First cholecystectomy with the new, highly versatile single port system for minimally invasive surgery

Salman Can[1], Hermann Mayer[3], Alois Knoll[3], Adam Fiolka[1], Armin Schneider[1], Johannes Maifeld[1], Dirk Wilhelm[1,2], Hubertus Feussner[1,2]

[1]Workgroup MITI, Klinikum r. d. Isar,
Technische Universität München (TUM), Germany
[2]Department of Surgery, Klinikum r. d. Isar, TUM, Germany
[3]Chair of Robotics and Embedded Systems, TUM, Germany

In laparoscopic surgery, the demand for a versatile and highly flexible support system is inevitable. The systems proposed so far do not meet these requirements. We developed the "Highly Versatile Single Port System" (HVSPS), a two armed device with an additional semi-flexible telescope, to overcome these drawbacks. The flexible manipulators are inserted independently through an insert with three lumens and this ensemble is guided over a four degree of freedom (DOF) telemanipulator. In a survival animal experiment, the first gallbladder could be successfully resected with the HVSPS. After the ligation of the cystic duct and artery with coagulation current, in an opposite configuration, the gallbladder could be hold with a grasper and dissected using a TT knife. The complete surgical intervention, without technical set-up, could be accomplished in 110 minutes. Laparoscopic cholecystectomy using the HVSPS is feasible. It is expected that the integration of an adequate man-machine interface (MMI) and a simulation environment can significantly ameliorate the procedure.

1. Introduction

In minimally invasive surgery (MIS), trauma to the patient can be reduced by diminishing the number of entry ports ("single port surgery"). Accordingly, the need for a multifunctional single port operation system is growing. [4] Furthermore, "high flexibility" is an inevitable issue investigated by different research groups. [1, 3, 5] The intra-abdominal flexibility limited due to the entry port is augmented with additional articulations.

Another stimulus for single port surgery was the introduction of "Natural Orifice Transluminal Endoscopic Surgery" (NOTES). This type of surgery depends even more upon a suitable single lumen universal tool. The first approach devoted to this problem is the endoscope-based Octopus system as developed by Swanstrom et al. [4] However, this system has a small working range, limited flexibility and the opposite or retroflective working is not possible. Thus a new support system is required to increased penetration of minimally invasive surgery and NOTES.

We developed the "Highly Versatile Single Port System" to overcome these drawbacks. The idea is, literally spoken, to bring surgeon's head, shoulders and arms into the abdominal cavity to regain the same flexibility as in open surgery. Compared to other systems, only one 4 DOF telemanipulator is required to guide the HVSP system. The surgeon controls the manipulators in an intuitive manner through a master console. Our aim was to prove the maturity for an in vivo surgical operation.

2. Material and Methods

Using the know-how and partially the hardware of flexible endoscopes we designed a two armed device with two manipulators and a semi-flexible telescope. Figure 1 shows the kinematic structure of the complete HVSPS. The flexible manipulators and the telescope are inserted independently through an insert with three lumens. This combination is implemented gas-tightly in a 33 mm trocar and guided over a 4 DOF telemanipulator. An additional restraint system is used to retract the liver out of operating field. Compared to the existing systems the footprint of the HVSPS and the occupied space around the patient is by far smaller.

The hollow manipulators with five DOF have an outer diameter of 12 mm. Flexible instruments are introduced through the central channels which are controlled and changed manually. The bendable section of the manipulator with two DOF, resembling to the human wrist, has a length of 75 mm followed by a 50 mm length hollow tube and an elbow articulation with one DOF. A rotation of 360 degrees and 50 mm linear movement into the abdominal cavity is possible with additional 2 DOF. The conceived semi-flexible telescope with 10 mm diameter consists of a commercial endoscope with 6 mm diameter which is inserted trough a 10 mm tube with an additional articulation. With this ensemble, providing 4 DOF, the telescope can be moved in an S-form so that the instruments can be observed over the complete working range.

Both manipulators are partially automated and controlled over a real-time Matlab-Simulik application. Accordingly, the complete system had to be operated by a team composed of physician and engineers. One surgeon controls the manipulators over two Joysticks, a second one controls manually the flexible instruments guided through the manipulators, a gastroenterologist guides manually the semi-flexible telescope and an engineer operates the manipulators remaining, not automated degrees of freedom.

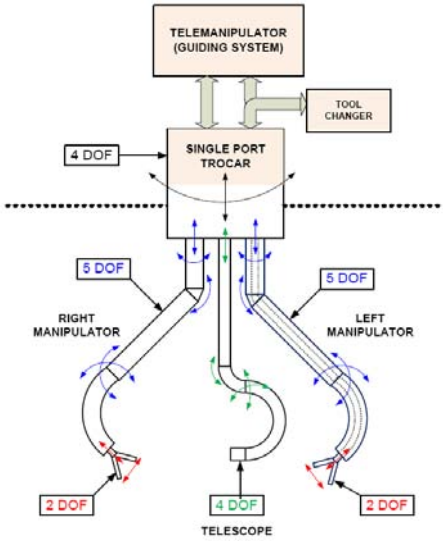

Figure 1: Schematically drawing of the "Highly Versatile Single Port System"

The HVSPS could be integrated into the ARAMIS platform, which comprises a telemanipulator to guide minimally invasive instruments. [2] This platform uses two Sensable PHANToMs as input devices and can be ideally used to steer the HVSPS manipulators by Cartesian control (i.e. intuitive control of x, y, z translations and rotations). An integrated simulation and planning interface is provided for virtual training and case studies of such new interventions.

In a first step, the complete system was tested on a human “mock-up” allowing the physicians to practice and get familiar with the control and kinematic of the HVSPS. After this training period the first laparoscopic in-vivo cholecystectomy could be performed in an animal experiment.

3. Results

We could successfully resect the first gallbladder with the HVSPS in a survival swine experiment. The complete surgical intervention, without technical set-up, could be accomplished in 110 minutes. Through one incision the HVSPS was introduced into the abdominal cavity. The manipulators were in a straight position during the introduction and expand afterwards in the peritoneum. A second incision was required to introduce a retractor for retain the liver out of the operating field. Two flexible, endoscopic instruments (grasper, scissors, etc.) were introduced afterwards through the manipulators. Within seconds, the instruments could be exchanged for different tasks.

Figure 2: First cholecystectomy with the HVSPS in an animal experiment

After the ligation of the cystic duct and cystic artery with coagulation current, dissection of the gallbladder was achieved by grasping and cutting instruments. Figure 2 shows how the gallbladder is hold with a grasper through the left manipulator and dissected by using a TT knife introduced through the right. The opposition of the manipulators was essential for an intuitive working. The gallbladder was recovered through the main incision after a last check up for bleeding. Finally, the manipulators were steered to a straight position so that the HVSPS could be pulled out of the abdomen.

The complete surgical intervention was managed by commands of the surgeon who controlled the manipulators. Coordination of the physicians and engineers was essential for the performance and quality of the intervention. We have realized the indispensability of previous interdisciplinary training for an effective teamwork. We suppose that the planning and coordination can be improved by integration of an adequate simulation environment.

4. Conclusion

This study demonstrated the applicability of the HVSPS for laparoscopic surgeries such as the cholecystectomy. The complete operation time can be reduced by optimizing the fully automated HVSPS and introducing an intuitive man-machine interface and a simulation and planning environment.

The kinematic structure of the HVSPS will also be evaluated with slight changes for natural orifice transgastric endoscopic surgery. It is also possible to use the HVSPS for retroflective interventions which were not possible yet. However, a new control design should be developed, since it was impossible to work in a head over position.

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