

A new, highly versatile mechatronic support system (HVSPS) for single port minimally invasive surgery

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Introduction

In laparoscopic surgery, a tendency towards further trauma reduction is to be observed by diminishing the number of ports to be used (“single port surgery”). Accordingly, the need for a multifunctional (viewing and manipulation) single port operation system is growing.

Beyond of the single port access, “high flexibility” is a basic request for laparoscopic surgery. [1; 3] The aim is to augment the intra-abdominal flexibility which is limited due to the entry port.

The introduction of so-called “Natural Orifice Transluminal Endoscopic Surgery” (NOTES) is an additional stimulus, since 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 miner access surgery and NOTES.

We developed the “Highly Versatile Single Port System” (HVSPS) 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 others, only one 4 degrees of freedom (DOF) telemanipulator is required to guide the HVSPS. The surgeon controls the end-effectors in an intuitive manner through a master console. We are planning to use the master console of the ARAMIS system, which is described in detail in [2].

Material and Methods

Based upon the concept of flexible endoscopes we designed a two armed device with an additional semi-flexible telescope. Figure 1 shows the cinematic structure of the complete HVSPS.

Both end-effectors and the telescope are inserted independently through an insert with three lumens and this ensemble is implemented gas-tightly in a 33 mm trocar and guided over a 4 DOF telemanipulator.

The hollow end-effectors with five degrees of freedom 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 end-effector with two DOF, similar 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 semi-flexible telescope usually with 10 mm diameter has 4 DOF and can be moved into an S-Form so that the instruments can be observed without problems in its complete working range.

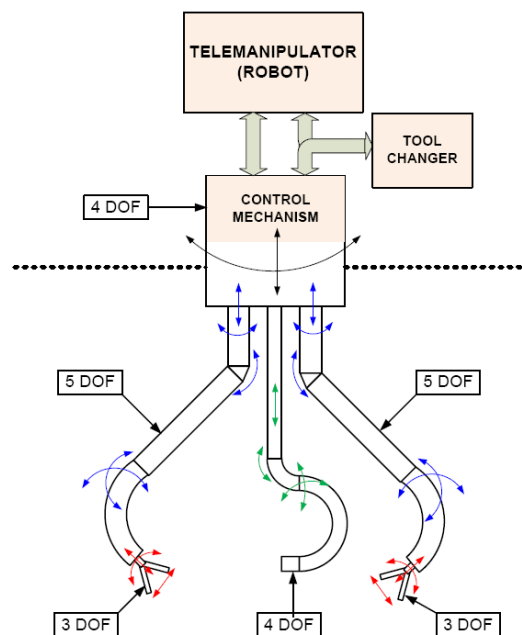


Figure 1: Schematically drawing of the "Highly Versatile Single Port" support system

The end-effectors are partially automated and controlled over a real-time Matlab-Simulink application. Accordingly, the complete system had to be manipulated by three physicians. As mentioned before, the HVSPS could be integrated into the ARAMIS platform, which comprises a telemanipulator to guide minimally invasive instruments. This platform uses two Sensable PHANToms as input devices and can be ideally used to steer the HVSPS end-effectors by Cartesian control.

At first, the complete system was tested on a human "mock-up". (Figure 2) After this training period the first laparoscopic in-vivo cholecystectomy could be performed in a swine experiment.



Figure 2: Prototype of the "Highly Versatile Single Port" support system

Results

The first gallbladder could be successfully resected with the HVSPS in a survival swine experiment under general anesthesia. After the insufflation, the HVSPS was introduced into the abdominal cavity through one incision in the middle of the abdomen. The end-effectors were in a straight position during the introduction and expanded afterwards in the peritoneal space. With a retractor introduced through an auxiliary incision the liver could be retained out of the operating field. Two flexible instruments (grasper, scissors or dissector) were introduced afterwards through the end-effectors. Within seconds, the instruments could be exchanged for different tasks.

After the ligation of the cystic duct and cystic artery with coagulation current, dissection of the gallbladder was achieved by using grasping and cutting instruments. The opposition of the end-effectors was essential for an intuitive working. The gallbladder could be hold with a grasper through the left effector and dissected by using a TT knife introduced through the right. The gallbladder was recovered through the main incision after a last check up for bleeding and complication. The end-effectors were steered to a straight position so that the complete system could be pull out of the abdomen and finally both incisions were sutured.

The complete surgical intervention, without technical set-up, could be accomplished in 110 minutes. Compared to the conventional laparoscopic cholecystectomy, however, the operation took considerably longer. This extended time can be deduced from the cumbersome handling of the interface and experience of the physicians.

Coordination of three physicians was essential for the performance and quality of the intervention. The previous interdisciplinary training was indispensable for that reason. It is expected that the integration of the simulation interface can significantly accelerate the planning and coordination of interventions.

Conclusion

Laparoscopic cholecystectomy using the HVSP support system is feasible. The intervention time can be reduced by optimizing the fully automated HVSPS and introducing an intuitive man machine interface and a simulation and planning environment.

For the first time, 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.

References

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