Objective: To compare the surgical performance of manual and robotically assisted laparoscopic instruments on basic maneuvers and intracorporeal suturing in inanimate models.

Design: A set of laparoscopic tasks was used to evaluate basic endoscopic movements and intracorporeal suturing: positioning a cylinder on a Peg-Board, dropping beads into receptacles, running a 25-cm rope, and capping a hypodermic needle. Intracorporeal knot tying and running a suture through predetermined points were evaluated separately. The sutures used for these tasks were 2-0 and 4-0 silk and 6-0 and 7-0 polypropylene.

Participants: Twenty surgeons completed the set of laparoscopic tasks manually and then with a robotically assisted system. None had used the robotic system before.

Main Outcome Measures: Time required to complete the tasks and the precision in performing them.

Results: The robotic system accurately reproduced the movements of the surgeons and filtered their hand tremors efficiently. In the basic tasks, operative times were significantly longer for the robotic system ($P < .001$). In the suturing tasks, operative times were longer with the use of the robotic system for sutures sizes 2-0 and 4-0 ($P < .001$). However, time differences were not significant for suture sizes 6-0 and 7-0 ($P \geq .07$). Precision measurements were similar for all tasks using the manual instruments and the robotically assisted system. No significant differences were found between the performance of advanced laparoscopic surgeons and laparoscopic fellows.

Conclusions: Laparoscopic maneuvering and suturing is faster and just as precise when performed manually as when performed with the prototype robotic system. These differences in speed are inversely proportional to the size of the suture. Future generations of the robotic system may eliminate these differences.

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Laparoscopic surgery requires a large number of small and precise movements to manipulate and suture tissue in a confined space.\textsuperscript{1,2} This precision needs to be maintained through an operation, despite the normal tremor of the human hand and the fatigue that accompanies difficult and prolonged surgeries. In addition, magnifying the surgical field also magnifies the effects of tremors, requiring even more dexterity and further prolonging the surgery, which in turn increases fatigue.

Robots can produce rapid, precise, and repeated movements for long periods. In contrast to surgeons, they experience neither tremors nor fatigue. Thus, the application of robotics to laparoscopic surgery could conceivably reduce if not eliminate some of the barriers to providing fast and accurate movements, especially in long operations.

We compared the ability of laparoscopic surgeons to manually perform a protocol of basic manipulation skills and suture tasks with conventional laparoscopic instruments with a prototype of a robotically assisted laparoscopic system.

RESULTS

BASIC TASKS

The results are given in Table 1. No significant differences were found between the dominant and nondominant hand in either group. The mean of precision scores was 95% for manual manipulation and 97% for the robotic system manipulation (data not shown).

SUTURING TASKS

The results are given in Table 2 and Table 3. Interestingly, for the manual
PARTICIPANTS AND METHODS

EXPERIMENTAL DESIGN

Twenty surgeons participated in the study: 8 staff surgeons, 10 surgical fellows, and 2 surgical residents. Each staff surgeon had performed more than 100 laparoscopic surgeries, and 4 of the fellows had performed more than 50, whereas the other 6 fellows had performed between 25 and 50, and the surgical residents had performed less than 25.

All participants were members of the Minimally Invasive Surgery Center at the Cleveland Clinic Foundation, Cleveland, Ohio. Among them were staff laparoscopic surgeons, laparoscopic surgery fellows, general surgery fellows, and surgical residents. All the surgeons were asked to complete a standardized laparoscopic skills protocol. They first manipulated the laparoscopic instruments manually and then with a robotically assisted laparoscopic system. Several tests were selected to evaluate their basic laparoscopic and intracorporeal suturing skills. Some of these tests were modified from previous descriptions.1,3

EXPERIMENTAL SETUP

The same setup was used for all tests. We used basic videoendoscopic equipment (Karl Storz, Culver City, Calif). The 3-chip video camera was connected to a 10-mm, 30° laparoscope, and the image was displayed on a 14-in monitor. A laparoscopic training box (Szabo-Berci-Sackier, Karl Storz) was placed on a 50-cm-tall stand, and the surgeon was seated on a chair with arm supports. All the manual laparoscopic drills were executed using disposable 3-mm Maryland dissectors (Endo-dissect, US Surgical Corporation, Norwalk, Conn). The manual laparoscopic suturing tests were carried out using a set of 3-mm laparoscopic needle-drivers (Szabo-Berci, Karl Storz) (Figure 1).

All the robotic tests were performed using the instruments developed by the manufacturer (Computer Motion, Goleta, Calif). The robotic system, called Zeus, is composed of 3 robotic arms. One arm handles the camera and the other 2 manipulate a variety of surgical instruments (Figure 2). For our experiment, we used 3-mm needle-drivers. The surgeon manipulates these instruments through 2 controllers that have a configuration and a mechanism similar to those of regular laparoscopic needle-drivers. The system has a feature that can scale the movements of the controllers. Thus, the surgeon can perform wider movements while the robotic instruments move within narrow margins. This scaling feature was set at a 4:1 proportion for our experiment. The camera is controlled through a voice-activated system or a foot pedal. In this way, the surgeon has direct control over the optical field and the movement of the instruments. The plastic models used for the tests were custom made.

PREPARATION FOR THE TESTS

Every participant was instructed about the main features of the endoscopic tasks to be performed and on how to operate the robotic system. The participants were allowed to manipulate the robotic system for 2 minutes to become familiar with its controls and setup. However, no time was allowed for preliminary practice on any of the tasks, with or without the robot. Questions were allowed and answered before and during the tests in a general and direct way, but no assistance was provided for manipulating the camera or the endoscopic instruments during the tests. The same order of tasks was followed for every participant. In certain tests, performance with the dominant hand and the nondominant hand was evaluated. In these tests, the dominant hand was evaluated first.

The same robotic tools were always used for a given test. During the tests, the surgeon was seated. Each test was performed twice, once manually and once with the robotically assisted laparoscopic system.

MANIPULATION TASKS

Cylinder Positioning

This drill consisted of moving 10 of 19 plastic cylinders (5 × 5 mm) from a starting position to a predetermined

measurements, longer operative times were observed with smaller sutures, although the difference was not significant (P = .13). This trend was reversed for the robotic system, which performed best with the 7-0 sutures. The same trend toward a longer operative time with smaller sutures was found for the manual measurements, and the opposite was true for the robotic system.

No statistically significant differences were found between staff surgeons and fellows in any of the tests performed with either of the systems.

COMMENT

Recently, medical robotics has come to the attention of the surgical community in its continuous search for improved instruments. Robots outperform humans in several tasks, particularly those in which precision and fatigue are important factors.5,6

Laparoscopic surgery has several features that lend themselves to robotic technology. The limited range of maneuverability imposed by the fixed-access ports increases the complexity of the surgical procedure. Furthermore, the surgeon’s posture during some laparoscopic procedures may be uncomfortable because the hands must accommodate the location of the access ports. In addition, prolonged operative times further increase fatigue. The optically magnified tremor in the surgeon’s hand and the use of long instruments also reduce surgical precision.2

Theoretically, an untiring and stable robotic system should improve the precision of many laparoscopic maneuvers.5,6,8 In our study, we used a prototype of a new surgical robot specifically built to assist surgeons during laparoscopic surgery. This robotic system is being reviewed by the Food and Drug Administration but is available for research purposes.

We found that the robot can operate safely and unobtrusively near humans. It accurately reproduced the movements of the surgeon, making them stable by eliminating the natural tremor in the surgeon’s hand. The ro-
position on a Peg-Board. Time was recorded from start to finish, and each hand was tested separately (Figure 3). Each correctly placed cylinder was awarded 10 percentage points; 10 correct placements were recorded as 100% precision.

Bead Drop

In this test, an initial receptacle (50-mm opening) contained 19 beads (10 × 4 mm). The task was to transfer and drop 10 of the beads, 1 at a time, inside a final receptacle (15-mm opening) (Figure 4). Each correctly placed bead was awarded 10 percentage points; 10 correct drops were recorded as 100% precision.

Rope Passing

This task was to run a 25 × 0.3-cm rope using a hand-to-hand technique. The rope was loose but fastened at both ends and had 10 specified alternate grasping points, 5 for the dominant instrument and 5 for the nondominant instrument. To evaluate each hand separately, the rope was first run toward the dominant hand and then toward the nondominant hand. Time was recorded from a starting position 5 cm from the rope to the moment when the 2 instruments were grasping the 2 last marks on the rope (Figure 5). Each grasp outside the specified markings reduced the ideal precision score (100%) by 5 percentage points.

Needle Capping

For this test, we used a disposable 20G1½ hypodermic needle and its cap. The purpose was to cap the needle after grasping both pieces from the floor of the training box. The only requirement was to cap the needle above the box floor. The test was executed first by manipulating the needle with the dominant hand and then with the nondominant hand. Time was recorded from a starting position 5 cm from the needle and its cap to the moment when the needle and the cap were coupled and held by 1 instrument (Figure 6). Every unsuccessful attempt to cap the needle reduced the ideal precision score (100%) by 20 percentage points.

Suturing and Knot Tying

We evaluated the ability to suture and tie on a latex glove using a variety of sutures. The following sutures and their order of use were used for the test: 2-0 silk MH needle, 18 cm; 4-0 silk CV-307, 15 cm; 6-0 polypropylene C-1, 10 cm; and 7-0 polypropylene BV-1, 7 cm. The stitch had to pass through 2 separated dots on the glove. The size of the dots and the distance between the dots were relative to the suture size. Dot sizes were 1.5, 1.0, 0.75, and 0.5 mm, and the distances between the dots were 10, 5, 3, and 1 mm, for the 2-0, 4-0, 6-0, and 7-0 sutures, respectively. Time was recorded from the beginning of the stitch to completion of the 3-knot tie. The time it took to position the needle in the needle-driver was not considered. The nondominant hand was not evaluated in these bimanual tests (Figure 7). If the knot was loose, the ideal precision score (100%) was reduced by 20 percentage points; if the suture was broken, the score was reduced by 50 percentage points.

Running Suture

After completing the previous test, the rest of the suture was run through 10 dots on the glove to complete a 4-bite running suture. The size of the dots and the distance between them were relative to the suture size as stated for the knot-tying task. The timer was started when the operator had the needle on the needle-driver, ready to take the first bite. The time to position the needle for the first bite was not considered (Figure 8). Every correct passing of the needle through a dot received 10 percentage points. If the suture was broken, the score was reduced by 50 percentage points.

STATISTICAL ANALYSIS

Two-tailed Wilcoxon signed rank tests (SAS software package, SAS Institute Inc, Cary, NC) were used to compare the 2 groups. P < .05 was considered significant.
Second, although we tried to keep the setup for the manual instruments and the robotic system as similar as possible, the instruments for the robotic system are 3-mm in diameter, whereas the manual instruments are 5-mm in diameter. Because the jaws of the instruments for the robotic system are very small, manipulating large structures, such as the beads, the cylinders, and the cap of the needle, was more difficult with them than with the manually operated laparoscopic instruments.

Third, there is a definite learning curve associated with the use of the robot. Although the robot's controllers resemble the handles of laparoscopic instruments, there are major differences. Without tactile sensation, the spatial orientation of the handles does not necessarily correspond with the spatial orientation of the instruments, and extra time is consumed because certain positions of the handles automatically deactivate the system.

Of most interest is that in the manual suturing tasks, the operative times increased as the size of the suture de-
After this preliminary study, we conclude that manual laparoscopic maneuvering and suturing is as accurate and faster than the prototype robotic system. The difference in speed between the manual and robotic systems is inversely proportional to the size of the suture. Future generations of the robot, which will feature improved controllers and force and tactile feedback, may be more effective for these tasks. A second evaluation of the participants is under way, this time after several practice sessions with the robotic system.

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REFERENCES


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