LASERS ON ROBOTS

Jason W. Motkoski[1,2], B.Sc., Fang Wei Yang[1], Alexander D. Greer[1], M.A.Sc.,
Garnette R. Sutherland[1], M.D., F.R.C.S.
[1]Division of Neurosurgery, Seaman Family MR Research Centre, Foothills Medical Centre, Calgary, Alberta, Canada
[2]Department of Chemical and Petroleum Engineering, Schulich School of Engineering, University of Calgary, Calgary, Alberta Canada

INTRODUCTION

There is no commercially available surgical robotic system with integrated laser technology in the world. In surgery, laser technology offers simultaneous tissue cutting and coagulation, which is particularly useful in the resection of vascularized tumors and pathology. When compared to electrocautery, laser technology also offers tissue-specific thermal penetration, as different tissue types will absorb different wavelengths of laser light. These properties are highly desirable for application in neurosurgery.

While neurosurgery has not historically adapted the use of laser technology, recent advancements have removed barriers for clinical applicability [1]. These include the development of fiber-guided technology for improved surgical ergonomics, novel diode lasers that operate at wavelengths safe for intracranial tissue, and the emergence of contact laser technology to provide tactile feedback for the surgeon.

Recently, surgical robotic systems have been introduced into neurosurgery [2]. While robotic technology allows for improved surgical accuracy, precision and dexterity, the concurrent integration of imaging technology has positioned robotic systems to become the technological center of operating room technology. A fiber-guided laser tool, based on contact technology is an ideal tool to integrate onto the platform of a surgical robot.

The purpose of this project is to integrate a 980nm contact diode laser system [1] with neuroArm for increased microsurgical precision. Pre-clinical and initial clinical results are included.

MATERIALS

NeuroArm is the world's first image-guided, Magnetic Resonance (MR)-compatible robot [3]. It is capable of both microsurgery and stereotactic biopsy, and is integrated with an intraoperative magnetic resonance imaging (iMRI) system. In microsurgery mode, the two end effectors of neuroArm are mounted on a mobile base (Figure 1), and positioned at the place of the primary surgeon in a neurosurgical case. The computerized workstation is designed to reproduce the sight, sound and touch of surgery using high-definition visual feeds, a wireless headset system and haptic feedback in 3 DOF, respectively (Figure 2).

Figure 1: The neuroArm mobile base (left) and end effector (right).

Figure 2: The neuroArm compuerized workstation.

The laser system used in this study was the 980nm contact diode laser system manufactured by Photomedex Inc. and distributed in Canada by Sigmacon Inc. The 980nm wavelength is situated at a local absorption maximum in both water and hemoglobin, which minimizes tissue penetration to 1 mm for optimal precision. The laser is fiber-guided, making for ergonomic use in neurosurgery. Finally, the contact technology involves a sapphire tip that is fastened to the distal aspect of the laser fiber. This tip prevents energy transmission directly out of the fiber by internally-reflecting the light energy within the tip. Upon contact with tissue, when the refractory difference of sapphire and its surrounding medium is decreased, the energy is transmitted out in the direction of tissue contact. This provides for very localized and controlled delivery of laser energy, as well as a tactile interface for the surgeon to utilize. The laser system is pictured below (Figure 3).

Figure 3: The 980nm diode laser system (left) and sample contact laser tips (right). Not to scale.

PROTOTYPE TOOL DESIGN

A bayonette-shaped tool was required to hold the laser fiber when attached to neuroArm. The prototype tool was manufactured from brass (Figure 4).

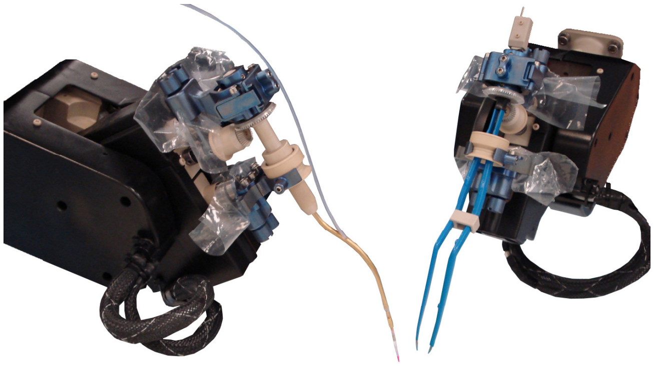
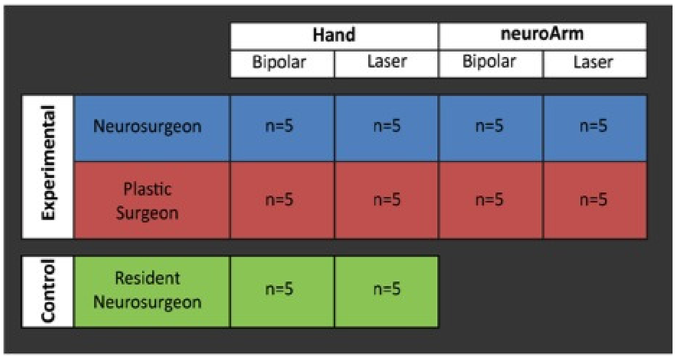


Figure 4: The neuroArm laser tool (left) and bipolar forceps (right).

PRE-CLINICAL STUDIES

Experimental Design

The experimental and control groups are outlined in Figure 5. As this study involved the use of (1) robotic and (2) laser technology, 4 groups were required to determine surgical effect of each technology independently and together. Two surgeons were previously trained to use neuroArm, so these individuals completed procedures using all four techniques. As it was not possible to blind the surgeon to the experimental groups, a senior neurosurgery resident surgeon completed procedures using the hand techniques for comparison.



		Hand		neuroArm	
		Bipolar	Laser	Bipolar	Laser
Experimental	Neurosurgeon	n=5	n=5	n=5	n=5
	Plastic Surgeon	n=5	n=5	n=5	n=5
Control	Resident Neurosurgeon	n=5	n=5		

Figure 5: Experimental design for the pre-clinical laser and robotic studies.

In each trial, the following parameters were recorded: total surgery time (seconds), amount of blood lost (grams), presence or absence of thermal injury to surrounding organs, and presence or absence of vascular injury to adjacent vessels. These parameters were combined into an overall performance score according to (1).

$$\begin{aligned}\text{Performance (sec)} &= \text{total surgery time (sec)} \\ &+ 60\text{ (sec) per }0.5\text{g blood lost} \\ &+ 120\text{ (sec) per thermal injury} \\ &+ 120\text{ (sec) per vascular injury}\end{aligned} \quad (1)$$

Methods

Each procedure involved bilateral partial hepatectomy, complete splenectomy and submandibular gland excision, performed on an adult male Sprague-Dawley rat model (300g size). Prior to each procedure, each rat was anesthetized using an intraperitoneal injection of 0.5 mL sodium pentobarbital (65 mg/100 mL). The liver, spleen and submandibular gland were exposed through midline abdominal and neck incisions. A common assistant surgeon served all cases; a Leica microscope (model M525 0H4; Leica Microsystems GmbH) provided magnification and illumination of the surgical site.

Following microsurgical procedure, each rat was perfusion fixed by intracardiac injection of 125mL distilled water, then two injections of 125mL 10% formalin in distilled water. A 1cm x 1cm size sample was removed from the distal portion of the lateral edge of the remaining section of liver of each liver lobe, and stored in 10% formalin in distilled water for histology.

In the robotic trials, the neuroArm bipolar forceps (Codman & Schurtleff Inc.) were placed in the neuroArm right end effector, and the neuroArm tissue forceps were placed in the left. The bipolar footswitch (Codman & Shurtleff, Inc.; Raynham, MA) was operated by the common assistant, who also used various microinstruments to assist with the procedure.

In hand procedures, surgeons could operate the bipolar or laser switch themselves. A standard selection of microinstuments was available to each surgeon. The neuroArm bipolar forceps were not used because the surgeons felt more comfortable using a smaller, more graspable set of forceps (Codman 1.0 mm bipolar forceps; Codman & Shurtleff Inc.; Montgomeryville, PA).

Results

The overall performance scores for each surgeon ad each technique are presented in Figure 6. Two observations are very interesting. (1) Each surgeon performed statistically unique in every modality except for the two experimental surgeons in the neuroArm-bipolar group. (2) Every surgeon demonstrated statistically significantly improved surgical performance when using the laser rather than the bipolar. This was true whether the surgeon was using conventional hand techniques or using neuroArm techniques.

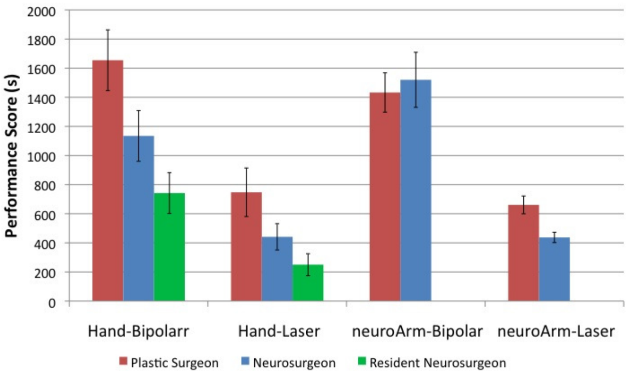


Figure 6: Performance scores for each surgeon and each technique.

As each surgeon completed 5 trials with each technique, the data can be presented in a longitudinal fashion (Figure 7). This allows for evaluation of the learning curve for each surgeon to adapt each technique. The significant observation is that the learning curve was not significant beyond 5 cases.

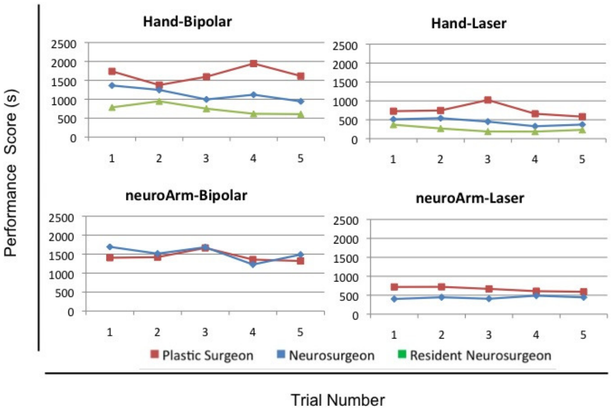


Figure 7: Perforamnce scores by method (quadrant) and surgeon (color line) to demonstrate learning curve.

CLNICAL STUDIES

Experimental Design

The paradigm for clinical integration of laser and robotic technology is as follows: (1)

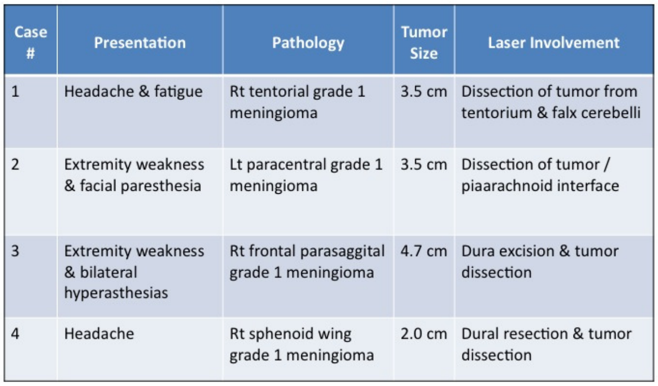
integration of robotic technology without laser (2) integration of laser technology without robotic (3) integration of both technologies together. The first component has been previously described (Pandya *et al.,* 2009). The second component has been completed and results included below. The third component is to be completed in summer 2011.

Methods

To date, the contact laser technology has been used in 4 clinical cases of intracranial tumors for this study. The basic premise was to use the laser for a minimal component of the procedure in the initial cases, then to use it for an increasingly larger proportion of tumor resection in each subsequent case. This ensured minimum disruption to surgical rhythm, maximum familiarity of other operating room staff with the technology, and maximum patient safety.

Results

The details of each clinical case, along with extent of the laser involvement, are presented in Figure 8, below. The laser was successfully used in an increasing proportion of tumor resection in each case.



Case #	Presentation	Pathology	Tumor Size	Laser Involvement
1	Headache & fatigue	Rt tentorial grade 1 meningioma	3.5 cm	Dissection of tumor from tentorium & falx cerebelli
2	Extremity weakness & facial paresthesia	Lt paracentral grade 1 meningioma	3.5 cm	Dissection of tumor / piaarachnoid interface
3	Extremity weakness & bilateral hyperasthesias	Rt frontal parasaggital grade 1 meningioma	4.7 cm	Dura excision & tumor dissection
4	Headache	Rt sphenoid wing grade 1 meningioma	2.0 cm	Dural resection & tumor dissection

Figure 8: Results from early clinical cases of 980nm diode laser system.

DISCUSSION

This study provides insight into surgical performance, and the impact of a new tool into neurosurgical procedure. First, it is interesting to note that each of the three surgeons in the pre-clinical studies performed surgery in a statistically unique way (Figure 6). This implies that each surgeon will have his or her own unique baseline performance. The second interesting trend is that each surgeon showed substantially improved surgical performance when using the laser – regardless of using neuroArm or hand techniques. This suggests that the laser tool does, in fact, improve baseline surgical performance in all three surgeons. Thirdly, when the trials using neuroArm are compared to those using hand techniques, it becomes clear that each surgeon's mean surgical performance will become more similar, and that the variability of each surgeon's own trials will also decrease. This suggests that the use of robotic technology increases consistency of surgical performance among surgeons with otherwise very different baseline measures of surgical performance.

Early clinical studies demonstrated successful, progressive integration of laser technology into neurosurgical procedure (Figure 8).

FUTURE DIRECTIONS

A clinical version of the tool is presently being manufactured. Once completed, this tool will allow for robotic manipulation of the surgical laser in the clinical setting: the final test of validation and applicability for this combined technology.

ACKNOWLEDGEMENTS

The author would like to acknowledge the assistance of Terry O'Reilly (Sigmacon Inc.) and Kevin Scanlon (Photomedex Inc.) for technical assistance with the laser unit. Special thanks also goes to the neurosurgical nursing team at the Foothills Medical Center for welcoming new technology and minor changes in operative flow.

REFERENCES

[1] Jallo, G.I., Kothbauer, K.F., Epstein, F.J., 2002, Contact laser microsurgery, *Child's Nervous System,* 18, pp. 333-336.
[2] Pandya, S., Motkoski, J.W., Serrano-Almeida, C., Greer, A., Latour, I., Sutherland, G.R., 2009, Advancing neurosurgery with image-guided robotics. *Journal of Neurosurgery* [epub], doi 10.3171/2009.2.JNS081334.
[3] Sutherland, G.R., Latour, I., Greer, A.D., Fielding, T., Feil, G., Newhook, P., 2008a, An image-guided magnetic resonance-compatible surgical robot, *Neurosurgery,* 62, pp. 286-292.