VivoForce instrument for retinal microsurgery

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We introduce an innovative 0.6mm diameter force sensing instrument allowing for safer epiretinal membrane peeling surgery. Force sensing relies on flexures and Fabry-Pérot interferometry.

1 Introduction

Our VivoForce instrument applies to retinal microsurgery. Epiretinal membranes severely degrade human vision and must be surgically peeled from the retina, a delicate procedure since the retina must not be damaged. The principal difficulty is the limitation of human performance at the required millinewton force range [1].

Current surgery relies on classical passive tools such as a membrane pick or forceps. This results in significant risk of retinal damage and long surgery time (up to 40 minutes) so the procedure is highly dependent on surgeon skill and experience. Our proposed force sensing instrument minimizes the possibility of irreversible retinal damage, thus simplifying the procedure and making it accessible to a wider range of surgeons. Other instruments for this application have fiber Bragg grating based force sensing [2,3,4], so diminished axial sensitivity. Moreover, only our mechano-optical transducer is monolithic, facilitating assembly.

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2 Tool development

2.1 Specifications and utilization

Our instrument is inserted into the eye with the force sensing element inside the eye. Standard retinal surgery requires removal of the vitreous gel and replacing it with 20°C water. Since body temperature slowly heats this water, the instrument must operate at a range of 20°C to 34°C.

The instrument peels away the epiretinal membrane with peak forces up to 15mN and the force sensor is calibrated to a resolution of ~0.03 mN. Peeling is done with a 23 gauge hook. The instrument is operated by the surgeon's hand and can be easily adapted to robotic surgery.

Force sensing is indicated by increasing frequency sounds as force approaches maximal limit, and a warning sound when above. Force is also recorded in real time and displayed on a screen, so an assistant can inform the surgeon of his measured force.

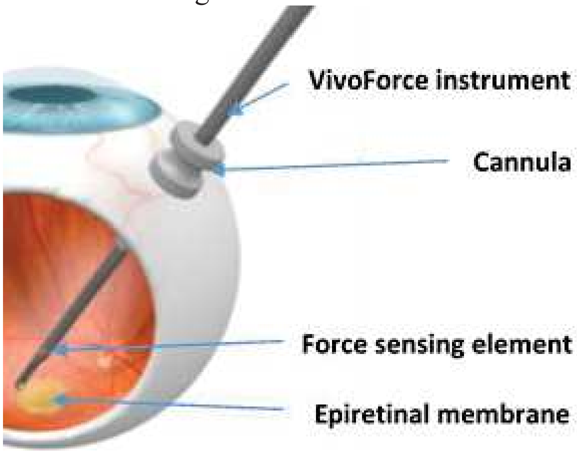

Figure 1: *Epiretinal membrane peeling setup*

2.2 Measurement principle

The force sensing load cell of our instrument consists of a mecano-optical transducer realized by flexures (compliant mechanisms) [5] by exploiting the nanometric precision of the Fabry-Pérot interferometer. The intellectual property of this solution belongs to Sensoptic SA [6] and was introduced by the authors in [7].

Figure 2 shows the VivoForce instrument and topology of a load cell. The mechanical part has one DOF kinematics, measuring the displacement along Z axis, so the component of force applied on the tip along X axis can be deduced, see Figure 2a). We identified this direction as the most crucial for the surgical procedure.

Figure 2b) shows a detailed section of the flexure body, its base is considered to be rigidly connected to the handle. On the other side is the pointed rigid tip, designed for membrane peeling according to surgeon specifications. The compliant mechanism forming the mecano-optical transducer links the tip to the base.

Since the compliant elements remain within their elastic domain while the force F_x applied along X axis is within the range of 0-50mN, this force is proportional to the displacement d measured on the axis of optical fiber, between base and rigid tip. By Hooke's law $F_x = k(d - d_0)$, where d_0 is a distance measured while no forces are applied and k is a constant stiffness coefficient.

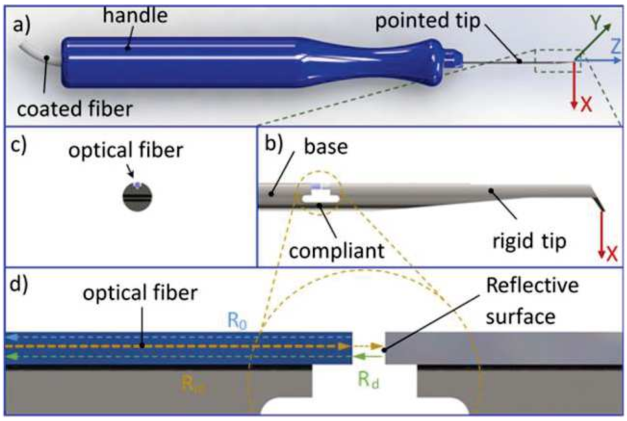

Figure 2: ***a)*** *VivoForce instrument,* ***b)*** *Flexure body,* ***c)*** *Cross section* ***d)****Fabry-Pérot cavity*

Converting displacement into an electric signal is done using an opto-electrical transducer exploiting white light interferometry. Figure 2d) shows the Fabry-Pérot cavity, whose length changes with the flexure body deformation. When force is applied, the initial distance between the optical fiber and mirror changes. A distal light source generates an initial ray R_{in} through an optical fiber of 125 µm diameter. A portion R_0 of this ray is reflected back from the end of the fiber, while the remaining portion R_d is reflected by the mirror and returns into the fiber. The interference between R_0 and R_d is detected by the interferometer. Displacements ranging from -5 µm to +5 µm from the rest position can be measured with a 5 nm resolution and with a 50 Hz acquisition rate.

2.3 Design and calibration

The tool shaft entering the eye has diameter 0.6mm, compatible with commonly used 23 gauge retinal instruments. This shaft is made of medical grade titanium due to biocompatibility requirements and its desirable properties for the flexible section.

Calibration of the instrument was conducted on the setup as in [7], where the only modification was a more sensitive reference sensor (Futek FSH03395).

3 Experimental setup

Due to the lack of a widely accessible model for performing epiretinal membrane peeling, we propose the novel simulator shown in Figure 3a), which we call ArtiEye. It consists of a sphere having the size of a human eye. Our instrument is inserted through a flexible membrane mimicking the sclera and there is a disposable membrane whose peeling is similar to an epiretinal membrane, see Figure 3b). As compared to pig eyes or fertilized chicken eyes previously used for instrument testing, these membranes are low cost and can be manufactured in high volume.

Our simulator coupled with our force sensing instrument facilitates surgeon training.

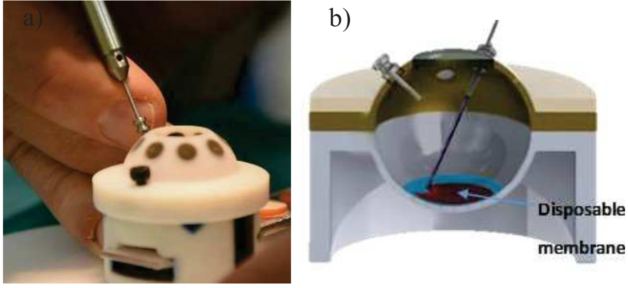

Figure 3: *ArtiEye simulator.*

4 Experimental results

Tests of the VivoForce instrument performed at the Jules Gonin Hospital, Lausanne, indicate that surgeons quickly take into account force sensing.

Professor Thomas Wolfensberger, a participant in the tool development, performed three consecutive membrane peelings on ArtiEye, with threshold sound feedback set to 30mN, 20mN, 15mN, respectively. This resulted in a lowering of both peak and average measured force, showing the potential for decreased damage during real surgeries.

5 Conclusion

We showed that the VivoForce instrument is ready for surgical testing. We also validated the Fabry-Pérot force sensing transducer at the submillimeter scale. Our current research applies this technique to other medical instruments at the submillimeter scale.

6 References

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