Safe Puncture Tool for Retinal Vein Cannulation

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1. Introduction

Retinal vein occlusion (RVO) is a major cause of vision loss in patients over 50 years old. RVO can be treated by cannulation of the retinal vein to remove clots. However, cannulation of small retinal veins is challenging as the required puncture force (~10 mN) is well below human sensing capability [1]. In this paper, we introduce a passive compliant tool for retinal vein cannulation having predetermined stroke and threshold force which allows safe and precise puncturing independent of actuation input. Our tool can be utilized in either stand-alone mode or mounted onto a robotic system.

2. Concept and design

Our tool uses a bistable mechanism, i.e., having two stable states and one unstable state, which releases a constant amount of energy when it passes from its unstable state to a stable state [2], see Figure 1. It follows that a threshold force can be obtained by limiting the stroke of the mechanism. This ensures safe and precise cannulation of the retinal vein, assuming a very thin wall, with puncturing force lower than the threshold force, cannulation is guaranteed. The surgeon simply displaces the mechanism across its unstable state.

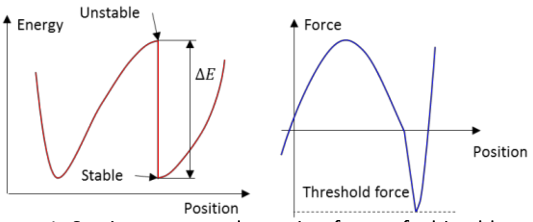

Figure 1: Strain energy and reaction force of a bistable mechanism

Figure 2 illustrates a puncture tool where bistability is realized by a buckled beam fixed on both sides by compliant pivots [3]. The beam is axially loaded on one end by a tuning stage and elastically driven by a spring loaded actuation stage. The other end is connected to a needle having an embedded micro-fluidic channel which cannulates the vein laterally. The dimensions of the mechanism are chosen so that maximum stroke is 500 µm and threshold force is 25mN with these parameters controlled by the position of the tuning stage.

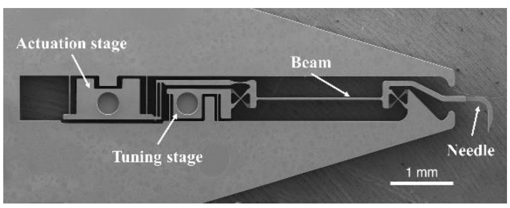

Figure 2: Puncture tool

3. Fabrication

The tool is monolithically fabricated in fused silica using femto-laser printing wet-etching [4], glass was used for its bio-compatibility and favorable elastic properties.
Figures 3 and 4 illustrate the 3D pivot and the outlet of the micro-fluidic channel embedded in the needle of the tool, their monolithic fabrication is very challenging without femto-laser technology.

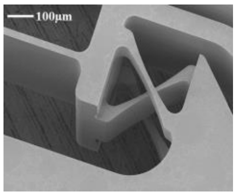

Figure 3: 3D cross pivot

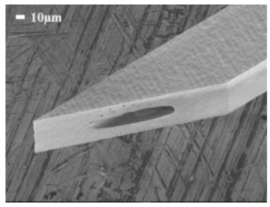

Figure 4: Needle tip

3. Results & Discussion

We validated our design using FEM simulations and experimental measurements, see Figures 5-7. Our tool successfully cannulated pig eye retinal veins.

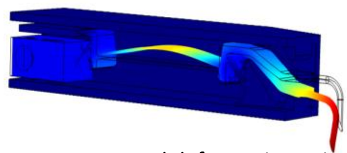

Figure 5: Puncture tool deformation using FEM

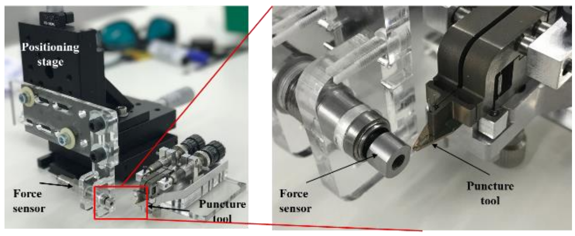

Figure 6: Measurement setup

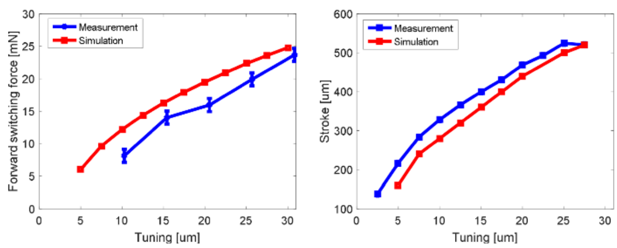

Figure 7: Experimental and numerical values of stroke and puncturing force for different tuning displacements

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References

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