Single port manipulator for minimally invasive surgery

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INTRODUCTION

Although minimally invasive surgery has many advantages compared to open surgery, its performance is restricted due to technical limitations. Besides the development of new instruments, the current focus is set on trauma reduction by performing single port operations or transluminal surgery (NOTES) [1]. The development of instruments with enhanced flexibility is a major challenge and therefore intensively investigated by various research institutes [e.g. 2]. Usually, the intra-abdominal flexibility of rigid laparoscopic instruments that is limited due to the entry port is augmented with additional distal articulations. NOTES operations depend to an even greater extend upon a suitable, newly designed single lumen universal tool [3]. The first approach devoted to this problem is the endoscope-based octopus system as developed by Swanstrom et al [4]. Anubis (Karl Storz, D) and Endosamurai (Olympus, J) are other NOTES platforms designed for transluminal surgery. However, these systems have a small operating range, limited flexibility and opposite or retroflective working is not possible. We developed the "Highly Versatile Single Port System" (HVSPS) to overcome these drawbacks. The idea is, literally spoken, to bring the surgeon's head, shoulders and arms into the abdominal cavity to regain the flexibility of open surgery. The specific aim of this study is the evaluation of the HVSPS prototype for single-port laparoscopic cholecystectomy.

MATERIALS AND METHODS

A: Hardware of the single port system

The developed semi-rigid single port platform consists of two manipulators and a telescope. Fig. 1 shows a schematic design of the HVSPS. The manipulators and the telescope are inserted together trough an insert with three lumens. This ensemble is introduced gas-tightly into the abdominal cavity using a 33 mm trocar. It is guided through a telemanipulator, which is attached to the insert. The guiding manipulator has four degrees of freedom (DOF), what enables pivoting the system at the fulcrum, a linear movement into the body and the rotation of the complete single port system.

The hollow manipulators with 5 DOF have an outer diameter of 12 mm. Flexible instruments are introduced through the central channels and can be controlled or changed manually. The bendable section of the manipulators (2 DOF) has a length of 75 mm followed by a 50 mm long hollow tube and an additional articulation (1 DOF). Two additional DOF at the distal end of the manipulators provide a rotation of 270 degrees in each direction and a linear movement of 80 mm into the abdominal cavity. Visualization of the situs is realized by a flexible telescope with 10 mm diameter and 5 DOF. This solution was implemented with a commercial 6 mm endoscope, which is inserted through a 10 mm tube that has a distal deflection of 30 degrees. Given this ensemble, the telescope can move in an S-form so that the instruments of both manipulators can be observed in their entire operating range.

The HVSPS is automated and controlled over a real-time Matlab-Simulik application. Currently, both manipulators, motorized and steered using Bowden wires, cope a total of ten degrees of freedom. The operator controls each articulation individually with two joysticks as input device. With two meters distance to the patient, the drive system is placed into the periphery.

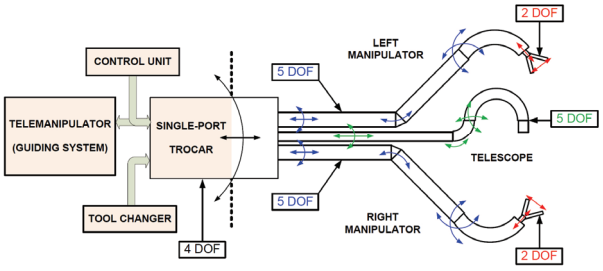

Fig. 1: Schematically design of the "Highly Versatile Single Port System"

B: Simulation environment of the platform

The simulation of elaborate mechanics plays a central role regarding the prediction of developing features, system functionality and teaching facilities. Therefore, a simulation environment of the complete system is programmed. The main reasons for this purpose are listed below:

- Development of new surgical manipulators
- Design optimization of the prototype
- Identification of the appropriate interface
- User training for the physicians

A complete surgical scenario with the HVSPS attached to the SoloAssist (Aktormed, D) telemanipulator, which is mounted on an operating table, is implemented in the Coin3D open source graphics development tool. Equal to the hardware, all the functionalities are controlled using two joysticks as input devices.

Instruments with multiple articulation and high flexibility, e.g. "snakelike" structures, lead to over-determined kinematics. Resulting difficulties in the

handling require new human-machine interface approaches. The simulation provides a platform to evaluate different input devices to determine an adequate interface for a single port system. Finally, the training and teaching with the simulation introduces the system to the physician. The functionalities of the HVSPS are taught to surgeons during repeated training sessions. Based on their performance the indented evaluation of the real system is accomplished.

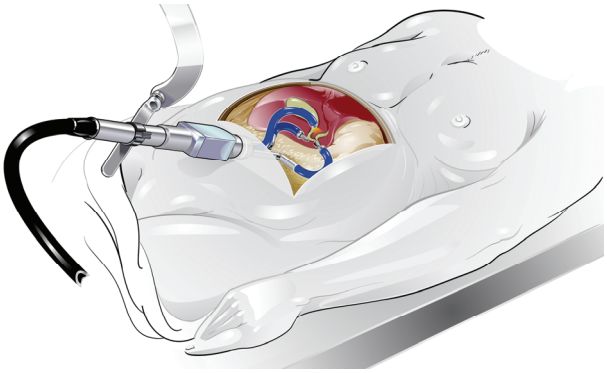

Fig. 2: Schematic drawing of a gallbladder dissection using the HVSPS

C: Evaluation scenario of the single port laparoscopic cholecystectomy

The experiments are performed by a surgeon, who controls both manipulators with the two joysticks, a gastroenterologist, who manually controls the flexible endoscope and two assistants who control the remaining functionalities, as well manually.

After insufflation of the peritoneum with a Verres needle, the HVSPS is introduced into the abdominal cavity through one incision in the middle of the abdomen (Fig. 2). With a retractor, which is inserted through an auxiliary incision, the liver can be retained out of the operating field. As a final step of the cholecystectomy, the gallbladder is recovered through the main incision after a last check up for bleeding.

RESULTS

A laparoscopic gallbladder dissection was accomplished during 2 hours on the ex-vivo ELITE trainer, which provides conditions close to the real in-vivo cholecystectomy. At present, we already performed three cholecystectomies with the HVSPS in survival animal experiments under general anesthesia. The complete surgical intervention, without technical set-up takes between 95 to 130 minutes.

The surgeries were accomplished using flexible instruments (grasper, scissors, etc.) that were introduced through the manipulators. They could be exchanged within seconds for different tasks. After the ligation of the cystic duct and cystic artery with coagulation current, dissection of the gallbladder was achieved by using the conventional grasping and cutting instruments. Fig. 3 shows the gallbladder, held with a grasper through the left manipulator and dissected using a TT knife introduced through the right one. The opposition of the manipulators was essential for intuitive working.

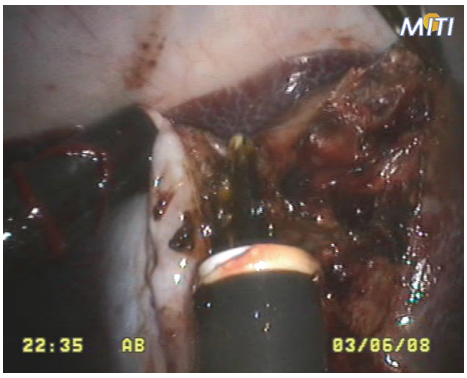

Fig. 3: Cholecystectomy in an animal experiment: Endoscopic view of the situs with the HVSPS manipulators

The complete surgical intervention was guided by commands of the surgeon, who controlled the manipulators. Proper coordination of the physicians was essential for the performance and quality of the intervention. Communication and occasional disaccord of the surgeons was time-consuming. Nevertheless, with increasing experience of the physicians, the operations are performed consistently in less time.

DISCUSSION

Minimally invasive cholecystectomy is feasible using the multifunctional single port platform HVSPS. However, compared to the conventional laparoscopic cholecystectomy, the operation took considerably longer. This is resulting from the difficult handling of the system with various degrees of freedom and the essential coordination of the individual actions of the participating physicians. This extended time can be reduced by optimizing the fully automated HVSPS, introducing an intuitive human-machine interface, an integrated simulation and planning environment. In addition to mechanical optimization and further evaluations, the main focus will be set on the intuitive human-machine interface and the integrated intelligence that is required for such elaborated systems.

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