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Robotic Cholecystectomy Using the Newly Developed Korean Robotic Surgical System, Revo-i: A Preclinical Experiment in a Porcine Model

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One Korean company recently successfully produced a robotic surgical system prototype called Revo-i (MSR-5000). We, therefore, conducted a preclinical study for robotic cholecystectomy using Revo-i, and this is a report of the first case of robotic cholecystectomy performed using the Revo-i system in a preclinical porcine model. Revo-i consists of a surgeon console (MSRC-5000), operation cart (MSRO-5000) and vision cart (MSRV-5000), and a 40 kg-healthy female porcine was prepared for robotic cholecystectomy with general anesthesia. The primary end point was the safe completion of these procedures using Revo-i: The total operation time was 88 minutes. The dissection time was defined as the time from the initial dissection of the Calot area to the time to complete gallbladder detachment from the liver bed: The dissection time required 14 minutes. The surgical console time was 45 minutes. There was no gallbladder perforation or significant bleeding noted during the procedure. The porcine survived for two weeks postoperatively without any complications. Like the da Vinci surgical system, the Revo-i provides a three-dimensional operative view and allows for angulated instrument motion (forceps, needle-holders, clip-appliers, scissors, bipolar energy, and hook monopolar energy), facilitating an effective laparoscopic procedure. Our experience suggests that robotic cholecystectomy can be safely completed in a porcine model using Revo-i.

Key Words: Robotic surgical procedure, cholecystectomy, device approvals

INTRODUCTION

Laparoscopic surgery is a standard surgical treatment of select patients with gastrointestinal diseases.[1] Laparoscopic surgery had replaced conventional open surgery for several reasons. Compared to open surgery, laparoscopic surgery reduces the incision size, reduces operative pain, allows for earlier recovery, and a rapid returning to normal activity.[2] However, there are some technical limitations to applying laparoscopic surgery. For instance, its use can be limited by the fulcrum effect, two-dimensional operative view, limited instrument motion, and exaggerated involuntary tremor motion. These limitations usually increase the learning curve to perform a safe and effective laparoscopic procedure.

Robotic surgery was introduced to overcome the limitations of laparoscopic surgery.[3] The unique characteristics of robotic surgery, in theory, allow surgeons to more easily adapt to the laparoscopic environment and produce effective results, especially when tasks require advanced laparoscopic skills.[4]

However, the currently available robotic surgical system seems to be struggling in the far advanced laparoscopic sur-

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gery era. A monopoly in robotic surgical systems and the subsequent high costs of establishing new robotic systems have stunted innovations. Cost-benefit analysis is considered to be one of the greatest obstacles for generalizing robotic surgery.[5]

The first robotic procedure performed in Korea was a robotic cholecystectomy in 2005.[6] In addition, meerecompany Inc. has been developing a Korean-based robotic surgical system. The company recently produced a robotic surgical system prototype called Revo-i (MSR-5000, meerecompany Inc., Hwaseong, Korea). We, therefore, conducted a preclinical study for robotic cholecystectomy using Revo-i. This report describes the first case of robotic cholecystectomy performed in a preclinical porcine model using Revo-i and discusses feasibility and technical aspects of the model.

CASE REPORT

In vivo porcine model

A total of four preclinical robotic cholecystectomy *in vivo* experiments were performed to test the safety and reliability of the current robotic surgical system, Revo-i. A 40 kg-healthy female porcine was prepared for robotic cholecystectomy with general anesthesia. General postoperative care was provided for two weeks after surgery. The primary end point was the safe completion of these procedures, and the secondary end point was the pig's safe recovery from the robotic surgical procedures without complications or mortality. This experimental protocol was approved by the Institutional Animal Care and use Committee of Yonsei University (2015-0358).

Robotic surgical system: Revo-i

Revo-i consists of a surgeon console (MSRC-5000, meerecompany Inc.), operation cart (MSRO-5000, meerecompany Inc.) and vision cart (MSRV-5000, meerecompany Inc.). The characteristics of Revo-i are described in Table 1.

Surgical procedure (Supplementary Video 1, only online)

The peritoneum was opened through a small 1.5 cm incision made around the paraumblical area. A 12-mm trocar was inserted. Under the view of the laparoscope, three additional ports were inserted for robotic arms. An additional port was placed for the assist port (Fig. 1). The operation cart was advanced to dock the individual robotic ports. The robotic A-arm was controlled by the surgeon's left hand, and both the robotic B-arm and C-arm were controlled by the surgeons' right hand. A cardiere forcep was inserted through the robotic C-arm to retract the gallbladder, and the Calot area was widely opened. The cystic duct and cystic artery were carefully dissected under three-dimensional operative view using Maryland forceps and a monopolar hook with articulating motion. Medium sized Hem-o-lock clips on a robotic clip-applier were used to ligate the cystic artery and cystic duct. Next, the gallbladder was dissected from the liver bed using monopolar

Table 1. Comparison between the da Vinci and Revo-i Systems (as of Dec. 2015)

	da Vinci	Revo-i
Mode of robotic movement	Master-slave	Master-slave
Components	Master console Slave robot Vision system	Master console Slave robot Vision system
Number of robotic arms	1 (camera)+3 (working)	1 (camera)+3 (working)
Robotic control	Finger grip type	Grip control
Wrist motion	Yes	Yes
Hand clutch	Yes	Yes
Pedal clutch	Yes	Yes
Camera control	Yes	Yes
Lateral arm-switching pedal	Yes	Yes
Energy sources	Monopolar Bipolar Harmonic Vessel sealer Recently, endo-GIA	Monopolar Bipolar
Clips	Micro-metal clip Hem-o-lock clip	Hem-o-lock clip
Instrument diameter	Φ8.4 mm	Φ7.4 mm
3D scope diameter	Φ12 mm	Φ10 mm
Response delay (master-to-slave)	<80 ms	<80 ms
Console adjustment function (ergonomic)	Yes	Yes
Scale motion	Yes	Yes

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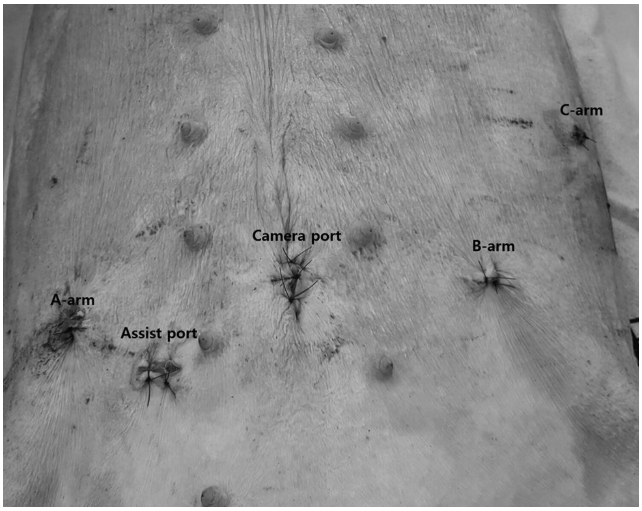

Fig. 1. Ports positioning. 1.5 cm incision was made for camera port around umbilicus. Other robotic ports were positioned approximately 10 cm from each other to reduce fighting between the arms. 8 mm incisions were made on A-arm, B-arm, and C-arm. 1 cm incision was made on assist port.

hook cautery. There was no gallbladder perforation or significant bleeding noted during the procedure.

Perioperative outcome

This first experiment suggests that robotic cholecystectomy using Revo-i can be safely completed in a porcine model. The total operation time was 88 minutes. It took approximately 4 minutes to complete the robotic docking. The actual dissection time[6] (defined as the time from the initial dissection of the Calot area to complete gallbladder detachment from the liver bed) was 14 minutes. The surgical console time was 45 minutes. Postoperatively, the pig survived without any complications for two weeks.

DISCUSSION

This is the first *in vivo* preclinical experiment that tested the clinical availability and feasibility of the Korean robotic surgical system, Revo-i. Our findings suggest that, in the near future, the Revo-i system would be a potential alternative to the currently available da Vinci robotic surgical system.

Like the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA), Revo-i provides a three-dimensional operative view and allows angulated instrumentation (forceps, needleholders, clip-appliers, scissors, bipolar energy, and hook monopolar energy) for effective laparoscopic procedures (Table 1). Although Revo-i is not yet clinically available to discuss the costs, potential advantage for Revo-i will be lower costs with the specifications similar to that of da Vinci surgical system. Furthermore, more cost reduction may be expected with number of instruments reuse greater than that of da Vinci's. However, various other energy sources, such as a robot-mountable harmonic scalpel, vessel sealer, and endo-GIA were not yet available. Other disadvantages of Revo-i, in current form, may include occasional system errors and resistance on the surgeon console during the operation. Although safe guard mechanisms are in place to prevent any undesirable injuries, more modifications are being made on the wire system and software in Revo-i to minimize such errors and inconveniences.

Our final results from four preclinical experiments of robotic cholecystectomy by Revo-i in a porcine model will be reported. Based on this preclinical study, a phase-I clinical trial for robotic cholecystectomy and robotic prostatectomy using Revo-i will soon be launched. We hope that the development of various new robotic surgical systems will overcome the cost-benefit issue of robotic surgery in general.[5]

SUPPLEMENTARY DATA

Video 1. The surgical video shows robotic cholecystectomy using Revo-i in a porcine model.

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