Experimental Investigation of Motion Planning for Successful Membrane Peeling and Cannulation

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BRIEF. This report contains the study of success rates on membrane peeling and cannulation using the Stewart-Gough parallel robot.

ABSTRACT. Vetrio-retinal surgery requires high precision. Traditional surgical interventions have limited intraocular dexterity and haptic feedback and also traditional imaging technics have limited depth perception. We hence propose an optical coherence tomography (OCT) guided robotic system that is capable of assisting surgeons in performing surgical interventions like internal limiting membrane (ILM) peeling, vitrectomy and cannulation. The presented robotic system contains a 6-DoF customized Stewart-Gough parallel robot and quick-changeable tools attached to it for different surgical interventions. This report addresses the research on developing an experimental investigation of motion planning for membrane peeling and cannulation on customized phantom retina models. The retina mock-up was made by agar with NEW-SKIN liquid bandage coated on top to simulate the membrane and channels with 100-200 microns in diameter created as blood vessels. Membrane peeling experiment was done by hand and the surgical grasp motion was tracked by Polaris Vicra optical tracker to record the gripper tip movement. The cannulation experiment was done using the robot to drive a micro-pipet and to inject dye into the mockup blood vessels. Future research will use results collected during this research to investigate the appropriate path plans for increasing the success rates of membrane peeling.

INTRODUCTION.

The retina is the light sensitive nerve tissue that lines the back of the eye. Its job is to receive light and create impulses that it sends through the optic nerve to the brain. The retina contains several veins known as retinal veins. These are important because they help circulate blood out of the eye and towards the heart. When these veins become blocked it is known as RVO (retinal vein occlusion). There are two types of RVO, central and branch. Central RVO which is when the blockage occurs in the main retinal vein located at the back of the eye and branch RVO, which is when the blockage occurs in the inner portion of the eye, where the retinal veins branch out into smaller veins. The blockage can cause negative effects ranging from decreased vision capability to vision loss.

There is currently no known cure for BRVO but the effect can be lessened by methods like laser surgery and steroid injection however these can have negative side effects as well. Surgery is a promising treatment but the procedure is very delicate and even with highly trained surgeons there is still a high risk of error due to inaccuracy and tremors. Robotics has been steadily advancing surgeon's ability of carrying out more and more complicated surgical interventions. [1-3]. Prof. Simaan and his group developed a dual-arm robotic system [5-6] aiming to assist surgeons in performing ophthalmic surgeries.. This robot has the potential to revolutionize this procedure because it can implement safety measures that humans cannot as well as scale down the motion of a surgeons hand tremors. The problem is that there has been no research to determine the safest/most effective motions for the robot to use when peeling the membrane and inserting the stent. In order to determine these motions a series of experiments will have to be conducted using a retinal vein model created from agar gel and a membrane model created by New-Skin liquid bandages. These materials simulate the eye while also being cost effective and reusable. The robot will utilize optical coherence tomography (OCT) scanning [7] to locate the vessels.. OCT produces images by reconstructing them form light that is scattered through an object. OCT requires the object that is being scanned has to be partially light transmitting or translucent. The robot will have quick changeable tools that allow it to perform several surgical interventions.

There is currently no treatment for BRVO. A promising treatment is surgery but this is very delicate and filled with the possibility of human error. If an Optical coherence tomography (OCT) guided robotic system that is capable of assisting surgeons in performing surgical interventions like internal limiting membrane (ILM) peeling, vitrectomy and cannulation, it will improve the safety and efficiency of robotic surgery. This would allow for the surgery to be performed more while improving the safety of the procedure.

MATERIALS AND METHODS.

Since new robotic technology is being evaluated, experiments were carried out to build phantoms [4] and use these phantoms to test peeling and injection. The following is a description of key materials and methods used to achieve this goal.

Agar Setup.

The materials used were agar powder, 250ml beaker, Coffee Mate©, a hot plate, and Petri dishes.

2.3g of agar was mixed with 110ml of water and heated to a boil on a 275°C hot plate. The mixture was stirred throughout this heating process. Once the agar began to boil it was mixed with 2.3g Coffee Mate© at a 1:1 ratio to allow it to show up on an OCT scan. This was then taken off of the hot plate and poured into the Petri dish.

Retinal Model preparation.

The materials used were 100 and 200 micron wires, 300 micron drill bit, Dremel©, Agar gel with Coffee Mate©. By using the Dremel© five 300 micron holes were drilled on each side of the Petri dish for wire to be run through. The holes were then marked with a sharpie to make the OCT scan easier. The gel was then poured over the wires and allowed to harden. Then the wires were carefully removed to create the vessel models.

Dye Injection.

The materials used were a Digital microscope, Dragonfly camera attached to the scope, Dino-Lite© Digital microscope, the Stewart-Gough parallel robot, Phantom retina models, and Robot actuated micro-pipette.

The Stewart-Gough parallel robot was outfitted with a syringe and a pipette tip filled with green dye. The tip was viewed through The top-view microscope to line it up with the vessel inside of the agar. Once the robot lined the tip with the vessel the dye was injected into the vessel.

New Skin© dilution.

The materials used included two Bottles of New Skin© liquid bandage, 1.0 and 0.5 ml of acetone (5 and 10 percent dilutions). 0.5ml of acetone was added to a bottle of liquid bandage to make a 5 percent dilution. 10ml of acetone was added to another bottle to create the 10 percent dilution.

Membrane application.

The materials used were New Skin liquid bandage©, acetone thinner, and hardened agar gel. The New Skin liquid bandage© was applied to the agar gel in small spots. This was then allowed to dry for about an hour before the peeling process was attempted. The bandage was applied in six spots per plate.

Membrane Peeling.

The materials used were Stewart-Gough parallel robot, Ophthalmic surgical gripper, mockup Sclera model, Polaris Vicra vision tracker with marker, and retinal models with liquid bandage. A surgical grasper was equipped with a vision marker for tracking the hand motion. Twenty-one peeling experiments were carried out for two peeling methods: a) peel straight up , b) peel up and fold over with horizontal motion). Hand movements were tracked and the membrane peeling results were tracked using the following scale: 1=Membrane torn without peeling. 2=Membrane edge lifted but not peeled and torn. 3=Membrane started to peel and then torn. 4=Membrane peeled more than 50% and torn. 5=Successful peeling.

RESULTS.

Fig.1 panels ABC (left) shows the setup of the vessel cannulation experiment. Panel A depicts the actual setup with the robot while B shows the Pro/E model of the injection tool and C. is the agar model with the channels. Panels ABC (right) show the setup for the membrane peeling experiment with A. demonstrating the position relation between tracker camera and tool, B. illustrating the membrane on Petri dish and C. is the Pro/E model of the tool.

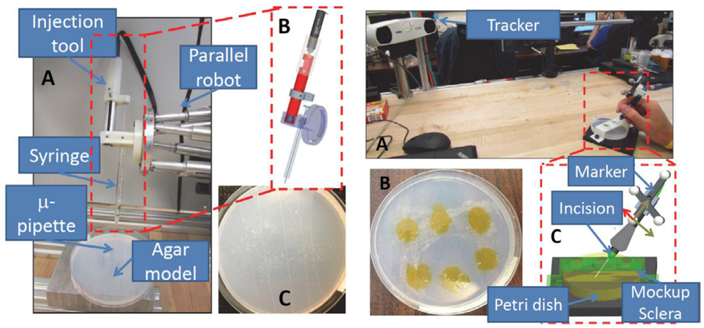

Figure 1. Panels **ABC (left)** demonstrates the vessel cannulation while panels **ABC (right)** shows the membrane peeling process.

The retina model was made using agar gel, 200 micron wires to simulate the vessels, and liquid bandage to simulate the membrane. The Stewart-Gough parallel robot was used to inject green dye into the simulated vessels.

Fig. 2B shows a typical successful peeling under a microscope. The peeling was done using agar gel and a mock up Sclara. Figure 2A and 2C show tip peeling movement for both motions in a 3D plot. Each color represents one trial. The success rate was recorded based on the five-point scale mentioned in the methodology section. The up and over had an average success rate score of 4.13 with an standard deviation of 1.2, while straight up had an average score of 3.73 with an standard deviation of 1.7.

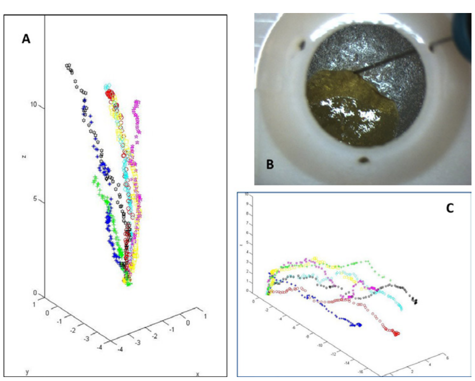

Figure 2. Membrane peeling results: **A**. One successful peeling; **B.** Gripper tip motion when peeling straight up; **C.** Gripper tip motion when peeling up and roll over.

Fig. 3 shows a successful vessel cannulation. The green dye was injected into the 200 microns blood vessel model using robotic telemanipulation under a microscopic top view. The micro-pipet is moving with a maximum linear and angular velocity of 10 mm/s and 10 deg/s. And the micro-pipet translation is scaled down to 1/25 times of the hand motion.

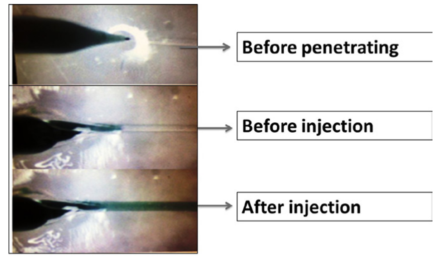

Figure 3. A successful cannulation with steps.

DISCUSSION.

The Phantom retina model for membrane peeling proved to work very well at simulating a human eyeball. The membrane peeling experiment showed that the up and over method was more successful at removing the membrane without damage. Through ten trials the up and over method not only had a higher success rate but also had a smaller difference in its standard deviation. The mockup Sclera proved to work well at simulating the incision point while leaving a clear view for the microscope.

The agar vessel models used for the cannulation experiment also proved to work very well. The experiment showed that it is possible to perform a vessel cannulation using the Stewart-Gough parallel robot and that the model can be used to realistically simulate a human eye vessel.

CONCLUSIONS.

These experiments developed mockup models for membrane peeling and vessel cannulation. These models will aid in future testing of the robot. A successful cannulation was also carried out using a pipette attachment and green die. It was also determined that the up and over membrane peeling method is more successful than the straight up method. This data will be utilized in the future to assist in motion planning for the robot. Although a lot of useful data was gathered from the experiments, in the future more trials should be conducted to provide even more evidence supporting the data. With more evidence supporting the peeling methods these methods can be applied to the robot to be used in retinal surgeries. The cannulation test can be used to fine tune the robots motion so that cannulation can also be performed during surgery.

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SUPPORTING INFORMATION.
Supplemental Figure 1. Chemical materials for making agar model for both membrane peeling and cannulation.
Supplemental Figure 2. Agar model and robotic setup for telemanipulation.

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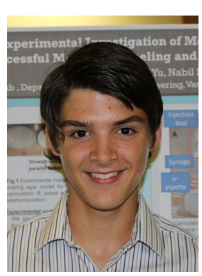

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