Hypothesis: Since the advent of laparoscopic surgery in 1987 and the introduction of robotics into medicine in 1991, medical technology has advanced to robotic applications in performing surgery. In our study, we investigated the feasibility of performing simple laparoscopic maneuvers and laparoscopic cholecystectomy using a robotic surgical system.

Design: The study used a ZEUS robotic system (Computer Motion Inc, Goleta, Calif), consisting of 3 interactive robotic arms fixed at the operating table and remotely controlled by the surgeon. After initial training, using a bench model and 3 isolated porcine livers to perform cholecystectomy, 7 female pigs underwent robotically assisted laparoscopic cholecystectomy. The surgeon, seated at the console, manipulated the 3-mm laparoscopic instruments and performed the surgery.

Results: Robotically assisted laparoscopic cholecystectomy was accomplished in all 7 pigs, with a mean operative time of 46 minutes (range, 30-62 minutes). There were no complications. The mean time to setup of the robotic system decreased from 30 minutes to 14 minutes. All the robotic maneuvers were performed without any particular difficulties, and the movements were stable, accurate, and reliable, with good control.

Conclusions: Our preliminary experimental study showed that robotically reproduced laparoscopic maneuvers, such as tying, suturing, dissection, clipping, and cautery, seemed to be as accurate and as fast as maneuvers made without robotics. We conclude that our initial experimental and animal study confirmed the feasibility of robotically assisted laparoscopic cholecystectomy. Further reports are needed to show that robotics can be used for clinical applications in surgery.
MATERIALS AND METHODS

The system used in our study was ZEUS (Computer Motion Inc, Goleta, Calif), a robotic surgical system with 3 interactive robotic arms fixed at the operating table, remote from the surgeon. One of these robotic arms (AESOP 3000, Computer Motion Inc) held the telescope and incorporated an automated surgeon voice-recognition control; the other 2 arms manipulated several 3-mm laparoscopic instruments, such as forceps, grasper, and needle-holder, which could be exchanged for scissors or diathermy hook. The surgeon control center was an ergonomic console composed of a mobile track that incorporated a high-resolution touch-screen video monitor and 2 attached robotic handles. The surgeon, seated comfortably in a chair in front of the monitor, performed the surgical procedure by manipulating instruments with robotic handles that resemble grasping devices of conventional laparoscopic instruments. A voice-activated headphone mounted on the surgeon’s head was used to control movements of the telescope. The ZEUS system had a dedicated computer that precisely interpreted and transmitted the surgeon’s hand movements by electromechanical interface to the remotely placed robotic arms. The robotic arms and the computerized control panel were linked by coaxial cables.

The handle movements can be scaled down to filter out hand tremors in such a way that the surgeon is able to perform not only laparoscopic procedures but also microsurgery, such as coronary bypass grafting. The magnitude of movements can be reduced by one half or one third, for example, by varying the settings. The surgeon is able to prevent inadvertent movement of the instruments by stepping off of a foot pedal to clear the controls. Additional systems to increase safety are dual sensors to continuously monitor each movable joint of the ZEUS and an automatic voice-regulated warning signal feedback system to the surgeon.

A bench model was tested by performing simple tasks with the robot in handling pins, beads, thread, and Neoprene synthetic tissue. This allowed familiarization with robot setup and robot-surgeon movements.

Isolated porcine livers (n = 3) were then used to simulate in vivo cholecystectomy. The bench model was placed on the operating table, with the liver specimen to the right, simulating its abdominal position. The robotic instruments were inserted through 2 lateral 5-mm ports and a 30° laparoscope was inserted through a central 10-mm port.

ANIMAL STUDY

Animal use was in compliance with the guidelines for care and use of laboratory animals at our institution. Seven female pigs (30-40 kg) were used for this study. Following induction of general anesthesia, pneumoperitoneum was created with carbon dioxide insufflation to 12 mm Hg of pressure through a 10-mm trocar. Three 5-mm trocars were inserted as shown in Figure 1. The ZEUS instruments were inserted into 2 of the 3-mm trocars; the 10-mm trocar was used for the AESOP telescope voice-control arm; and another lateral 5-mm trocar was used by an assistant to retract the gallbladder fundus and to clip the cystic structures. The 2 robotic arms were fixed to the operating table and adjusted for optimal operating positions. The right robotic arm held a 3-mm forceps and the left arm held a 3-mm diathermy hook or scissors (Figure 2). The surgeon, seated at the console, manipulated the 3-mm instruments and performed the surgery (Figure 3). After isolation of Calot’s triangle, the assistant inserted 5-mm titanium clips. The surgeon divided the cystic duct and completed cholecystectomy using the ZEUS systems. After the experiment, the animals were humanely killed with a lethal dose of potassium chloride.

COMMENT

Our preliminary experimental study showed that robotic movements, such as tying, suturing, dissection, clipping, and use of cautery, seemed to be as accurate and as fast as maneuvers made without the robot. The new-generation robot ZEUS can be rapidly positioned and easily set up. The robotic arms showed the same degrees of freedom on the axial planes as do standard laparoscopic procedures and mirrored the movements of the robotic handles operated by the surgeon at the remote control. The central computer regulated the surgical movements, and a scale of 1.8 to 3.5:10 was used in all axes. In this way, a 3.5 movement by the surgeon at the handle was translated into a 1.0 movement at the tip of the instrument, while a scale of 1:1 was selected for rotational movements at the wrist joints of instruments. In our study, the ZEUS robotic system enhanced surgical dexterity for laparoscopic maneuvers, such as dissection, suturing, tying, and coagulation.

We successfully performed simple and complex surgical maneuvers remotely and suggest that robotic surgery can be considered for clinical applications in specialized centers. In our pilot study, the 3-mm surgical instruments used for tissue dissection, division, and electrocautery were designed primarily for performing microsurgery in coronary artery bypass grafting. These instruments, particularly the needle-holder, are less optimal than 5-mm instruments because of a lack of tactile feedback. Further innovations in instrumentation for ro-
Robotic surgery should make devices more user-friendly, thus improving ergonomics, tactile perception, and force feedback. Probably in the near future, with the use of telemanipulators and miniaturized probe tips, tactile sensation by intuitive feel will be made available to the laparoscopic surgeon.

In conclusion, our initial experimental and animal studies confirmed the feasibility of robotically assisted laparoscopic cholecystectomy. Results of the procedure seemed to be comparable to those of the conventional techniques. Further reports will be needed to show that robotic surgery can be useful for applications in clinical practice.

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