# Quantification of Forces During a Neurosurgical Procedure: A Pilot Study

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■ OBJECTIVE: **Knowledge of tool-tissue interaction is mostly taught and learned in a qualitative manner because a means to quantify the technical aspects of neurosurgery is currently lacking. Neurosurgeons typically require years of hands-on experience, together with multiple initial trial and error, to master the optimal force needed during the performance of neurosurgical tasks. The aim of this pilot study was to develop a novel force-sensing bipolar forceps for neurosurgery and obtain preliminary data on specific tasks performed on cadaveric brains.**

■ METHODS: **A novel force-sensing bipolar forceps capable of measuring coagulation and dissection forces was designed and developed by installing strain gauges along the length of the bipolar forceps prongs. The forceps was used in 3 cadaveric brain experiments and forces applied by an experienced neurosurgeon for 10 surgical tasks across the 3 experiments were quantified.**

■ RESULTS: **Maximal peak (effective) forces of 1.35 N and 1.16 N were observed for dissection (opening) and coagulation (closing) tasks, respectively. More than 70% of forces applied during the neurosurgical tasks were less than 0.3 N. Mean peak forces ranged between 0.10 N and 0.41 N for coagulation of scalp vessels and pia-arachnoid, respectively, and varied from 0.16 N for dissection of small cortical vessel to 0.65 N for dissection of the optic chiasm.**

■ CONCLUSIONS: **The force-sensing bipolar forceps were able to successfully measure and record real-time tool-tissue interaction throughout the 3 experiments. This pilot study serves as a first step toward quantification of tool-tissue interaction forces in neurosurgery for training and improvement of instrument handling skills.**

## INTRODUCTION

Currently, tool-tissue interaction in neurosurgery is largely taught and learned through the novice/expert apprenticeship model. In this model, novice surgeons acquire technical surgical skills through years of hands-on training in the operating room, and receive supervision and feedback from their mentors relative to performance. However, because of the lack of quantitative measures to assess aspects of technical surgical skill, the knowledge acquired, and subsequently relayed through generations of neurosurgeons, remains largely qualitative. As a result, trial and error often constitutes a major part of learning psychomotor skills for a novice surgeon. With decreasing operating hours and training resources, there is an increasing demand to improve training efficiency and provide quantitative evaluation of surgical performance (9, 16).

The prerequisite for objective assessment of technical surgical skills is the ability to measure and study essential aspects of surgical performance. One important component of instrument handling is the understanding and ability to apply an appropriate amount of force during tool-tissue interaction to effectively, yet safely, accomplish the surgical goal. This force can vary depending on the tissue type, region of the brain, or surgical task. In the operating room, this knowledge is usually conveyed from the mentor to the trainee through qualitative instructions such as "be gentle" or "push harder." Quantification of these forces could be made possible through the incorporation of sensor technology onto surgical tools. Although such advances have occurred, they are mainly limited to surgical robotic systems or applications other than neurosurgery (3, 15, 18, 21-24). To date, quantitative data on the forces exerted on human brain tissues when performing neurosurgical tasks remain largely unavailable. Experimental studies reporting manipulation forces of brain tissues mostly involved non-penetrating indentation forces for characterization of the mechanical properties of brain tissue (6, 8, 13) or penetration studies to estimate probe, electrode, or needle insertion forces (10, 19, 20, 26).

The authors have previously reported on forces exerted during microneurosurgery via a robotic, tele-operated system, where forces

**Key words**
- Bipolar forceps
- Coagulation
- Dissection
- Neurosurgery
- Sensors
- Tool-tissue interaction forces

**Abbreviations and Acronyms**
**CR**: Cranial nerve
**SD**: Standard deviation

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of tool-tissue interaction were recorded with a blade and Rhoton dissector held by a robotic arm (12). However, surgical forces applied with a tele-operated robotic system can be dependent on the fidelity of the haptic/visual feedback mechanism, and hence might not be truly representative of neurosurgical forces in conventional surgery. In this study, a newly developed force-sensing bipolar forceps is presented. Bipolar forceps is one of the most important surgical instruments in neurosurgery and is used to perform a variety of complex tissue manipulation tasks, including coagulation of critical neurovasculature and dissection of delicate brain structures (11, 25). It is postulated that a force-sensing bipolar forceps can provide a unique means for quantification and assessment of real-time neurosurgical forces and can assist in the training and improvement of neurosurgical skills, in particular the application of force in the performance of neurosurgery. The goal of this pilot study was to develop and evaluate the above-mentioned force-sensing bipolar forceps. The forceps was used in 3 cadaver experiments to quantify the forces of neurosurgical dissection and coagulation. To the authors' knowledge, this is the first study to report forces of dissection and coagulation of human brain tissues with neurosurgical bipolar forceps.

## MATERIALS AND METHODS

### Force-Sensing Bipolar Forceps

The force-sensing bipolar forceps used to measure coagulation and dissection forces is shown in **Figure 1**. The forceps consisted of a commercially available bipolar forceps (Codman & Shurtleff, Inc., Raynham, Massachusetts, USA) equipped with 4 strain gauge sensors (CEA-12-125UN-350 [Micro-Measurements, Wendell, North Carolina, USA]) to detect forces applied perpendicular to the longitudinal axis of the prongs, i.e., coagulation (closing) and dissection (opening) forces (**Figure 1C**). To maintain the properties of the bipolar forceps and its functionality, the strain gauge sensors were installed on the lateral surfaces of the bipolar forceps prongs, 3.5 cm away from the tips. The use of these strain gauge sensors allowed interaction forces at the forceps tips to be indirectly sensed by measuring the strains on the prongs of the forceps (14). Based on the direction of the force applied to the tips of the forceps, the strain sensors readings could be positive or negative, resulting in a positive or negative output signal (**Figure 1C**).

### Data Acquisition

The data acquisition system consisted of a data acquisition board (Quanser Q8-QPID [Quanser Consulting Inc., Markham, Ontario, Canada]) connected to a Dell Precision M4700 laptop computer (Dell Inc., Round Rock, Texas, USA). The data acquisition board allows for digitization of the sensor output signals so that the data can be read and stored digitally. A software module was developed to acquire the real-time strain gauge readings at a sampling rate of 500 Hz using MATLAB (version 7.12), Simulink (version 7.7) (MathWorks, Massachusetts, USA) and QUARC (version 2.2.1, Quanser Real-time Control) software packages.

### Calibration System

The calibration system of the force-sensing bipolar forceps is shown in **Figure 2**. A force calibration device customized for the bipolar forceps was designed and developed for the strain gauge sensor voltages to be mapped to forceps-tip forces (**Figure 2B**). A high-accuracy force/torque sensor (Titanium Nano17 [ATI Industrial Automation, North Carolina, USA]) with 1/682 N resolution is used to allow for accurate calibration of the output readings provided by the strain gauges. **Figure 2A** shows the calibration plot correlating the strain sensors voltage readings to force readings.

### Experimental Procedure

The study was performed with approval from the Conjoint Health Research Ethics Board of the University of Calgary. Three fresh unpreserved cadaver heads were obtained through the Body Donation Program, Department of Anatomy at the University of Calgary, Alberta, Canada. A Leica microscope (M525 0H4 [Leica Microsystems GmbH, Wetzlar, Germany]) was used to provide illumination and magnification. The neurosurgical procedures were conducted by an experienced neurosurgeon (GS) along with a surgical assistant (SL or FWY). During the experiments, the force-sensing bipolar forceps was only used by the primary surgeon when deemed appropriate so that the tool-tissue interaction forces recorded closely represent those exerted by a surgeon during neurosurgical procedures. Microscope videorecording of the procedure was performed using high-resolution microscope cameras (HDL-20D [Ikegame Tsushinki Co. Ltd, Tokyo, Japan]) mounted on the microscope and a Blu-Ray recorder (Panasonic, Osaka, Japan).

A frontotemporal craniotomy was performed on the cadaver heads in the same manner as conventional neurosurgery. The scalp vessels were coagulated with the force-sensing bipolar forceps. The primary surgeon simulated the coagulation task by closing the bipolar forceps with forces similar to those during neurosurgery. Following durotomy, microsurgical technique was used to dissect basal cisterns, cerebral vasculature, and exiting cranial nerves. The optic chiasm was exposed and the opticocarotid cistern was dissected between the optic nerve and the carotid artery. To determine the dissection forces required to inflict nerve damage, high force dissection was deliberately performed on the optic and oculomotor nerves to the point where structural damage was observed. Temporal lobectomy and corpus callosotomy were performed to quantify forces related to white matter dissection.

Forces of dissection and coagulation were measured for the following surgical tasks: 1) dissection of small cortical vessels; 2) dissection of the middle cerebral artery; 3) dissection of the sylvian fissure; 4) dissection of the interhemispheric fissure; 5) dissection of the optic chiasm between the optic nerve and the carotid artery; 6) dissection of the oculomotor nerve; 7) coagulation of the scalp vessels; 8) coagulation of the pia-arachnoid over the temporal gyrus; 9) division of the temporal stem; and 10) division of the corpus callosum.

## RESULTS

### Forces of Dissection

Illustrative examples of the forces recorded during the 6 dissection tasks are shown in **Figure 3**. The force level was zero when the forceps tips were not in contact with any tissues. As the bipolar forceps was closed in preparation for a dissection motion, the tips met and an inward closing force (negative value) was