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An Ergonomic Comparison of Robotic and Laparoscopic Technique: The Influence of Surgeon Experience and Task Complexity

Ramon Berguer, M.D.,*,[1] and Warren Smith, Ph.D.†

**Department of Surgery, University of California Davis, Sacramento, California and Surgical Service at Contra Costa Regional Medical Center, Martinez, California; †College of Engineering and Computer Science, California State University, Sacramento, Sacramento, California*

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Background. **This study compares the mental and physical workload of laparoscopic and robotic technique while performing simulated surgical tasks in a laboratory setting.**

Materials and methods. **Ten volunteer surgeons performed two tasks in a laparoscopic trainer using laparoscopic (LAP) and robotic (ROB) techniques. Outcome measures included: Task time, task-error, vertical/horizontal arm displacement, percent maximum electromyographic signal from the thenar, forearm flexor, and deltoid muscle compartments, skin conductance, and perceived difficulty and discomfort levels. A two-way repeated-measures ANOVA compared surgical technique and laparoscopic experience level (E = expert, N = novice).**

Results. **For the simple task, ROB technique was slower and had higher errors, and the surgeon's arm was more elevated. For the complex task, ROB electromyographic signal was lower. Stress was lower in both tasks for ROB, but the decrease was not statistically significant.**

Conclusions. **Robotic technique appears slower and less precise than laparoscopic technique for simple tasks, but equally fast and possibly less stressful for complex tasks. Previous laparoscopic experience has a complex influence on the physical and mental adaptation to robotic surgery.**

Key Words: **robotic surgery; laparoscopy; ergonomics.**

INTRODUCTION

The development of computer assisted telemanipulation devices for surgery (commonly referred to as surgical "robots") has opened the possibility for surgeons to operate without directly contacting the patient and without the limitation of current laparoscopic instruments [1]. Initial clinical studies of robotic surgery have demonstrated its viability and safety [2]. However, problems such as slow setup and takedown times and the high capital cost of the equipment remain to be solved [3]. One purported advantage of a robotic system is that it can provide a five- or six-degree-of-freedom movement of the surgeon's instrument inside the body, essentially giving the surgeon a virtual "wrist" inside the patient. This technical advance could reduce the significant ergonomics problems associated with use of current laparoscopic instruments, hopefully leading to more efficient and comfortable surgical procedures.

The aim of this study is to compare the effects of robotic laparoscopic surgery and standard laparoscopic surgery on the performance, error rates, and the physical and mental workload of surgeons. The hypothesis is that robotic surgery will not reduce procedure time, but will reduce the physical and mental workload of simulated laparoscopic tasks.

METHODS

This study was IRB-approved and carried out at the 8th World Congress of Endoscopic Surgery in New York, NY, hosted by the Society of American Gastrointestinal Endoscopic Surgeons (SAGES) in March of 2002. The investigation took place in a dedicated ergonomics station located in a 10′ × 20′ booth in the Learning Center inside the exhibit hall.

The study compared surgeon performance and workload during simulated standard laparoscopic tasks and robotically assisted laparoscopic tasks for 10 volunteer laparoscopic surgeons (Table 1). Each subject used laparoscopic and robotic techniques, in random order, to perform two simulated surgical tasks: A Pin Move task (PIN); and a Suture task (SUT). To work manually, each subject stood at a tra-

[1] To whom correspondence and reprint requests should be addressed at Surgical Service at Contra Costa Regional Medical Center Martinez, Martinez, CA 94553. E-mail: rberguer@yahoo.com.

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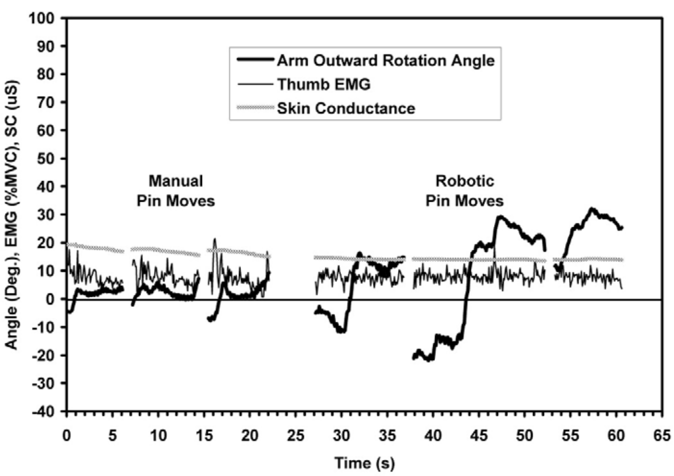
TABLE 1

Subject Demographics

Subject	Age	PGY Yr.	Practice yrs	Robot exp	LC exp	Lap Surg exp	Overall Exp rating	Dominant hand	Task order
1	42		10	n	200	Gen.	n	R	R M
2	35		3	n	100	Gen.-TEP	n	R	M R
3	35	6		n	300	Adv.	y	L*	R M
4	29	4		n	100	Gen.	n	R	M R
5	32		3	y	300	Gen./Adv.	y	R	M R
6	30	3		y	40	Gen.	n	R	R M
7	51		20	n	5000	Adv.	y	R	M R
8	35		3	y	200	Gen.	n		M R
9	45		15	n	50	Gen.	n	R	M R
10	33		2.5	n	100	Gen./Adv.	y	R	R M

EXP = experience.
* Uses right hand to perform surgery.



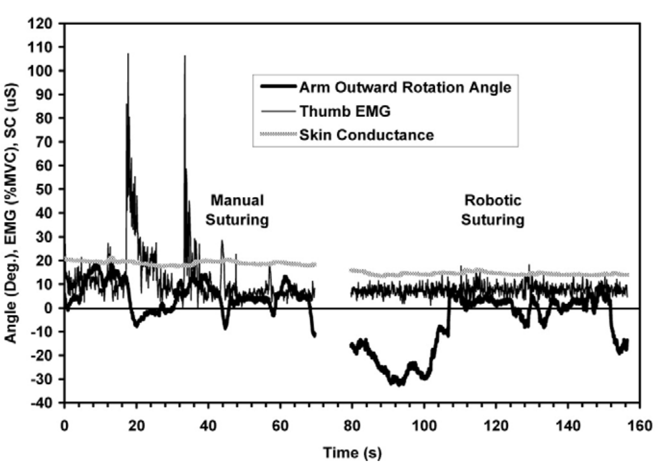


FIG. 1. Top: A subject's time plots of right arm outward rotation angle (abduction), thumb electromyography, and skin conductance for the three Pin Move trials laparoscopically (left) and robotically (right). Bottom: A subject's time plots of right arm outward rotation angle (abduction), thumb electromyography, and skin conductance for the Suture task laparoscopically (left) and robotically (right). The individual recordings were concatenated for these figures.

ditional laparoscopic trainer box (Karl Storz Endoscopy, America, Culver City, CA), which was height-adjusted to place the instrument handles at each subject's elbow level. The PIN task was performed using two disposable curved laparoscopic dissectors. Suturing and knot-tying were conducted with a standard laparoscopic needle-driver and needle holder (Karl Storz Endoscopy) and 2.0 silk suture. To perform robotically assisted laparoscopic tasks, the subject sat at the console of a ZEUS Robotic Surgical System (Computer Motion, Inc., Goleta, CA) with a MicroWrist interface and 3D display. The Zeus equivalent of the standard laparoscopic instruments was used for each task. Subjects received a standard 30 min training session for the Zeus robotic system before taking part in this study. The simulated surgical field was a blue, 10 × 13-cm platform with two 1.7-cm-diameter circles on it, centered 30 mm on either side of a stretched surgical glove finger. The PIN task (repeated three times) consisted of picking up a poster pin standing on its head in the left-hand circle, and attempting to set it down standing on its head in the right-hand circle. The SUT task consisted of driving a suture needle through a surgical glove finger and tying three knots (one surgeon's knot plus two squared throws).

Performance measures for the study were the task times for the Pin Move and Suture tasks, and Accuracy and Control errors for the Pin Move task only. An Accuracy error occurred if the pin was not set down within the target right-hand circle. A Control error occurred if the pin fell down when released. The physical workload measures for the upper extremity have been previously described [4] and included the abduction, flexion, and outward rotation angles of the surgeon's right upper arm (measured by an orientation sensor strapped to the arm) and the root mean square electromyographic (EMG) signals recorded from pairs of skin surface electrodes placed over the thenar compartment of the right hand, the right forearm flexor digitorum superficialis, and the right deltoid muscles. Mental workload and stress was measured through skin conductance (SC) [5] on the subject's right palm. ECG was not recorded for this study, because it was awkward in the conference setting for the subjects to partially disrobe to attach the electrodes. After competing each task subjects rated their level of difficulty ("Very Easy" = 0 to "Very Difficult" = 10) and discomfort ("No Discomfort" = 0 to "Severe Discomfort" = 10) for that task.

The physiological measures of workload and stress from each subject along with audio and three video channels were simultaneously recorded by a tetherless ergonomics workstation (for details, see [4]). The physiological recording system consists of a module worn by the subject and a base station laptop computer. The wearable module consists of a lightweight electronics "fanny pack" signal acquisition box, a 22-oz wearable computer (ViA, Burnsville, MN) housed in a belt across the lower back, and one or two 16-oz batteries for up to 6 h of operation. The physiological