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.

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INCE THE ADVENT of laparoscopic surgery in 1987 and the initial introduction of robotics into the field of medicine in 1991,1 advancement in medical technologies, such as computers, imaging systems, and transduction of digital signals, has resulted in the first clinical reports of robotic surgery.2-4 Telemedicine was a product of developments in the use of digitalized data, and teleradiology and telepathology were in use before telesurgery was initiated.5 With the introduction of laparoscopic surgery6 and the possible applications of use of digital surgical data, such as image standards format, data interfaces and transfers, and image fusion, robot-surgeon interface systems have been considered a goal of minimally invasive surgery. Toward this end, significant technological advances have accompanied developments in new instrumentation,7,8 improved surgical approaches, and advanced operative techniques in various fields of surgery (digestive, thoracoscopic, orthopedic, gynecological, cardiac, and others).5,9-12 However, more analysis is needed to show whether efforts to improve surgical technology can benefit the patient in terms of low morbidity, less pain, and shorter hospital stay. Furthermore, the application of advanced technology to surgery by combining robotics and telemanipulated enhancement of surgical skill has minimized natural tremors and increased dexterity and precision.8,13 The aim of our study was to investigate the feasibility of performing laparoscopic cholecystectomy using a robotic surgical system.

RESULTS

EXPERIMENTAL TRAINING

Before the animal study, exercises simulating dissection and suturing were performed by the surgeons to improve their dexterity and to assess different equipment setups. One-hour daily sessions were performed during the training. The ro-
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.

The robotic system was then used to perform cholecystectomy in ex vivo liver specimens.

ANIMAL STUDY

Robotically assisted laparoscopic cholecystectomy was accomplished in all 7 animals. The median operative time was 46 minutes (range, 30-62 minutes). There was no injury to adjacent organs or tissue. The mean blood loss per pig was less than 50 mL. All operations were carried out uneventfully, and there was no deviation from the protocol. The mean time to setup of the robotic system decreased to 19±8 minutes. No technical problems occurred with the ZEUS system. All surgical reproducible maneuvers were performed without any particular difficulties, and the robotic movements were stable, accurate, and reliable, with good control.

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 the 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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Corresponding author and reprints: Davide Lomanto, MD, PhD, Division of General Surgery II, Department of General Surgery, Surgical Specialty and Organ Transplantation “P. Steffani,” University of “La Sapienza,” Policlino Umberto I, Viale del Policlinico, 155, 00161 Rome, Italy (e-mail: davide.lomanto@uniroma1.it).

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