A Comparison of the Physical Effort Required for Laparoscopic and Open Surgical Techniques

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Hypothesis: Performing complex tasks requires greater muscle effort with laparoscopic instruments than with open surgical instruments.

Design: A nonrandomized 2-condition trial.

Setting: A semienclosed ergonomics station in the exhibit hall at the Annual Meeting of the Society of American Gastrointestinal Endoscopic Surgeons.

Subjects: Twenty-one surgeons volunteered to participate in the study.

Interventions: Knot tying during 90 seconds, performed first using a laparoscopic technique (ie, axial instruments in a standard laparoscopic trainer) and then using an open technique (ie, 2 hemostats).

Main Outcome Measures: Mean and peak surface electromyographic (EMG) signals collected from the thenar compartment, the flexor digitorum superficialis, and the deltoid muscles of the dominant arm.

Results: Compared with open knot-tying, laparoscopic tasks resulted in higher average EMG amplitudes in all 3 muscles (thumb, $P = .02$; forearm flexor, $P = .01$; and deltoid, $P = .01$) and higher peak EMG in the thumb ($P = .04$) and deltoid ($P = .02$) muscles. Body part discomfort scores were significantly higher during laparoscopic knot-tying for the forearm flexor and deltoid muscles ($P = .02$ for both).

Conclusion: Complex manipulative tasks using laparoscopic techniques require substantially higher upper-extremity muscle effort compared with open surgical techniques.

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As laparoscopic operations have become commonplace, surgeons are experiencing new patterns of physical fatigue and discomfort from the use of laparoscopic instruments. Even among experienced laparoscopic surgeons, significant musculoskeletal complaints related to the neck and arms appear to be common. Two general factors related to laparoscopic surgery appear to contribute to this problem: an increase in static head and trunk postures and a greater amount of movement required of the shoulder and upper arm when using long laparoscopic instruments. In addition, there are 2 instrument-specific problems that may contribute to surgeons' musculoskeletal problems: the poor mechanical efficiency of laparoscopic instruments and the awkward design of laparoscopic instrument handles. The end results of these factors are longer laparoscopic operations, surgeon fatigue, and the potential for work-related musculoskeletal injuries in surgeons. To encourage manufacturers to correct the mechanical and ergonomic shortcomings of today's laparoscopic instruments, we need objective evidence that these instruments require more physical effort than do open instruments.

This article investigates whether realistic surgical manipulations require more muscular effort when performed with laparoscopic instruments compared with the use of open surgical instruments. The limited research to date has employed simple tasks, such as closing a grasper against a spring-loaded force, to confirm this hypothesis. However, it is not clear whether these data are applicable to realistic and more complex laparoscopic manipulations. The current study addresses this question by comparing objective and subjective measures of surgeons' upper-extremity muscle effort during realistic knot-tying tasks performed with both laparoscopic and open surgical instruments.
The study was conducted during the Society of American Gastrointestinal Endoscopic Surgeons annual meeting, April 1-4, 1998, Seattle, Wash. The experimental setup was located in one of eight 4.5-m x 4.5-m booths composing the Learning Center, which was located in a corner of the general exhibit hall. Subjects were 21 surgeons (20 men and 1 woman) who visited the Learning Center and volunteered to participate in the study. The study was approved by the Human Subjects Committee of California State University, Sacramento, and all subjects signed informed consent forms prior to participation.

A portable Ergonomic Measurement Station (ERGOSTATION) was developed by the California State University, Sacramento, Biomedical Engineering Program to measure, analyze, and display surface electromyographic (EMG) signals. Pairs of silver-silver-chloride surface electrodes were placed on the thenar compartment, the superficial digital flexor, and the deltoid muscle of each subject according to published descriptions. A common reference electrode for all 3 sites was placed on the ipsilateral biceps. The ERGOSTATION consisted of analog circuitry and a LabVIEW (National Instruments, Austin, Tex) software program running on a Macintosh PowerBook 5300c (Apple Computer, Cupertino, Calif) with a National Instruments DAQCard-700. The raw EMG signal was processed electronically by the analog circuitry prior to the analog-to-digital conversion, thereby allowing the LabVIEW software to sample at the lower per-channel frequency of 9 samples per second. Each of the 3 channels of analog processing consisted of an instrumentation amplifier, an isolation amplifier, a band-pass filter (with a passband between 20–180 Hz), a full-wave rectifier, and a smoothing filter (with a cutoff point of 2 Hz). The overall gain per channel was 5600. Prior to each experiment, normalizing EMG data were obtained by asking subjects to perform maximum voluntary contractions of each muscle against a fixed resistance.

The experimental station consisted of a laparoscopic training box (Karl Storz Endoscopy, Culver City, Calif), a laparoscopic light source, a 10-mm 0° laparoscope, and a 3-chip laparoscopic camera (Olympus Optical Co, Ltd, Tokyo, Japan) connected to a 53-cm video monitor (Sony Corp, Tokyo). Knot tying was performed using 8-cm lengths of 2.0 silk suture passed through and through a medium-sized latex glove suspended between 4 alligator clips at the base of the training box. Subjects used a pair of Szabo-Berci (Karl Storz Endoscopy) laparoscopic needle driver and needle holder instruments to perform the laparoscopic knot-tying. Open knot-tying was performed with 2 standard Cottle hemostats held in each of the subject’s hands. Subjects were instructed to continuously tie alternating square knots for a 90-second period bracketed by a start beep and a stop beep from the ERGOSTATION (fixed-performance experimental design). When performing the laparoscopic knot-tying, the training box was positioned such that the instrument handles were at each subject’s elbow height. Open knot-tying was performed without the endoscopic equipment, with the top and sides of the trainer removed, and with the task height adjusted to allow the subjects to hold the hemostats at elbow height. Subjects were asked to record their degree of perceived muscular discomfort for the 3 muscle areas after each task on a scale of 0 to 3 (0, none; 1, mild; 2, moderate; and 3, severe). The ERGOSTATION saved the physiologic data to disk and printed out a summary sheet of the EMG waveforms for the 3 muscles under the laparoscopic and open conditions as well as summary statistics computed for the waveforms. Statistical analysis of the results of this study was carried out using STATISTICA software, version 5.0 (StatSoft, Tulsa, Okla) and paired t tests with significance set at P < .05.

The mean age of the subjects was 47 years (range, 28–59 years). Summary data are presented in Figures 1, 2, and 3. The use of the laparoscopic technique for knot tying increased the average upper extremity EMG values for all 3 muscles by 49% to 60% (thumb, P = .02; forearm flexor, P = .01; and deltoid, P = .02), and the peak EMG values for the thumb (P = .04) and deltoid (P = .02) muscles by 25% to 103%. Body part discomfort scores were only obtained from 10 of 21 subjects due to unclear instructions. Body part discomfort scores during laparoscopic knot-tying were significantly higher for the flexor digitorum and deltoid muscles (P = .02 for both).
and moderately higher for the thenar compartment ($P = .07$) compared with the open technique.

### COMMENT

This study provides concordant subjective and objective evidence that complex manipulations such as knot tying performed with laparoscopic instruments demand a substantial increase in upper-extremity muscular effort compared with the use of standard open instruments. These data are consistent with previous data from our laboratory using simpler grasping tasks, suggesting that it may be possible to extrapolate data from simple tasks to more realistic surgical tasks in some situations. The parallel increases in the subjective body part discomfort scores and the objective EMG values adds to the face validity of our conclusions and supports the use of surface EMG measurements to measure the physical work of surgery. The increase in the thenar compartment body part discomfort scores with the use of laparoscopic instruments was substantial (47%) but statistically nonsignificant, whereas the increase in thenar compartment EMG values was statistically significant. This was likely due to the smaller sample size for the body part discomfort scores compared with EMG measurements. Conversely, we observed only slightly higher (25%) and statistically nonsignificant peak EMG values for the flexor digitorum superficialis muscle with the laparoscopic technique, whereas the increase in body part discomfort scores for this muscle was statistically significant. This finding illustrates that although our subjective and objective measures always changed in the same direction, they sometimes differed in magnitude and hence in statistical significance.

The causes of the increased physical work required to use laparoscopic instruments are probably multifactorial. Certainly, the lower mechanical efficiency of the instruments and the awkward wrist postures adopted during their use are important factors. It is important to note that the current study was conducted with an optimum instrument configuration and very short task times. Thus, our results are likely to underestimate the surgeon’s upper-extremity physical workload because during actual laparoscopic operations, surgeons work for longer periods of time under much less ideal circumstances.

Our subjects reflected a cross-section of practicing surgeons, ranging from very experienced to recently graduated from residency. This variability in our subjects’ laparoscopic skills makes the statistical significance of our results even more relevant. Nevertheless, our conclusions are subject to some limitations. All but one of our subjects were male, and female surgeons with smaller hands might have experienced an even more pronounced increase in upper-extremity physical effort during laparoscopic knot-tying owing to a greater mismatch between hand size and handle size. Another limitation is that we measured the workload required to complete a fixed-time task (ie, knot tying for 90 seconds) instead of measuring both the workload and subjects’ performance (eg, the number of knots tied or the time needed to tie a certain number of knots). Our observations were that subjects uniformly tied fewer knots using the laparoscopic technique compared with the open technique, although this was not quantified or recorded. This suggests that if subjects’ workload and performance were to be taken into account, the effort-performance ratio for laparoscopic techniques would be much higher than the ratio for open surgery. A final consideration is that although knot tying is a laboratory task commonly used to simulate complex laparoscopic manipulations, this specific task typically represents only a small fraction of most laparoscopic operations. We can only hypothesize that the physical work of cutting and dissecting with laparoscopic instruments is similarly increased relative to open instruments. Ultimately, more complete and realistic ergonomic studies correlating physical workload in surgeons with the type of task being performed are required to fully understand the biomechanics and physical demands of minimal access surgery.

We conclude that the use of laparoscopic techniques for knot tying requires a substantial increase in the work of the surgeon’s upper-extremity muscles compared with the use of open instruments. This increased workload is accompanied by an increase in the subjective discomfort of the surgeon in the affected body areas.

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REFERENCES


Surgical Anatomy

The first 3 intercostal nerves are irregular and interesting: (a) the lateral and anterior cutaneous branches of the first intercostal nerve are small or wanting; (b) the lateral branch of the second runs across the dome of the axilla in the laminated fascia and then descends on the posteromedial aspect of the arm as the intercostobrachial nerve; (c) the lateral branch of the third sends a branch to the medial side of the arm.

Source: Boileau Grant JC. A Method of Anatomy: Descriptive and Deductive. 5th ed. Baltimore, Md: Williams & Wilkins Co; 1952-93.