ERGONOMIC LAPAROSCOPIC TOOL HANDLE DESIGN

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ABSTRACT

Twenty-two subjects were tested and categorized according to hand size (small, medium, or large). Each subject selected the best location for a trackball and a trigger on a handle. Each subject specified the optimum diameter/size of the handle that he or she preferred. Additionally, subjects selected their preferred pivot range for opening and closing the handle. Finally, each subject exerted his or her preferred force for the trackball and trigger controls in the selected positions. Based on the data collected in this experiment, the recommended handle diameter is in the range of 4.3 to 5.7 cm. The recommended handle pivot is the range of 8.1 to 17.3 degrees for the open and closed positions. The recommended trackball actuation force is 3.0 lbs and the recommended ratchet actuation force is 0.6 lbs, on average.

INTRODUCTION

Laparoscopy is a relatively recent advancement in surgery that allows for less painful surgery and faster recovery for the patient. However, laparoscopy requires more effort from the surgeon than traditional open procedures (Berguer 1998). Laparoscopic surgery involves making several small incisions for instrument and camera ports, as opposed to open surgery where a large incision is made (Cavusoglu, et al. 2003). These ports average from 3 – 15 mm in size and allow the tools to enter and exit the abdominal cavity without damaging the surrounding skin tissue.

Specialized instruments are required for laparoscopic surgery due to the small ports. The design of these instruments is critical to the result of the surgery. Berguer (1999) provides two main criteria for designing laparoscopic instruments: "the mechanical efficiency of the linkage from the instrument handle to the tip and the ergonomic considerations of handle design and the surgeon – instrument interface".

Current laparoscopic instruments have been found to be very poorly designed ergonomically and it is likely that ergonomics were not considered at all. Additionally, Berguer et al. (1998) found 8-12% of practicing laparoscopic surgeons frequently experience post operation pain or numbness. This is generally attributable to pressure points on the laparoscopic tool handle. Matern et al. (1999) studied four different handle designs (shank, pistol, axial, and ring handle) and found that all resulted in either painful pressure spots or caused extreme ulnar deviation.

This study explores 'sizing' of laparoscopic tool handles to better fit surgeons' hands in general, thus reducing pain and discomfort. According to Goonetilleke et al. (1997), the preferred grip span for a hand tool, in the Asian population, is 4.7 cm. Another study by Sancho-Bru et al. (2003), found that a grip span of 3.3 cm is optimal. Both of these findings are based primarily on resulting grip strength. This handle design seeks to optimize the comfort of the tool, while allowing precision by exploring possible handle sizes with respect to comfort and ease of use.

Study Objectives

- Determine the optimum diameter for a laparoscopic tool handle
- Assess the minimum and maximum actuating angle for the rear-pivot handle
- Determine the optimum trackball and ratchet control placements on the handle
- Determine the optimum force required for actuation of trackball and ratchet control

METHODS

Subjects

Twenty-two subjects were tested and categorized according to hand size. Three categories were defined according to hand length of the right hand (small, medium, and large). Categories were determined using data reported by Greiner (1991) as shown in Table 1. 'Small' was defined as female 5th percentile hand length to male 5th percentile hand length. 'Medium' was defined as male 5th percentile hand length to male 50th percentile hand length. 'Large' was defined as male 50th percentile hand length to 95th percentile male hand length. Six subjects were tested from the 'small' category, 8 from the 'medium' category, and 8 from the 'large' category. Subjects were UNL students, faculty, and

Table 1: Hand Size Categories

	Small	Medium	Large
Lower Cutoff (cm)	16.3	17.9	19.4
Upper Cutoff (cm)	17.9	19.4	21.2

staff, age 19-52 (no other restrictions were placed on the subjects). The experimental procedures were explained to each subject prior to beginning testing, and all subjects gave consent.

Anthropometric Measurements

Anthropometric measurements gathered from each subject included: standing elbow height, forearm length, hand length, hand breadth, length of digits 1 through 5, distance from distal wrist crease to tip of thumb, and digit 1/digit 3 inner circumference.

Apparatus

A sliding caliper was modified by attaching two handle forms (top surface of the handle and bottom surface of the handle) to the sliding bars to simulate a quasi-cylindrical handle with a continuously variable circumference. A grid of dimension 0.5 cm X 0.5 cm was affixed to the surface of both top and bottom handle forms (Figure 1). A spreading caliper was also modified in a similar way to simulate a tool handle that pivoted to open and close the handle. This apparatus was used for determining a comfortable grip span for the open and closed handle (Figure 2).

A wooden hemisphere was constructed to simulate a trackball control mechanism for the tool. A force sensing resistor was embedded in the hemisphere for measuring actuation forces (Figure 3). A wooden trigger was constructed to simulate a ratchet control mechanism. A force sensing resistor was embedded for force measurement (Figure 3). Forces were gathered through a Measurement Computing PMD-1208LS Analog to Digital computer interface device (Figure 4). FlexiForce force sensing resistors rated from 0 to 25 pounds were used for the force measurement. The UNL electronics shop constructed the necessary circuits to interface the resistors with the computer. Data was collected through LabVIEW (version 7).

Figure 1: Grid affixed to handle surface.

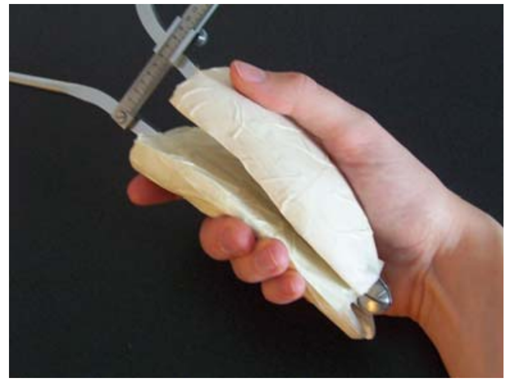

Figure 2:Grip Span Apparatus.

Figure 3: Force sensing resistors embedded into wooden hemisphere and trigger.

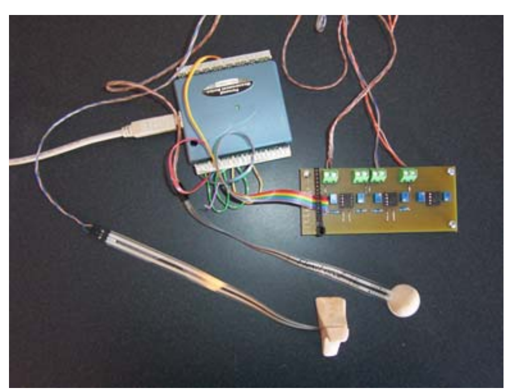

Figure 4: Computer interface.

Procedure

Each subject was given the sliding caliper with attached handle forms (Figure 5). Each subject self-adjusted the handle apparatus until he or she found their maximum and minimum comfortable diameter.

Each subject selected his or her preferred location on the handle for each of the simulated controls for the right hand. The locations were marked with stickers and their locations were recorded using the grid on the handle forms.

The markers for control locations were replaced by each of the simulated controls with mounting putty (Figure 6).

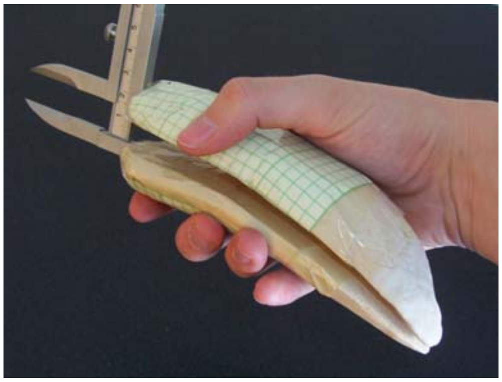

Figure 5: Sliding caliper with attached handle forms.

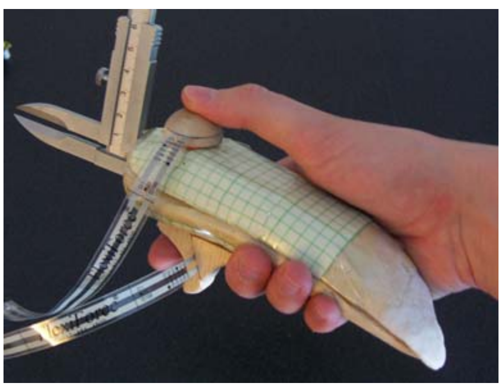

Figure 6: Markers for control locations.

Figure 7: Spreading caliper apparatus.

The subject was instructed to press on the controls with their preferred force and to hold the force for 3 seconds. Preferred force was measured in three trials, and the average force over the 3 second period was recorded for each trial.

The subject was given the spreading caliper apparatus to determine the pivot range on the handle (Figure 7). Subjects self-adjusted the calipers until he or she reached their maximum comfortable distance between the handle forms (representing the comfortable grip span for an open tool), and their minimum comfortable distance (representing the comfortable grip span for a closed tool) between the handle forms.

RESULTS

Handle Diameter and Pivot

The average minimum and maximum distances of the comfortable handle diameter were calculated for each hand size group. Similarly, the average minimum and maximum angles of the comfortable handle pivot were calculated for each hand size group. Kruskal-Wallis tests were performed to determine if there were significant differences between the three different hand size groups for each dependent variable.

No significant differences ($p = 0.260$) between minimum distance values or maximum distance values ($p = 0.623$) were found for handle diameter differences. Additionally, no significant differences between minimum angle ($p = 0.660$) and maximum angle ($p = 0.619$) values were found for handle pivot. Therefore, the data was pooled for further analysis to produce a range of diameters that is comfortable for all hand sizes, as well as a range of pivot angles that is comfortable for all hand sizes. The optimum ranges were produced by taking the largest minimum value and the smallest maximum value to ensure that the ranges were not extreme for any hand size group. Table 2 shows the average minimum and maximum diameters and pivot angles for each hand size category, and the optimum range for the pooled data.

Table 2: Diameter and Pivot Ranges

	DIAMETER (CM)		PIVOT ANGLE (DEGREES)	
	Avg MIN	Avg MAX	Avg MIN	Avg MAX
SMALL	4.6	6.4	4.4	17.6
MEDIUM	4.8	6.1	7.0	17.7
LARGE	4.3	5.7	8.1	17.3
OPTIMUM	4.8	5.7	8.1	17.3

Trackball and Ratchet Location

The x- and y- coordinates of the trackball locations and the ratchet locations were each separately analyzed with a Kruskal-Wallis test to investigate the differences among the three size groups. No significant differences in the dependent variables of preferred trackball locations for either the x-coordinate (p = 0.453) or the y-coordinate (p = 0.432) were found. Furthermore, no significant differences in the dependent variable of preferred ratchet locations were found for either the x-coordinate (p = 0.387) or the y-coordinate (p = 0.636). Therefore, locations for the trackball and ratchet were calculated that should be comfortable for all three hand sizes. Table 3 shows the locations for each hand size group, and the combined (overall) location.

Table 3: Trackball and Ratchet Locations

	MEAN TRACKBALL LOCATION (CM)		MEAN RATCHET LOCATION (CM)	
	X	Y	X	Y
SMALL	0.0	3.8	0.1	2.9
MEDIUM	-0.3	3.7	-0.2	2.6
LARGE	-0.3	3.3	0.2	2.6
AVERAGE	-0.2	3.6	0.0	2.7

Trackball and Ratchet Actuation Force

Kruskal-Wallis tests were conducted to analyze mean and maximum preferred actuation force both for the trackball and ratchet controls for all three hand size groups. No significant differences were found for either the mean trackball force (p = 0.130) or the maximum trackball force (p = 0.120). Significant differences were found for the dependent variables of preferred mean ratchet force (p = 0.002) and for maximum ratchet force (p = 0.002) for at least one pair of the three hand size groups. The Dwass-Steel-Critchlow-Fligner post hoc test revealed significant differences only between the medium and large hand groups for both dependent variables of mean and maximum preferred ratchet force. Despite the significant difference between the groups, data were combined to yield an overall force for all hand sizes by taking the mean of all three categories. By taking the mean, the two groups with lower force were weighted more than the group with higher force. This resulted in a force that should be possible and comfortable for all three hand size groups. Table 4 shows the trackball and ratchet actuation forces averaged, as well as for each hand size category.

Table 4: Trackball and Ratchet Actuation Forces

	TRACKBALL (LBS)		RATCHET (LBS)	
	MEAN	RANGE	MEAN	RANGE
SMALL	2.8	0.07	0.8	0.02
MEDIUM	4.0	0.10	0.6	0.01
LARGE	2.4	0.04	0.4	0.002
AVERAGE	3.1		0.6	

DISCUSSION

The recommended handle diameter range is 4.8 to 5.7 cm. This range overlaps the comfortable ranges reported by all but one subject and is within 0.7 cm of that outlier. The recommended range of the handle pivot is 8.1 to 17.3 degrees. This is entirely within the range of all but 2 of the 22 subjects tested. The data indicate the trackball should be located at 0.2 cm to the left (using the right hand only) of the center line of the long axis of the handle when looking at the top surface of the handle with the back of the handle facing towards you, 3.6 cm from the front of the tool along the long axis of the handle. It was also determined that the ratchet should be located at 0.0 cm to the right of the center line of the long axis of the handle when looking at the bottom surface of the handle with the back of the handle facing towards you, 2.7 cm from the front of the tool along the long axis of the handle. The recommended actuation forces for the trackball and ratchet are based off of the mean force measurements rather than the maximum force measurements because the maximum force is not as representative of each subject's preferred force as the mean force measurement. Therefore, the recommended trackball actuation force is 3.0 lbs. and the recommended ratchet actuation force is 0.6 lbs.

There are some general conclusions for this study. In theory, creating an infinitely variable prototype provides a good means for each subject to select/convey his or her individual preferences for tool characteristics based on his or her unique anthropometry. However, in practice this did not seem to be the case. It was very difficult to analyze the data in a meaningful way. Future hand tool design studies will be conducted by constructing several different physical prototypes that are not adjustable. Subjects will be asked to rate or evaluate each different prototype in order to determine which design is most preferred. Additionally, the subject population used is not necessarily representative of the target population. While the anthropometry of the subject population may potentially reflect the target population, the subjects did not have the expertise to determine what would be a comfortable tool diameter, pivot, force, etc. for surgical tools. Future studies are needed to specifically test the target population.

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