The Benefit of Force Feedback in Surgery: Examination of Blunt Dissection

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Abstract—Force feedback is widely assumed to enhance performance in robotic surgery, but its benefits have not yet been systematically assessed. In this study we examine the effects of force feedback on a blunt dissection task. 20 subjects used a telerobotic system to expose an artery in a synthetic model while viewing the operative site with a video laparoscope. Subjects were drawn from a range of surgical backgrounds, from inexperienced to attending surgeons. Performance was compared between three force feedback gains: 0% (no force feedback), 37% and 75%. The absence of force feedback increased the average force magnitude applied to the tissue by at least 50%, and increased the peak force magnitude by at least 100%. The number of errors that damage tissue increased by over a factor 3. The rate and precision of dissection were not significantly enhanced with force feedback. These results hold across all levels of previous surgical experience. We hypothesize that force feedback is helpful in this blunt dissection task because the artery is stiffer than the surrounding tissue. This mechanical contrast serves to constrain the subjects' hand from commanding inappropriate motions that generate large forces.

Index Terms—Force feedback, surgery, haptics, dissection, blunt dissection, telemanipulation, telesurgery, telerobotics.

I. Introduction

Ask a surgeon if force feedback is needed for robotic surgery, and the answer is predictably "yes." The basis for this intuitive answer is perhaps less immediate. High-fidelity force information is certainly not

essential for all surgical tasks, as surgeons regularly execute a wide variety of minimally invasive procedures using hand-held instruments that provide little haptic information. Similarly, current commercial robotic surgery systems provide no force feedback from the instruments, yet surgeons have demonstrated the ability to use these systems to perform delicate procedures such as coronary artery bypass grafting [1, 2]. Despite this demonstrated ability to work without force information, dexterity with current minimally invasive instruments, manual or robotic, is clearly less than optimal. What is lacking is an understanding of the role of force sensation in surgical tasks that would allow a principled assessment of the benefits of force feedback systems.

Previous studies of the role of force feedback in surgery have focused on perceptual capabilities and device design. In the perceptual experiments, subjects differentiated the compliance of various tissues and synthetic materials using manual and telerobotic instruments [3-9]. A considerable body of work has also appeared on the development of force feedback technology, including the design of force-sensing surgical instruments [10-14], and force feedback instruments [7, 15-17]. Kazi [6] demonstrated improved performance in telerobotic catheter insertion with force feedback, but this study focused on telemanipulator control design issues. Kitigawa et al. demonstrated the usefulness of force feedback during a knot tying task with fine suture, but did not use a surgical environment [18]. Additionally, task based performance evaluation using force feedback outside the realm of surgery has centered on interaction with stiff objects [19]. None of these studies have focused on the role of force feedback in manipulation of soft tissue, which is the central aim of most surgical procedures. This is a particularly important omission, as neurophysiological studies have shown that important aspects of sensorimotor control of the hand are not consciously perceptible [20].

In this study, we experimentally evaluate the role of force feedback in blunt dissection, a surgical manipulation task frequently employed in minimally invasive surgery. Our hypothesis is that force feedback is useful in this context when there is a large contrast in mechanical properties along the

dissection plane between adjacent regions of tissue. Subjects in the experiments used a laboratory telesurgical system with high fidelity force feedback to dissect a relatively stiff lumen from a softer substrate. We compare their abilities to perform this task with varying degrees of force feedback. Further, we evaluate performance variation with amount of previous surgical experience. The results presented here indicate that force feedback allows more precise dissection with lower applied forces and fewer errors, independent of surgical training.

II. Methods and Materials

We selected dissection as the focus of these experiments because it is an important surgical task, accounting for 25–35% of the time spent on most surgical procedures [21]. Additionally, dissection ranks second in terms of the estimated effort required for performing a surgical task. Dissection is most often performed using scissors or specialized dissectors such as hooks and coagulators. Regardless of the instrument used, dissection is composed of three distinct phases: (1) tissue recognition, (2) accurate instrument positioning, and (3) tissue cutting/spreading. While carrying out the dissection, the surgeon tries to minimize tissue trauma and preserve surrounding structures. We have chosen to use a hook dissector because of its simplicity and popularity in general laparoscopic surgical procedures.

A.   Telemanipulation System

The experiments use a laboratory teleoperation testbed consisting of two Phantom haptic interface devices (Model 1.5, SensAble Technologies, Inc., Woburn, Mass.)[22]. One Phantom acts as the surgeon master controller and the other acts as the surgical robot. The master is an unmodified Phantom with the stylus attachment. Subjects control the motion of the surgical robot by moving the stylus, held in a pen grasp, where the tip of the stylus maps to the proximal end of the instrument shaft.

The instrument used for the blunt dissection task is a right angle hook with a depth of 1 cm, a diameter of 0.9 mm, and a rounded tip. The hook is attached to a 50 cm rigid shaft that passes through a fixed pivot, simulating the incision into the patient's abdomen. The surgical robot is attached to the proximal end of the shaft with a two degree-of-freedom joint that prevents rotation of the instrument (Fig. 1).
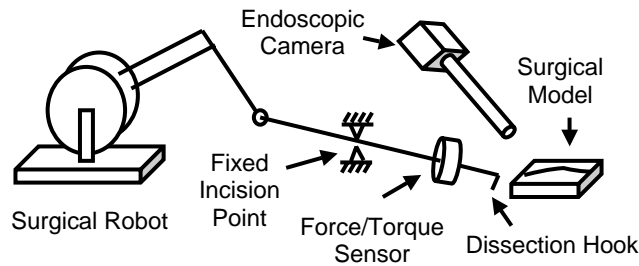
Fig. 1. Surgical Setup

   Forces are sensed at the tip of the instrument by a six-axis force/torque sensor (Nano43 transducer, ATI

Industrial Automation, Apex, North Carolina) built into the instrument shaft. The master and surgical

robot are controlled with the bilateral force feedback controller (i.e. position feedforward and force

feedback) traditionally used in teleoperated systems [19]. The Phantom control computer samples the

forces at 1 kHz and transforms the forces to the proximal end of the shaft by assuming that the instrument

shaft acts a perfect lever. That force is scaled for the appropriate experimental condition and then

reproduced by the surgeon master controller; ideally, this results in the user feeling the forces that would be

experienced if the stylus tip was attached directly to the proximal end of the instrument shaft. The force on

the master is thus given by

$$f_{master} = g_{ff} A(x_{robot}) f_{sensor}$$

where g_{ff} is the force feedback gain and A is the position dependant matrix that transforms the sensor force

f_{sensor} so as if acting on the proximal end of the instrument shaft.

   The teleoperation system, including the master, the surgical robot, and the force/torque sensor, are

controlled by a 333 MHz Pentium computer running Windows NT. The surgical robot's position is

controlled using proportional position/velocity control, independent of force feedback, defined by

$$f_{robot} = k_p(x_{master} - x_{robot}) + k_d(\dot{x}_{master} - \dot{x}_{robot})$$

where x_{master} is the position of the tip of the interaction stylus, x_{robot} is the position of the connection

between the surgical robot and the proximal end of the instrument shaft, and $k_p = [0.5\ 1.0\ 0.5]^T$ N/mm and

$k_d = [0.0001\ 0.0010\ 0.0005]^T$ Ns/mm. These values were empirically derived to provide uniform stiffness

in the portion of the workspace used for these trials while maintaining stability of the teleoperation system

[22].   The control algorithm is implemented in Visual C++ along with the force/torque sensor interface.

B. Visual Feedback

   The subjects received visual feedback from a fixed surgical endoscope, camera, and light source

(Telecam SL NTSC/Xenon 175, Karl Storz Endoscopy-America, Inc., Culver City, Cal.), to provide the

same visual feedback encountered in minimally invasive procedures. The relative orientation between the

master controller and the monitor is approximately the same as the orientation between the endoscope

camera and the instrument, to minimize the mental effort of relating visual and instrument frames [23].

However, lack of depth perception and the laparoscopic movement constraint at the incision point remain

sources of difficulty.

C.   Surgical Models

   The surgical models used are intended to simulate a vital structure such as an artery embedded in its

surrounding tissue. Two types of model were constructed: in one the "artery" was visible through the

"tissue" and in the other the "tissue" completely obscured the "artery." These models contain materials of

different stiffness on the order of the pertinent biological tissues to provide realistic stiffness contrast.

Further, the models are straightforward to dissect with a fixed endoscopic view and an instrument with
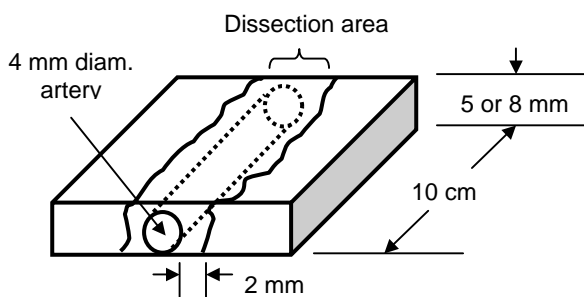
fixed orientation.

Fig. 2. Surgical Model

The material chosen to simulate the tissue bed is a laboratory-made clay. The artery is represented by a stiffer clay material (Weatherstrip and Caulking Cord, Mortite, Inc., Kankakee, Ill.) in cylindrical strips 4 mm in diameter. The tissue bed clay is colored pink to provide visual contrast to the gray artery material. The key feature of the clay tissue model is that it is a reproducible material that captures the plastic failure that is the goal of blunt dissection procedures. This provides the advantage of repeatability over biological tissue, removing the effects of model variation between trials. To quantify the material properties, we measured the steady dragging force of the blunt dissection hook embedded 5 mm into the model tissue material as 0.5 N, and embedded into the model artery material as 3.5 N.

A uniform and easily replicated process was used in the construction of these models. To fabricate each model, we placed a straight 10 cm length of artery on a mass of clay, then compressed the model with a flat plate to a uniform height. For the model where the artery was visible, the tissue was compressed to a height of 5 mm. For the obscured artery case, the model was compressed to 8 mm and the model was then flipped and squared off to regular dimensions, so that the artery was at the bottom of the resulting model (Fig. 2).

D. Protocol

Subjects carried out several dissection tasks with varying levels of force feedback provided by the teleoperation system. Subjects were instructed to expose the artery, clearing away tissue 2 mm on each side of the artery as well as removing any tissue on top of the artery. The subjects were also told to minimize the number of errors, defined as any scratch or puncture of the artery that produced visible damage to the artery, corresponding to 1.0 N. Aside from the primary goal of minimizing errors, subjects were instructed to minimize the area of tissue disturbed outside of the region to be exposed. Finally, after meeting the above two requirements, subjects were to expose as much of the artery as possible in the allotted time.

In every case, the subject was to start at the same point and progress down the artery, working to clear both the sides and the top of the artery at the same time. In the trials where the artery was not initially visible, the subjects were to find and then expose the artery. Subjects were informed that the artery was

always generally straight and centrally located within the model. Lastly, the subjects were to always use the same motion when clearing away tissue, that of a small scrape or dig with the hook instrument.

Subjects trained approximately 15 minutes in order to become familiar with the system and the task. By the end of the training, subjects were required to 1) reliably execute the correct scraping motion and 2) reliably remove excess clay from the hook. Longer times were allowed for some participants to ensure a similar level of proficiency; no subject required longer than 20 minutes.

Each subject participated in several trials of 5 minutes each, where each trial involved a force feedback scaling of 0% (no force feedback), 37%, or 75%. The 75% scaling level was the highest gain available that maintained high fidelity and stability. To examine the effect of previous surgical experience on performance, subjects from 5 different levels of training were chosen (Table 1). A higher group number corresponds to a higher level of previous experience. Subjects in group 1 participated in 6 trials, where each force feedback level was repeated for one model with a visible artery and one with an obscured artery, as a pilot study. After finding little difference in performance between the visible artery and obscured artery trials, and in the interest of surgeons' time, subjects in groups 2-5 used only the visible artery model (3 trials each). 20 subjects, 12 male and 8 female, participated in the study.

The graduate student group had little to no formal surgical background, but were familiar with the robotic equipment used in the experiment. The 3rd and 4th year medical students were knowledgeable about various surgical procedures, yet had little hands-on surgical training. The 1st-3rd year surgical residents had some hands-on experience with both general and laparoscopic procedures. The senior residents had extensive experience with general and laparoscopic procedures and were well versed in surgical technique. The attending (permanent staff) surgeons had the greatest surgical training and experience, with expert knowledge of laparoscopic procedures.

A final set of trials was conducted using a porcine liver and gall bladder to validate the clay surgical model. The liver/gall bladder interface is a reasonable comparison to the contrasting stiffnesses of the artery/tissue model [24]. Further, removing the gall bladder from the liver is a common surgical task for

blunt dissection. Three trials of one minute each at the three force feedback levels were performed by a

medical student, a senior resident, and an attending surgeon for a total of nine trials. The liver and gall

bladders used were harvested and frozen, then defrosted prior to the trials.

All forces encountered by the instrument tip were recorded by the software. To avoid recording force

data when cleaning the tip of excess "tissue", a button on the stylus was used to pause the logging of data.

Peak and root-mean-square (RMS) force values were then calculated from the complete force record.

Errors are defined as exceeding a force threshold when contacting the artery. An observer noted the times

of possible error occurrences during each trial. The force log was later examined at the times of the

possible errors to determine if the subject did exceed the force threshold of 1.0 N. Area affected was

calculated using a digital image of the completed models. The area affected was segmented from the image

by hand and then measured using software. Finally, length dissected was extracted by a similar method,

using the digital image to measure the length of artery exposed.

Table 1.
Subject Groups

Group #	Subject group	n (M/F)	Mean Age	Trials
1	Graduate students	8 (3/5)	25	6
2	3rd-4th year Med. students	3 (2/1)	25	3
3	1st-3rd year residents	3 (2/1)	28	3
4	Senior residents	3 (2/1)	33	3
5	Attending surgeons	3 (3/0)	45	3

E. Measures

Four different outcome measures were examined for each trial. The applied forces, the number of errors,

the length of dissection, and the area of tissue affected were chosen to best characterize the performance of

a subject. The applied forces, number of errors, and total area affected correlate directly with tissue

trauma. The length dissected, given a fixed trial duration, provided a measure of productivity.

F. Statistical Analysis

To determine statistical significance of our experimental conditions (force feedback scaling, training, artery visibility) we used the nonparametric Friedman test of k related samples in place of a conventional multi-factor ANOVA. The nonparametric test was chosen because of the relatively small sample and the lack of information concerning the distribution of the variables under study. The statistical analysis included examining the RMS forces, the peak forces, the length dissected, the area affected per cm dissected, and the number of errors per trial. The SPSS statistical analysis software package (Version 10.1, SPSS Inc., Chicago, Ill.) was used to carry out the analysis. A p value of less than 0.05 was considered statistically significant.

III. Results

Force feedback significantly reduced the magnitude of the forces applied at the instrument tip during dissection, independent of previous surgical knowledge. Fig. 3a-e show histograms of the force samples for all subjects and all trials with the visible artery. Subjects applied high force levels for longer durations when force feedback was not available. Conversely, during trials with force feedback, less time was spent applying higher forces; forces above 3 N were of negligible duration (less than 5 ms on average over a 5 minute trial) for 75% force feedback scaling, and above 4 N were negligible for 37% scaling. Further, the greater the force feedback gain, the less time was spent applying larger levels of force. For the graduate student group, these results also apply whether or not the subject can initially see the artery (Fig. 3a and f). In addition, neither the average RMS force nor the average peak force for the occluded artery trials are statistically different from the visible artery trial results ($F(1,7) = 0.175$, $p = 0.688$; $F(1,7) = 0.526$, $p = 0.492$). We therefore consider the visible artery case for the rest of the analysis.
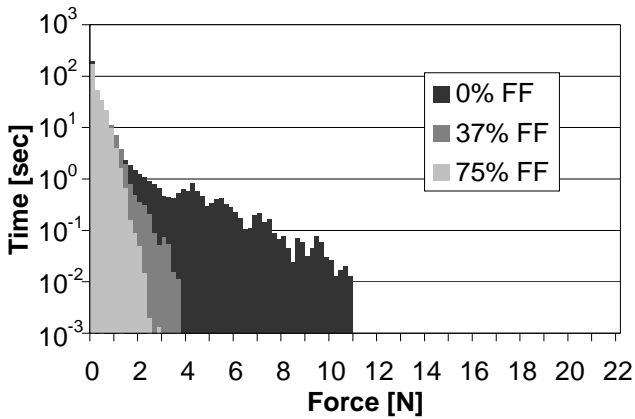
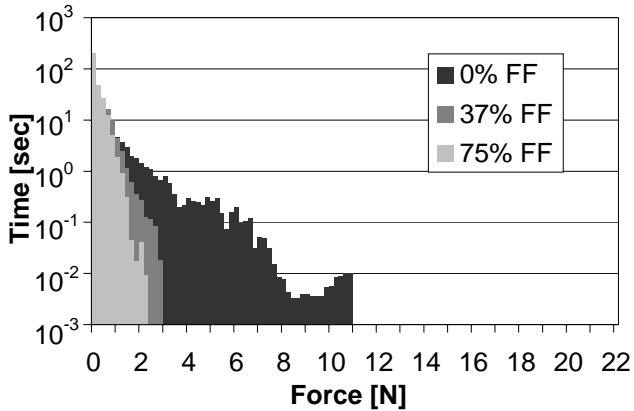a) Subject group 1: Graduate students (n = 8)
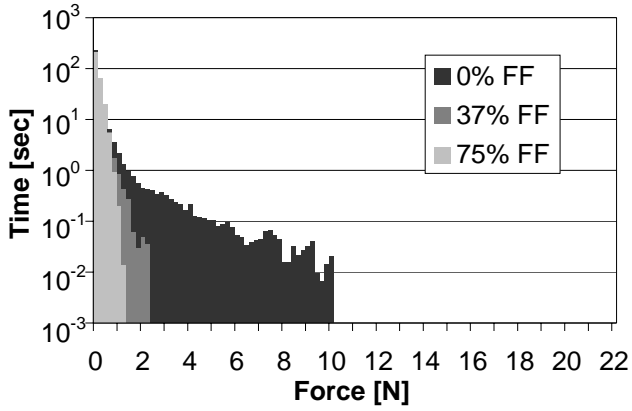
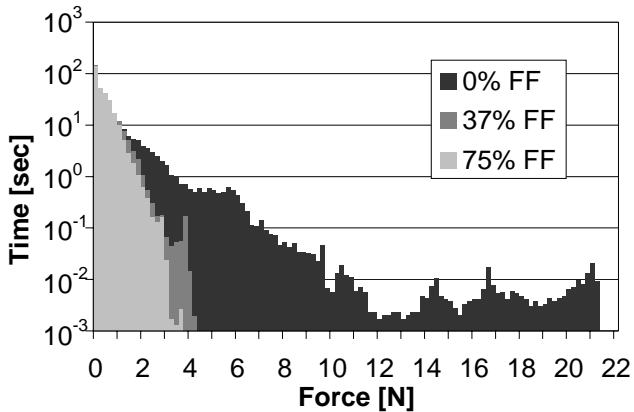b) Subject group 2: 3rd-4th year medical students (n = 3)
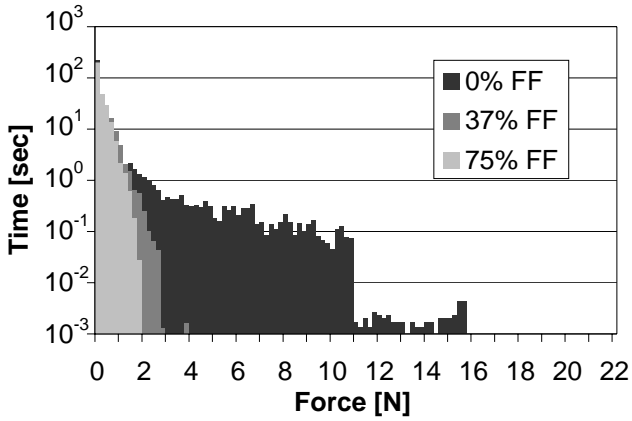
c) Subject group 3: 1st-3rd year surgical residents (n = 3)

d) Subject group 4: Senior surgical residents (n = 3)

e) Subject group 5: Attending surgeons (n = 3)

f) Subject group 1: Grad. students, occluded artery (n = 8)
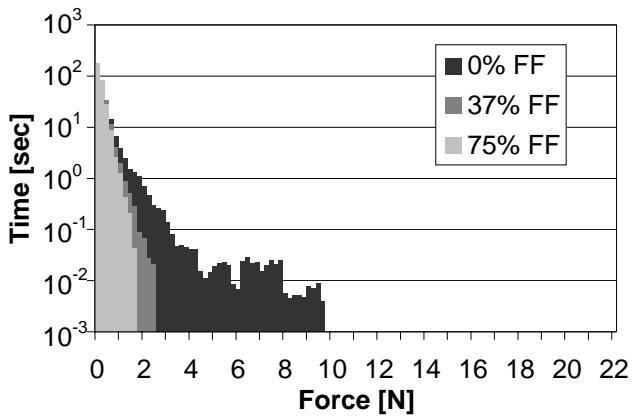

Figure 3. Average time spent applying different levels of force, for each level of force feedback. Bins (0.2 N spacing) represent the average time spent applying the corresponding force. Every figure represents a

total of five minutes at each force feedback level. (a)-(e) Visible artery trials for all subject groups. (f) Occluded artery trials for subject group 1.
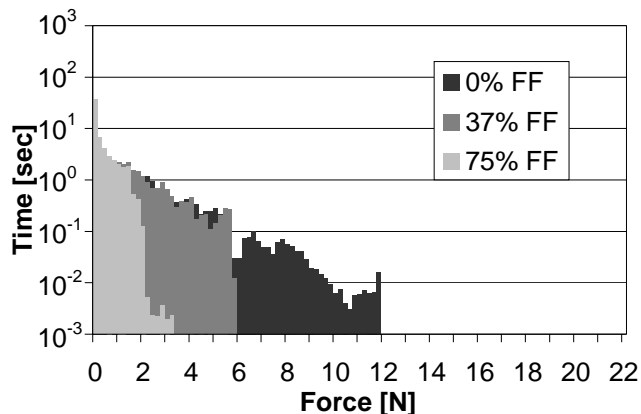

Fig. 4. Average time spent applying different levels of force for blunt dissection of gall bladder from liver surface.

Task results for the porcine tissue trials yield a similar force profile (Fig. 4). Again, as force feedback scaling increased, peak force (8.59 N, 4.88 N, 3.08 N) and RMS force (1.65 N, 1.40 N, 0.54 N) decreased.

Figs. 5 and 6 show the RMS and peak forces of each of the subject groups. The addition of force feedback significantly reduced the RMS force by 30% to 65% ($F(2,30) = 49.13$, $p < 0.001$) and the peak force by a factor of 3 to 6 ($F(2,30) = 58.69$, $p < 0.001$). Again, higher force feedback gain resulted in a reduction of forces applied across all subject groups. The factor of training was also significant for both RMS and peak force applied ($F(4,15) = 6.33$, $p = 0.003$; $F(4,15) = 7.69$, $p = 0.001$). A polynomial contrast shows both a significant linear and cubic trend that an increase in surgical experience results in higher RMS and peak applied forces ($F(4,15) = 6.331$, $p = 0.003$; $F(4,14) = 7.685$, $p = 0.001$).
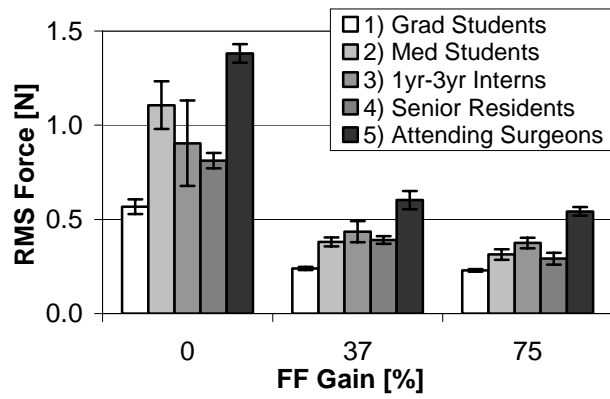
Fig. 5. Average RMS force applied versus force feedback gain. Error bars show standard error.
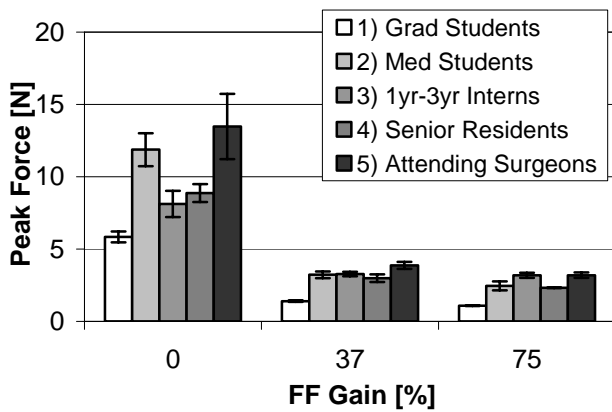

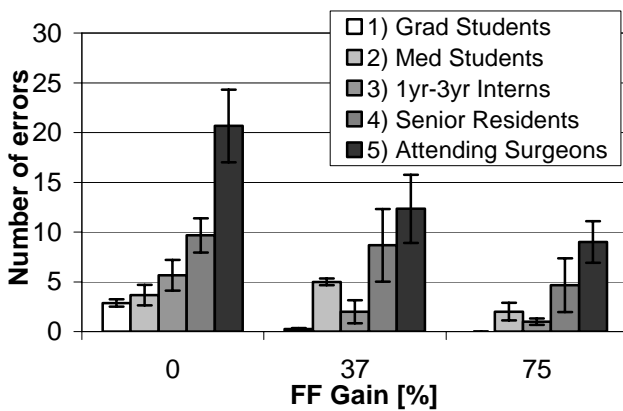Fig. 6. Average peak force applied versus force feedback gain. Error bars show standard error.

Fig. 7. Average number of errors vs. force feedback gain. Error bars show standard error.

The average number of errors during a trial was also affected by the addition of force feedback (Fig. 7).

Increased force feedback led to a significant reduction in the average errors ($F(2,30) = 12.54$, $p < 0.001$).

Training level of the subjects was also a significant factor, where an increase in previous surgical training

led to a maximum of a 7 fold increase in the number of errors committed of the untrained group ($F(4,15) =$ 5.39, $p = 0.007$).
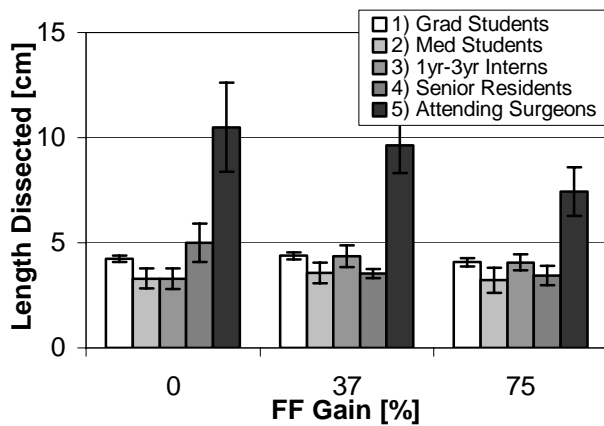

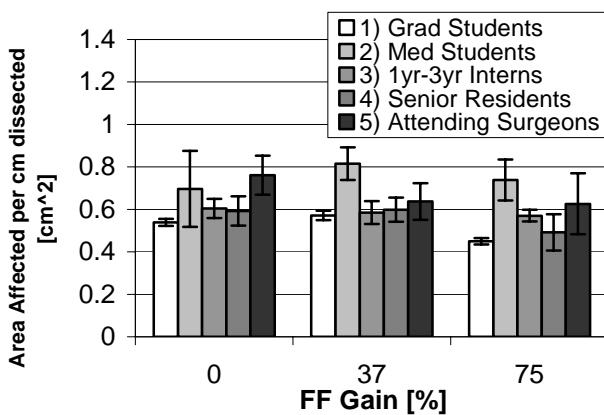Fig. 8. Length dissected vs. force feedback gain. Error bars show standard error.

Fig. 9. Area affected per cm dissected vs. force feedback gain. Error bars show standard error.

Two measures that were not significantly affected by the addition of force feedback were the productivity measures (Figs. 8, 9). The length of artery dissected did not change significantly over different levels of force ($F(2,30) = 2.673$, $p = 0.09$). Similarly, the amount of area affected was not influenced by the addition of force feedback ($F(2,30) = 1.371$, $p = 0.269$). The factor of training did not significantly alter the trends or levels of length dissected or area affected except for the length dissected by the attending surgeons ($F(3,13) = 0.321$, $p = 0.810$; $F(4,15) = 0.869$, $p = 0.505$). The surgeons were able to dissect more then twice the amount, on average, as any other group. Also, for only the surgeon group, there was a trend that increased force feedback levels resulted in decreased length dissected; however, this trend did not reach

significance.

IV. Discussion

    In this study we examine the effects of force feedback on a blunt dissection task, where we hypothesized that the addition of force feedback improves surgical performance. Our results show that force feedback improves performance by reducing the overall forces applied, thus reducing tissue trauma. Force feedback also aids surgical performance by reducing the number of accidental incursions into sensitive structures.   These results hold across all levels of previous surgical experience. Therefore, in this task surgeons do not appear to acquire skills through extensive experience in minimally invasive surgery that decrease the benefits of force feedback. The addition of force feedback did not seem to affect the productivity of subjects, as measured by the length of the artery dissected and the amount of surrounding tissue accidentally affected. We also observed trends with respect to surgical experience; as level of experience increases, applied forces and accidental incursions increase. No significant trend was observed with respect to surgical experience and the productivity measures except that the attending surgeon group dissected significantly more artery than all other groups.

    Conditions in this study simulated the essential aspects of laparoscopic hook dissection in minimally invasive surgical procedures. Visual feedback was provided by a standard surgical laparoscope, and the instrument control mode included the fixed pivot at the incision point. While the mechanical properties of the synthetic clay models were not identical to actual tissue, the key behavior in this task is plastic deformation under traction loading. In this respect, the clay material replicates the behavior under blunt dissection with electrocautery of friable tissue such as liver parenchyma and thin layers of connective tissue such as the liver-gallbladder junction [25].   This is verified by the trials executed using excised animal tissue as the experimental environment, where we observe a similar force profile as the clay artery trials, along with comparable force ranges. It is important to note that these results pertain to tissues where plastic deformation forces dominate in blunt dissection. This is the case in many surgical procedures because blunt dissection is useful for separating tissue planes joined by relatively weak connective tissue

[21]. These results may also apply to blunt dissection of tissues with significant elastic and viscous forces, but further experimental investigation is required.

A. *How Force Feedback Benefits Surgery*

This study leads to the hypothesis that there are two mechanisms that produce the benefits of force feedback in surgery. At high levels of force feedback, we speculate that the intrinsic mechanical properties of the tissues being manipulated are transformed into physical constraints on the surgeon's motions. Subjectively speaking, it is difficult to move the instrument into a damaging configuration because a large force on the hand will oppose any motion that involves contact between the instrument and the tissue. Further, this constraint not only acts as a safety barrier, reducing the forces applied and the number of errors, but the constraint can also act as a guide to the surgical instrument. For instance, when the instrument is positioned between two structures of different stiffness, accurate dissection can simply be achieved by first applying a minimal force to press the instrument against the stiffer tissue. Then, the instrument can be dragged along the surface of the stiffer tissue while relying on the force feedback to maintain a uniform and safe contact force between tissue and instrument.

As the level of the provided force feedback decreases, the benefit of force feedback is hypothesized to arise less as a physical constraint and more as a supplemental source of information. Because the forces are now harder to perceive, the surgeon must devote increased mental processing capacity to recognize and interpret this additional information. Thus, at low levels of force feedback, a conscious response is required to take advantage of the available forces. However, because we observed similar force profiles with no change in productivity at the gains of 75% and 37%, forces at these gains likely act as physical constraints, not solely as a supplemental information source. Further experimental investigation is required to understand the role of force magnitudes in this lower range.

Based on the experiments with real tissues, we conjecture that the relationships among force feedback gain and performance measures will persist over a range of mechanical properties; in particular, the same constraint mechanism functions in both cases. The variation in performance measured in this study as a

function of force feedback gain was large and repeatable, shown to a high degree of statistical significance.

B. Surgical Experience

An interesting result is the variation in performance with respect to previous surgical experience. While all subject groups benefited from the addition of force feedback, the attending surgeon group had entirely different performance levels then the other four groups. Specifically, attending surgeons consistently applied higher forces and committed more errors across all levels of force feedback scaling. On the other hand, the surgeons were able to expose twice the average length of artery as any other group, without a higher level of unwanted area affected. The attending surgeons were clearly using a different performance tradeoff then other groups.

Several hypotheses can be made about why attending surgeons applied higher average forces. One possibility is that surgeons had a different prior expectation of their performance. Because they expect to expose a certain amount of artery in a trial, they disregard the possibly excessive forces applied to achieve their goal. One reason the surgeons may disregard these forces is that the feedback, both haptic and visual, does not accurately represent the range of subtle cues encountered in actual surgery. For instance, when an instrument contacts tissue, the surgeon not only receives haptic feedback, but observes deformation, color change, and functional change (e.g. blood vessels rupturing). Without these coordinated cues, an experienced surgeon may not register the haptic signal alone as a damaging force. Another reason the surgeons may have disregarded the haptic force feedback is that the interface mechanism is different than a laparoscopic dissector handle. Thus, the surgeons may not have regarded (consciously or subconsciously) the task as a surgical one, so were not drawing upon their expertise.

Another possible explanation for the high applied forces (as observed by [3, 4]) is that the surgeons expected to apply a certain amount of force because dissection procedures require controlled damage to tissue (e.g. the liver capsule is severed when separating the gall bladder from the liver). Surgeons are trained to apply appropriate forces that cause this controlled damage. Subjects who do not have extensive surgical experience may limit force application to prevent irreversible damage to tissue, slowing the

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dissection process.

The effect of force feedback on the length of artery dissected by surgeons is also notable. An increase in the force feedback scaling level served to *decrease* the length dissected by the surgeons. An explanation offered by the surgeons is that they are accustomed to receiving some (however slight) force feedback during laparoscopic surgery. When that feedback is removed, as in the 0% scaling case, the surgeons were unaware of the magnitude of forces applied and attempted to dissect as much artery as possible. With the addition of force feedback, the force cues coincided with the visual cues and the surgeons sacrificed speed to lower forces.

The graduate students consistently applied lower peak and average forces while maintaining the same level of length dissected and area affected. They were also the only subject group familiar with the Phantom haptic interface device used as the basis for the telemanipulation system. One hypothesis is that the familiarity with the equipment allowed a more rapid understanding of the force information being provided. This may speak to the relative importance of task training versus equipment training in teleoperated environments. Regardless, the graduate student subject group still derived the force magnitude and error reduction benefit of force feedback.

Observing a similar force trend across all levels of previous surgical experience strongly points to the physical constraint benefit of force feedback. The advanced training and experience of expert surgeons do not diminish the value of this enhancement mechanism. An additional benefit of force feedback to experienced surgeons may be to reduce mental workload. Experienced laparoscopic surgeons have developed perceptual and motor skills to deal with the constraints of minimally invasive surgical techniques, and are able to use visual information to guide fine motions to avoid generating large forces. This visual approach would probably require significant cognitive processing and attention, however, so the aid provided by the physical constraint benefit of force feedback may serve to reduce that cognitive workload.

From this study, the benefit of force feedback is clear when accurate instrument positioning is required

and/or when the involved structures are sensitive and surrounding tissue trauma has severe implications. Microsurgical procedures meet all these conditions and may be considered the likely candidates for dexterity enhancement by instruments with force feedback capabilities. Presently the visual acuity, dexterity and tactile sensitivity of the surgeon define the limits of microsurgical procedures. The use of force feedback would allow scaling of forces up to perceivable levels, providing the aforementioned advantages to the microsurgical realm [26].

III. Acknowledgements

IV. References

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