Low Cost Eye Surgery Simulator with Skill Assessment Component

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Abstract. Ophthalmic surgeons require years of training and continuous practice to successfully manipulate the delicate tissues of the human eye. Development of the fine motor skills is a crucial component of this training. Virtual eye surgery simulators have come on the market in recent years leveraging the advantages of virtual procedures. However adoption is limited by the high initial investment and availability of models. Our approach consists of a low cost hybrid approach that employs a standard porcine model for cataract training and a platform that is instrumented to record interaction forces and video. In a preliminary study we have recorded procedure data for a small number of experts which shows good signal-to-noise ratio suitable for development of objective skill assessment models.

Keywords. Surgical Training, Skill Assessment

Introduction

The human eye is one of the most delicate structures in the human body. Ophthalmic surgeons need years of training and continuous practice to carefully and successfully manipulate the tissues. Tool motions and forces used in these procedures are extremely small. Development of the fine motor skills is therefore an important component of resident training and generally consists of wetlab practice on cadaveric eyes and assisting experts with surgery in live cases in the operating room.

For wetlab practice a cadaveric eye is mounted in a Styrofoam training prop. The ex-vivo specimens are used to practice various common intraocular surgical procedures such as cataract removal, glaucoma and retinal surgery [1]. In a simulated wetlab procedure the resident in training can carry out several complete procedures in a short time frame and practice critical steps without risk to a patient. However in order to obtain performance feedback for the resident, a skilled surgeon has to observe and evaluate the practice session [2]. Due to the workload demands on expert surgeons and high cost of their time, residents currently go through only one supervised and 5 to 10 unsupervised wetlab sessions. The residents are quickly transitioned into the OR working live cases. The expert surgeon will perform most of the procedure at first and assign increasingly larger and more difficult parts of the procedure to the resident. With this approach, the resident will practice critical steps in the procedure for only a few brief periods per patient once basic skills are fully mastered.

Virtual eye surgery simulators such as the EYESI® from VRmagic GmbH have come on the market in recent years leveraging the advantages of simulated procedures [3,4]. Due to the virtual nature of the model, they are well suited to simulate standard procedures as well as unexpected and rare circumstances. Performance assessment is feasible since the state of the model is known. These simulators currently do not provide tactile feedback for tissue interaction [5,6,7,8,9]. This component is critical in developing the motor skills necessary to successfully handle the extremely delicate tissues of the human eye.

With availability of high fidelity data of surgeon/tool and tool/tissue interaction, objective skill assessment for surgical applications has recently been subject to intense study. Integrative and averaged metrics have been employed to this goal [10,11]. More recently approaches using stochastic tools such as Markov models have been employed to capture the dynamic nature of the surgical task. [12,13,14,15,16]

The goal of this project is to improve the understanding of the biomechanical properties of the human eye, eye socket and surgical tools, leading to the development of objective surgical skill assessment methodology and improved training tools for ophthalmic surgeons. Current trends in medical training indicate that simulator based certification for surgical procedures may become more common. The device proposed here lends itself to training and certification of proficient surgeons for new procedures and materials. In the initial phase of this project, we developed, built and tested a surgical platform for data collection during cataract procedures on porcine and human ex-vivo eyeballs and collected preliminary data.

1. Methods

1.1. Simulator platform

We developed a novel device to measure, record and evaluate surgical tool/tissue interaction data for eye surgery. A cup supporting an ex-vivo human or porcine eye is placed on top of a 6-axis force/torque sensor (Nano 17 from ATI Industrial Automation). The cup is available in several sizes to allow a somewhat customizable fit to the specimen size. Because the force/torque sensor is easily damaged by exposure to fluids, the cup and supporting structure are shaped to allow fluids from the surgical site to drain to the base without pooling or contacting the sensor. An internal channel in the platform connects the fluid catch basin with a hose barb, where external drain tubing can be attached. A Styrofoam head prop representing patient anatomy is mounted to the platform. The head prop is mechanically isolated from the sensor to allow the surgeon to use it for support as is commonly done in real surgery.

With its placement directly below the specimen, the 6-axis sensor allows us to track direction and magnitude of resulting forces and torques applied to the specimen throughout the procedure. Placing the sensor on the specimen enables the use of unmodified surgical tools as well as standard handpieces used with phacoemusification machines.

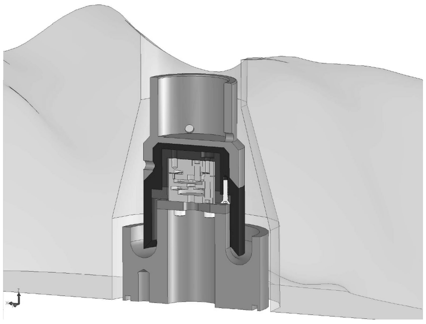
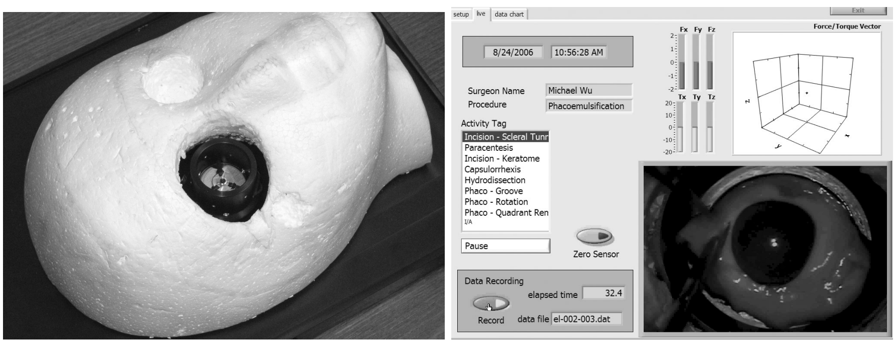


Figure 1. CAD rendering of sensor support with drainage system and specimen cup.

1.2. Specimen Suspension and Pressure Regulation

Preliminary testing with the platform revealed that the porcine eyes obtained from Sierra for Medical Science Inc. made it difficult to place the specimen in the cup with satisfactory consistency and biomechanical realism of the suspension. Several methods of attachment of the eye were considered and tested. Method 1 is a simple velcro lining of the bottom of the cup to increase friction between specimen and cup. Method 2 consists of fixation with a needle transversely penetrating the specimen, holding the eyeball more rigidly to the cup. Method 3 is a 10mm pin penetrating the globe from the back. The pin is attached to rubber bands that suspend the pin flexibly to the inner circumference of the cup. These methods were tested with cup sizes of 22, 25 and 28mm inner diameter.

The specimens we obtained varied in intraocular pressure mainly due to decreased and variable vitreous volume. To improve specimen consistency and maintain intraocular pressure throughout the procedure we implemented a simple pressure regulator based on a gravity feed of saline solution to a needle that penetrates the posterior segment from the side. With this placement of the needle port, the workspace of the surgeon was not affected and correct pressure could be maintained continuously. Normal intraocular pressure (18mmHg) was obtained with reservoir fluid level at 25cm above the cornea.



(a) (b)

Figure 2. Device with Styrofoam prop, cup and suspended pin (a) graphical user interface (b)

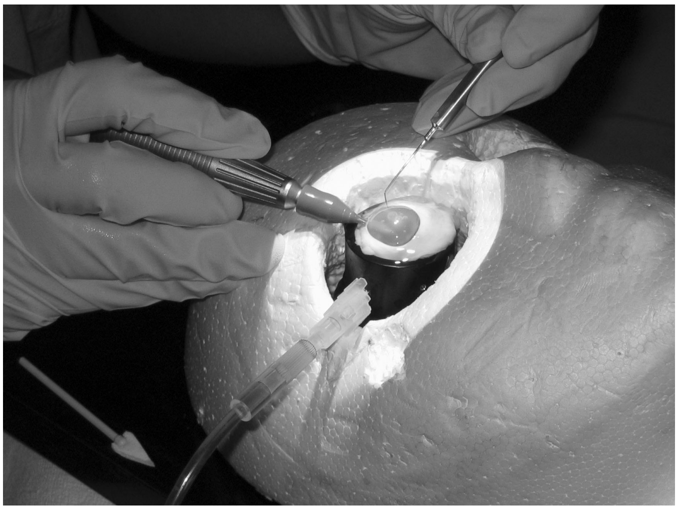


Figure 3. Test procedure performed on a porcine specimen

1.3. Data and Video Acquisition

The sensor data is acquired and recorded using a National Instrument data acquisition card and a Labview program. Force/torque data is recorded at 100Hz. The software provides a simple user interface that allows the surgeon or a nurse to record data and view results with little or no training. To aid with development of the skill assessment component the recorded data can be tagged manually to identify data corresponding to distinct procedural steps during a phacoemulsification procedure. Tags are displayed in a list and the user simply selects the appropriate item. The Labview program also displays and records live video from the microscope camera to facilitate off line evaluation and model validation.

2. Results

The cornea size of 6 porcine eyes was measured. The cornea is slightly elliptical and the average length of the major axis was measured at 15.1mm with a standard deviation of 1.2mm. For evaluation of the suspension, the eyes were reformed using the pressure regulator. Fit was tested for cups of 21, 25 and 28mm inner diameter and found to be best for the 25mm cup. The suspension methods for the eye were evaluated for realism of suspension, expected consistency and sensitivity to eyeball size. Method 1 (velcro) resulted in moderately realistic suspension; consistency of the method and sensitivity to changes in specimen size were poor. Method 2 (transverse needle) resulted in consistent, size insensitive, but very unrealistic rigid suspension of the eyeball. Method 3 (suspended pin) showed good consistency and size insensitivity with very good physiological accuracy of the suspension. This method was selected for further experiments.

To date, multiple procedures performed by two experts were recorded during phacoemulsification procedures on porcine eyes (see Figure 3 and 4). The collected data displays a high signal to noise ratio with peak forces during phacoemulsification recorded at around 0.7 N. Similar values were recorded by Charles et al. with a tool-based measurement [17]. The data shows well defined periods of activity corresponding to the typical steps of the procedure and the manually assigned tags. Video of the procedure was recorded simultaneously. Average procedure completion time of the procedure was 838s ($\sigma = 141s$), completion time for the phaco sections was 235s ($\sigma = 40s$).

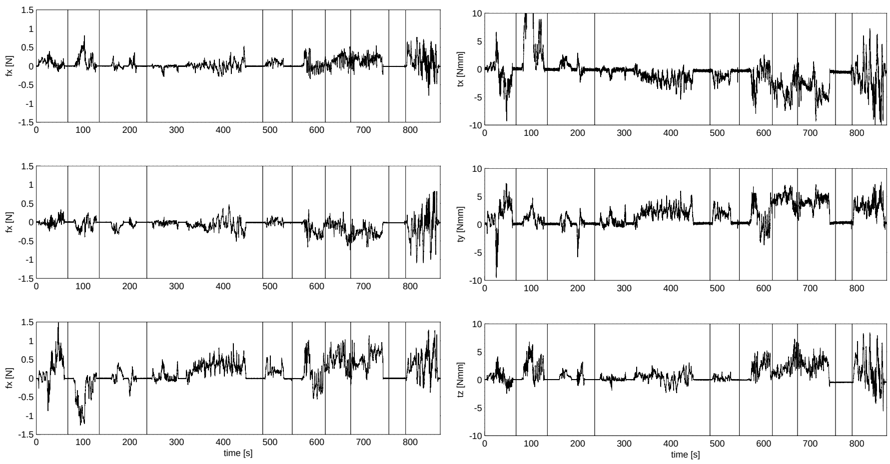
3. Conclusion and Future Work

A novel device for training in eye surgery has been proposed. Much like traditional wet-lab work, residents train on porcine models. The collection of force and torque data provides the means to develop a better understanding of the interaction of tissue and surgical tools in this discipline. The data will also be used to develop statistical models for assessing resident skill objectively. Primarily aimed at improving the training experience of surgical residents, this approach lends itself to broad adaptation due to its relatively low complexity and cost.

We are in the process of collecting data from procedures by more experts as well as less experienced residents and are evaluating the feasibility of using artificial eyes with our device.

Acknowledgments

The authors would like to acknowledge support from Department of Ophthalmology, Bucy Chair Memorial Funds and University of Washington Technology Gap Innovation Funds. The authors would also like to thank Dr. Michael Wu.



(a) (b)

Figure 4. Sample of recorded forces (a) and torques (b)

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