualize needle position and spread of anesthetic on the sonogram by inserting the needle under the ultrasound imaging probe. Therefore, ultrasound-guided PNB is becoming a common procedure in regional anesthesia [1]. However, high expertise is required by an anesthesiologist for procedures such as maintaining the needle tip in the sonogram as the needle is advanced towards the target, guiding the needle to the target nerve, and avoiding vascular puncture. Extant studies proposed different types of ultrasound-guided PNB support systems in conjunction with magnetic sensors or mechanical guidance. However, magnetic sensors are affected by metallic objects in the surroundings, and mechanical guides limit the freedom of movement [2].

In this research, two images captured by two small USB cameras are converted into top- and side-views, on which the navigation line for the guiding needle path is superimposed. Moreover, images of the needle at intervals of 10 and 20 mm are captured by stereo cameras fixed on the ultrasound imaging probe, and three-dimensional positions of marks on the needle, insertion position, angle, and depth are measured. The purpose of this research is to develop a system that can support navigation along the needle progression path, predict tip position, and superimpose the navigation line on the images to perform PNB in a precise and safe manner.

Methods

The proposed system consists of an ultrasonic diagnostic imaging system, a PC, and two small USB stereo cameras, as shown in Fig. 1. Intrinsic and extrinsic camera parameters from several views of the calibration board are obtained in advance, and distortion correction of the image is performed using these parameters. The image of the needle advanced towards the target is captured by the stereo camera, and the image is finalized. Then, the mark on the needle can be recognized automatically by label processing, and the three-dimensional coordinates of the marks are calculated using the stereo camera method. Subsequently, insertion position, angle, and depth are measured using the three-dimensional coordinates of the marks. From the results of insertion position, angle, and depth, the needle progression path and tip position are predicted and displayed on the sonogram. In addition, the navigation line that guides the needle under the ultrasound imaging beam to maintain the needle in the sonogram is displayed on the image taken from the overhead camera. Moreover, images taken from the camera diagonally overhead are converted to images representative of those taken from the side camera, to match the needle and guide line easily. Then, the guidance line, which guides the needle towards the target nerve, is displayed on the image (Fig. 1). These images are displayed on the PC monitor and support the ultrasound-guided PNB operation.

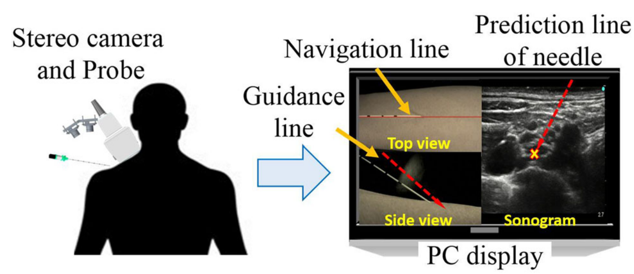

Fig. 1 System configuration of peripheral nerve block system

To verify the accuracy of the measured three-dimensional coordinates of the mark on the needle and calculated angle of the needle, experiments were performed using the needle employed in the operation.

Results

Stereo cameras were fixed as shown in Fig. 2 to measure the mark and calculate the inserted angle. The distance between the two cameras was set as 60 mm, and the heights of the left and right camera were set to 120 and 105 mm, respectively. The right camera was inclined at approximately 30° against the vertical line.