

EFFECT OF HANDLE DESIGN AND TARGET LOCATION ON WRIST POSTURE DURING AIMING WITH A LAPAROSCOPIC TOOL

Judkins, T.N.¹, DiMartino, A.¹, Doné, K.¹, Hallbeck, M.S.¹, and Oleynikov, D.²

¹Department Industrial Engineering, 175 Nebraska Hall, University of Nebraska, Lincoln, NE 68588

²Minimally Invasive and Computer Assisted Surgery, University of Nebraska Medical Center, Omaha, NE 68198

ABSTRACT

Laparoscopic surgery is a rapidly increasing field in healthcare today. However, current laparoscopic tools have inadequate handle designs and have been directly linked to post-surgery pain among surgeons. This study recruited forty subjects (20 male, 20 female) to evaluate the effect of handle design as well as target location on accuracy, precision, and wrist posture during an aiming task. Two laparoscopic tools were used for this study: a commercially available scissor-grip tool and a custom-designed ergo-grip tool. Each subject was asked to aim through a trocar at the center of one of five targets using one of the tools. The target was viewed by a laparoscopic camera and presented on a television. The results of this study showed that accuracy and precision were affected by both target position and tool; however, the differences were small (<2 mm). Wrist flexion and ulnar deviation angles were affected by both target position and tool. Differences due to target position were expected given different hand locations are required to hit each target. Flexion angle was significantly smaller for the ergo-grip tool as opposed to the scissor-grip tool. Ulnar deviation angle was significantly smaller for the scissor-grip tool than for the ergo-grip tool. All but one subject preferred the ergo-grip tool when performing the task, suggesting that wrist flexion is a stronger predictor of comfort than ulnar deviation though both should be considered when designing ergonomic hand tools.

INTRODUCTION

Laparoscopic surgery is becoming more prevalent in healthcare today. The benefits to patients have long been accepted and include reduced risk of infection and significantly shorter recovery times. Surgeons, however, are forced to use tools that lack proper design. Tools must be developed which will provide comfortable use.

Currently, laparoscopic tools are unwieldy and have been directly linked to post-surgery pain among surgeons after laparoscopic operations (Berguer, 1999; Doné, 2004). Inadequate handle designs and inefficient handle to tip force transmission were found to lead to surgeon fatigue, discomfort and hand paresthesias (Berguer, 1998). In a similar study of 62 surgeons in 19 countries, significant discomfort was found from pressure on the thumb and fingers and lack of control of the ratchet, found on many grasper tools (Van Veelan, 1999). These compressive pressure areas may cause persisting nerve lesions, as cited in the literature by Matern et al. (1999b). Emam et al. (2001) examined the influence of handle design on the surgeon's upper limb movements. Results showed that handles with finger loops fatigued all muscle groups of the arm during suturing. Matern et al. (1999a) compared four different handle designs. Despite extensive research and the identification of problem areas, few tool designs have offered suitable solutions.

Researchers in the IDEA Lab at the University of Nebraska-Lincoln have worked to remedy this deficiency. A new ergonomically designed tool focused on a number of improvements, in particular, wrist flexion and arm posture. The shape and angle of the handle was designed in order to reduce the time surgeons spend in awkward postures during surgery. The handle is set at a 135° in order to reduce flexion of the wrist. The shape of the tool handle is also more conducive to comfortable manipulation and intuitive control. This improvement in the hand/handle interface has the potential to ease the workload required during laparoscopic surgery, thereby increasing patient safety by lessening surgeon fatigue and decreasing the danger of injury to the surgeon, and by extension the patient. This experiment was designed to investigate how handle design and target location affect accuracy, precision, and wrist posture (flexion and ulnar deviation) during a pointing task. The task was designed to closely simulate a laparoscopic surgeons reaching for various targets within the body.

METHODS

Subjects

A total of forty right-handed healthy subjects (20 men and 20 women) with normal corrected vision ranging in ages from nineteen to fifty-six were recruited as subjects for this study. All subjects stated they had no previous experience in manual

aiming tasks. In addition, the subjects had no previous injury or illness in their upper limb. All subjects provided informed consent prior to participation in accordance with University Internal Review Board requirements.

Apparatus

Two laparoscopic tools with different handle designs were used for this study: scissor-grip and ergo-grip (Figure 1). The ergo-grip tool was designed as a result of several studies and interviews with laparoscopic surgeons. Both tools have a shaft diameter of 10 mm and a shaft length of approximately 35 cm. A pointed, plastic sleeve was placed over the end of the tool for aiming with the tool. The tip of the sleeve was coated with rubber to protect the touch screen used during the study. A seventeen-inch (17") ELO flat panel LCD touch screen was connected to a personal computer (PC) to analyze the accuracy of the aiming task. A graphical interface was created using Visual Basic 6.0 to collect data and present each trial in random order. A target (crosshair) was displayed on the LCD touch screen in one of five positions: center, top, bottom, left, and right. The center target was located in the center of the screen. The other targets were located 5 cm from the center target in each of the corresponding directions.



Figure 1: Scissor-grip Tool (top) and Ergo-grip Tool (bottom).

A plastic skin from a laparoscopic trainer with two trocars was used in order to closely simulate the surgical environment. The plastic skin was mounted 15 cm above the surface of the touch screen. One trocar was centered directly above the center target. Bergeur et al. (2001) suggest placing instruments and trocars so as to minimize extreme horizontal and vertical displacement of their hands away from the resting position of comfort. Therefore, the touch screen was angled 45 degrees relative to the subject's sagittal plane and 45 degrees relative to the horizontal plane such that the subject reached medially, down, and away from the body to hit the target with the tool. The subject was positioned such that the trocar was centered at the shoulder and at elbow height. This placed the center target at approximately the midline of the body. The touch screen was draped with a green surgical cloth to prevent direct view of the touch screen. A laparoscopic camera (Olympus WA50295L) was inserted through the other trocar to provide visual feedback. The camera was connected to a 21" television mounted at a similar height to the televisions in the operating rooms (200cm from the floor). The camera was held stationary by a freestanding flexible stand and positioned so all targets could be viewed without moving the camera. The experimental setup is shown in Figure 2.

A digital goniometer system (Biometrics, Ltd) was used to measure wrist flexion and ulnar deviation during the study. The data were collected using the Visual Basic interface.

Procedure

Each subject was asked to hold the handle of the tool and aim at the center of the target. When using the scissor-grip tool, the subject was instructed to place the thumb through the thumb loop, index finger on the trigger, and last three fingers through the finger loop. When using the ergo-grip tool, the subject was instructed to place the thumb on the trackball and wrap the fingers around the handle (Figure 3). Despite the flexibility to use the ergo-grip tool in a variety of postures, subjects were instructed to keep the hand in one position for both tools to match the scissor-grip tool. The subject stood on



Figure 2: Experimental Setup.

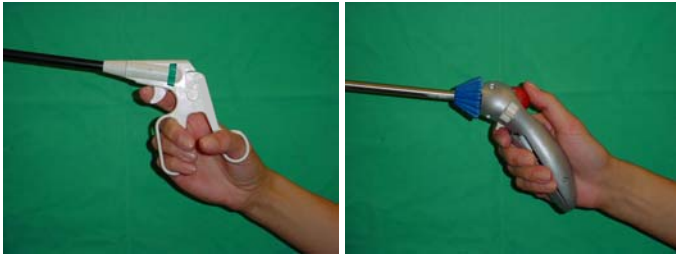


Figure 3: Hand grips for scissor-grip tool (left) and ergo-grip tool (right).

a block approximately 50 cm from the trocar. The pace of the aiming task was set to 75 beats per minute. The subjects were given an audio signal in the form of a beep to adjust their pace. A randomized set of the thirty trials was presented before the subject with instructions. The instructions were both explained by the experimenter and also were presented in the interface developed. Each trial commenced with the subject holding the tip of the tool onto the screen. The subject was then instructed to hit the target with the beeps and lift the tool approximately one centimeter from the touch screen between hits to replicate a grasp/regrasp motion with a surgical tool. This oscillatory movement was continued for ten successful hits on the target. At the end of the experiment, subjects were asked which tool he/she preferred.

Experimental Design

Four dependent variables were analyzed using Analysis of Variance (ANOVA): accuracy, precision, wrist flexion angle, and wrist ulnar deviation. Accuracy was measured as the vector distance of each hit from the target in mm. Precision was measured as the vector distance from the mean of the ten-point cluster during the trial in mm. Wrist flexion and ulnar deviation were measured in degrees. There were three independent variables analyzed: tool type, target position, and gender. Each tool type (scissor-grip and ergo-grip) was tested three times in each of the five target positions for a total of 30 trials. During a trial, the subject was asked to hit the target with the tool ten times in sync with an 800 ms beep generated by the computer. All the subjects performed all thirty trials leading to a total of three hundred (300) hits for each subject. The resulting design is a 2(tool type) x 5(target position) x 2(gender) mixed-factor, full-factorial design. The dependent variables were analyzed using SAS (V. 8.0). The experimental order of the trials presented was completely randomized.

RESULTS

The following Analysis of Variance (ANOVA) model was used to analyze each dependent variable:

$$y = \mu + G + S(G) + R + G \times R + R \times S(G) + T + G \times T + T \times S(G) + R \times T + G \times R \times T + R \times T \times S(G) + \epsilon$$

where *y* is the dependent variable, μ is the mean, ϵ is the error, *G* is gender, *S* is subject, *R* is target, and *T* is tool. (*G*) refers

to nesting within gender and the \times refers to interaction effects. Table 1 summarizes the significant factors for each dependent variable of the four investigated: accuracy, precision, wrist flexion angle, and wrist ulnar deviation angle.

Main Effects

Accuracy – The ANOVA on vector distance of each hit to the target showed that significant main effects were gender ($p=0.0255$), target ($p<0.0001$), and tool ($p<0.0001$). Interaction effects were found between gender and target ($p=0.0101$) as shown in Table 1. The gender differences were 3.1 mm for females and 2.7 mm for males. Tool differences were found to be 3.1 mm for the scissor-grip tool and 2.8 mm for the ergo-grip tool. Target differences are summarized in Table 2: the left target was least accurate; the right target was most accurate.

Precision – The ANOVA on vector distance of each hit to the mean of its ten-point cluster showed that significant main effects were target ($p<0.0001$) and tool ($p=0.0319$), as shown in Table 1. Tool differences were found to be 1.9 mm for the scissor-grip tool and 1.8 mm for the ergo-grip tool. Target differences are summarized in Table 2: the left, bottom and top targets were least precise; the center and right targets were most precise.

Flexion Angle – The ANOVA on wrist flexion angle showed that significant main effects were target ($p<0.0001$) and tool ($p<0.0001$) as shown in Table 1. Interactions effects were found between gender and target ($p=0.001$) as well as target and tool ($p<0.0001$). Tool differences were found to be 39.8°

Table 1: Summary of Significant ANOVA Factors by Dependent Variable.

Accuracy		
Factor	F-value	p
Gender = G	5.41	0.0255
Target	85.73	<0.0001
G×Target	3.44	0.0101
Tool	23.6	<0.0001
Precision		
Target	12.61	<0.0001
Tool	4.96	0.0319
Flexion Angle		
Target	315.03	<0.0001
G×Target	4.87	0.001
Tool	60.42	<0.0001
Target×Tool	35.01	<0.0001
Ulnar Deviation Angle		
Target	200.27	<0.0001
Tool	499.64	<0.0001
Target×Tool	12.83	<0.0001
G×Target×Tool	6.8	<0.0001

Table 2: Post-hoc Test on Target.

Target	Accuracy (mm)	Precision (mm)	Flexion Angle (deg)	Ulnar Deviation Angle (deg)
Left	A (3.8)	A (2.0)	A (55.1)	C (11.0)
Top	A B (3.7)	A (1.9)	B (40.0)	D (7.3)
Bottom	B (3.2)	A (1.9)	C (33.7)	A (29.8)
Center	C (2.5)	B (1.6)	C (35.4)	B (24.1)
Right	D (1.8)	B (1.6)	D (5.8)	A (30.4)

Different letters are significantly different. Means are given in parenthesis.

for the scissor-grip tool and 28.2° for the ergo-grip tool. Target differences are summarized in Table 2: the left target produced the greatest flexion; the right target produced the least flexion.

Ulnar Deviation Angle – The ANOVA on wrist ulnar deviation angle showed that significant main effects were target ($p < 0.0001$) and tool ($p < 0.0001$) as shown in Table 1. Interactions effects were found between target and tool ($p = 0.001$) as well as gender, target, and tool ($p < 0.0001$). Tool differences were found to be 11.8° for the scissor-grip tool and 29.2° for the ergo-grip tool. Target differences are summarized in Table 2: the bottom and right targets produced the greatest ulnar deviation; the top target produced the least ulnar deviation.

Interaction Effects

Simple-effects F-tests by target were performed to determine the interaction effects between gender and target as well as tool and target for significant interaction terms. The results are graphically summarized in Figure 4.

Accuracy – Post-hoc testing on gender-target interactions found significant effects for the left and bottom targets. In both cases, male subjects were more accurate than female subjects. Post-hoc testing on target-tool interactions found the ergo-grip tool more accurate for all but the bottom target.

Precision – No gender-target interaction effects were found for precision. Post-hoc testing on target-tool interactions found the ergo-grip tool more precise for the top and right targets.

Flexion Angle – No gender-target interaction effects were found for precision. Post-hoc testing on target-tool interactions found less flexion for the ergo-grip tool for all but the bottom target.

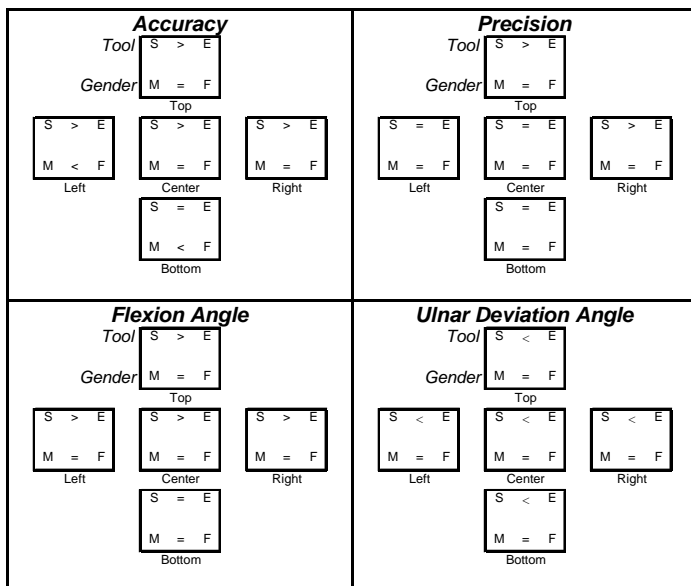


Figure 4: ANOVA Results by Target. The figure above graphical depicts the ANOVA results grouped by target position (Top, Left, Center, Right, and Bottom). Each target contains comparisons for tool and gender, i.e., interaction effects of the target with tool and gender. An arrow indicates the difference is statistically significant difference and points in the direction of the lesser value. S stands for scissor-grip, E for ergo-grip, M for male, and F for female.

Ulnar Deviation Angle – No gender-target interaction effects were found for precision. Post-hoc testing on target-tool interactions found less ulnar deviation for the scissor-grip tool for all targets.

Tool Preference

Only one of the forty subjects preferred the scissor-grip tool when asked which tool he/she preferred while performing the experiment.

DISCUSSION AND CONCLUSIONS

Although statistically significant differences were found for accuracy and precision, the differences were on the order of 1-2 millimeters over a 5 cm distance between targets from the center target. These differences may not be practical to prefer any tool or target to another. Laparoscopic surgeons also endure an intensive training program for the purpose of increasing accuracy and precision. It is expected that this training would further minimize errors in accuracy and precision.

This study also showed the right target produced significantly smaller wrist flexion angles when compared with other targets. This is not surprising given different arm postures are required to hit each target, and the right target requires the subject’s hand to be closest to his/her body, since only the right hand was used in this study. Also, the flexion angle for the ergo-grip tool was 11.6° less than when using the scissor-grip tool. It is expected that this decrease will result in reduced joint strain of the wrist during surgeries and reduced surgeon fatigue. Furthermore, the wrist flexion was smaller for the ergo-grip tool in all but one target location ranging from 6.1° less (right target) to 23.8° less (top target) than the scissor-grip tool.

The top target produced significantly smaller wrist ulnar deviation angles when compared with other targets. As with wrist flexion, this is not surprising given different arm postures are required to hit each target. Also, the ulnar deviation angle for the scissor-grip tool was 17.5° less than when using the ergo-grip tool. This result is not surprising given the shaft to handle angle of the ergo-grip tool is 135° versus 90° for the scissor-grip. This difference inherently produces larger ulnar deviation angles for the ergo-grip tool. This same difference in ulnar deviation angle was found when analyzing by target. The ulnar deviation angles were smaller for the scissor-grip for all targets ranging from 10.8° less (bottom target) to 23.0° less (center target) than the ergo-tool. This was also a function of the constraints the experimenters put on the subjects, not letting them change hand position of the ergo-grip tool.

The present research findings strengthen the initial premise that hand tool design can result in better wrist posture. The ergo-grip tool tended to reduce wrist flexion. However, ulnar deviation was increased due to the 135° handle-to-shaft angle. On the other hand, the scissor-grip tool resulted in the increased wrist flexion and reduced ulnar deviation while performing the task. Although it is expected that larger

flexion angles lead to increased joint strain and fatigue, ulnar deviation must be considered in new tool designs. Thirty-nine (39) of the forty (40) subjects preferred the ergo-grip tool over the scissor-grip tool and made representative comments such as “that (ergo-grip) tool was easier to hold,” leading to the conclusion that employing ergonomic principles in design, which can lead to better accuracy and precision and lower wrist flexion, appears to be linked with preference.

Practical Implications

The present experiment is extremely useful in the case of surgical tools. Anecdotal evidence suggested that the subjects were uncomfortable using the scissor-grip tool to perform the task. Since an ergo-grip tool is not currently available commercially, it is not known whether surgeons will respond in the same manner. A further study to determine surgeon preference is currently being performed to address this question.

Future Study

A future study is necessary to ascertain if the ergo-grip tool design also improves shoulder posture. Another study will also test the ergo-grip tool in different hand orientation as it is designed to be held in more than one orientation.

Thus, the overall results of the study show that the ergo-grip tool gives rise to statistically significant, but not practically significant, increases in accuracy during manual aiming tasks and precision (after increases in accuracy). The ergo-grip tool also provided better wrist postures with respect to flexion during the task and was preferred overall.

REFERENCES

- Berguer, R. (1998). "Surgical technology and the ergonomics of laparoscopic instruments." *Surgical Endoscopy* **12**: 458-462.
- Berguer, R., D. L. Forkey and W. D. Smith (1999). "Ergonomic problems associated with laparoscopic surgery." *Surgical Endoscopy* **13**(5): 466-468.
- Berguer, R., D. L. Forkey and W. D. Smith (2001). "The effect of laparoscopic instrument working angle on surgeons' upper extremity workload." *Surgical Endoscopy* **15**: 1027-1029.
- Doné, K., A. DiMartino, T. N. Judkins, M. S. Hallbeck and D. Oleynikov (2004). *Evaluation of laparoscopic tools for functionality, usability and comfort*. Proceedings of the Human Factors and Ergonomics Society, 48th Annual Meeting, New Orleans, LA.
- Emam, T. A., T. G. Frank, G. B. Hanna and A. Cuschieri (2001). "Influence of handle design on the surgeon's upper limb movements, muscle recruitment, and fatigue during endoscopic suturing." *Surgical Endoscopy* **15**: 667-672.
- Matern, U., M. Eichenlaub, P. Waller and K.-D. Rückauer (1999a). "MIS instruments: An experimental comparison of various ergonomic handles and their design." *Surgical Endoscopy* **13**: 756-762.
- Matern, U. and P. Waller (1999b). "Instruments for minimally invasive surgery." *Surgical Endoscopy* **13**: 174-182.
- Van Veelan, M. A. and D. W. Meijer (1999). "Ergonomics and Design of Laparoscopic Instruments: Results of a Survey among Laparoscopic Surgeons." *Journal of Laparoendoscopic and Advanced Surgical Techniques, Part A* **9**(6): 481-489.