Concentric Tube Robotics for Non-linear Navigation within the Ventricular Space

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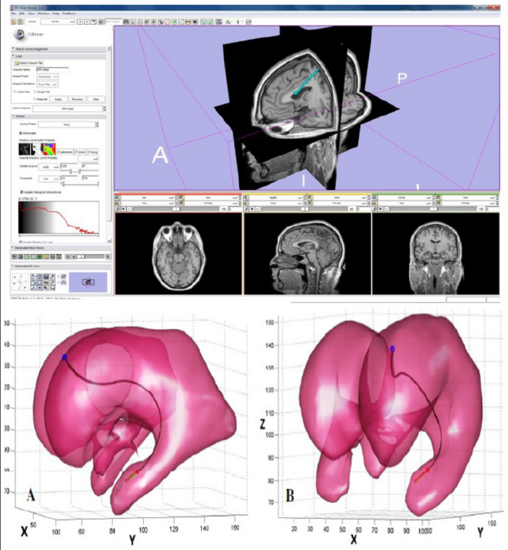
Introduction

Current intracranial surgical approaches remain almost exclusively linear, using direct trajectories from cranial entry point to surgical target. Flexible, minimally invasive navigation within the intracranial space is an unmet challenge. Concentric tube robotics recently developed for neurosurgery open a way to meet this challenge. These robotic platforms are constructed from telescoping curved tubes with cross sections comparable to catheters and needles. Through the translation and rotation of their individual tube segments, precise snake-like motions can be achieved. We present a novel design and prototype concentric tube robot for non-linear navigation within the intraventricular space as a representative example of this technology.

Methods

Utilizing an MRI-derived 3D computer model of a hydrocephalic ventricle (Figure 1), a navigation challenge was chosen whereby the choroid fissure would be followed from the Foramen of Monro to ipsilateral temporal horn via a frontal Kocher's point ventricular entry. Tube design algorithms previously developed by our group (1,2) were used to arrive at optimal tube designs, and these were manufactured. A series of navigation and position accuracy tests were performed in an ex vivo 3D printed model of this hydrocephalic ventricle using the custom tube design loaded in our robotic platform.

Figure 1

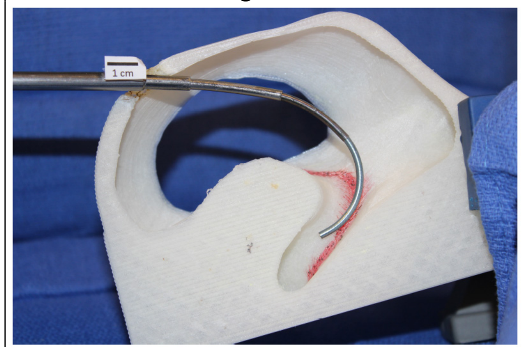


High-resolution T2 weighted MRI imaging of a hydrocephalic ventricle from a 13month old child was processed using the open source imaging software 3DSlicer. This computer-generated 3D model of the ventricular system could be processed using our concentric tube robotics planning algorithm to arrive at an optimal tube design to perform the surgical task. In this example, the navigation challenge of reaching the temporal tip at the level of the choroid fissure was chosen.

Results

Design algorithms applied to the navigation challenge identified a 4-tube design, which was manufactured. Utilizing a 3D printed model of the hydrocephalic ventricle and our novel robotic control software (1), the cannula design successfully and accurately navigated from a Kocher's Point ventricle entry to the temporal horn of the hydrocephalic ventricle (Figure 2).

Figure 2

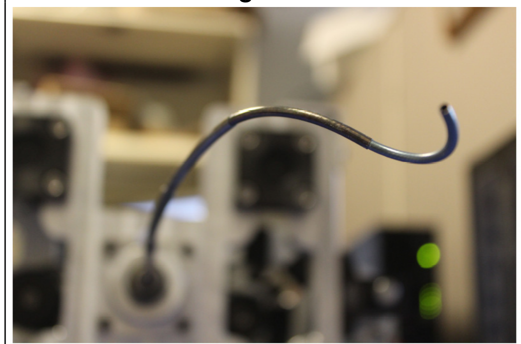


The four-tube concentric tube robot generated based on the design algorithm was manufactured utilizing Nitinol tubes heat-shaped to the design parameters. Application of this tube set to the concentric tube robotic platform previously designed by our group allowed navigation of the choroid fissure from a frontal approach, completing the desired navigation challenge.

Conclusions

We have recently developed a novel neurosurgical concentric tube robot system (Figure 3). As a representative task, we present successful navigation of a custom concentric cannula throughout a hydrocephalic ventricle. Through ongoing interative design of this prototype, concentric tube robotics stand to expand avenues for non-linear surgical approaches and minimally disruptive neurosurgery.

Figure 3



The custom-designed concentric cannula loaded into the neurosurgical concentric tube robot. While a choroid fissure navigation challenge was chosen here, custom tube designs and our novel robotic hardware and control software allow a wide spectrum of navigation challanges to be met.

Learning Objectives

To become familiar with concentric tube robot technology for use in neurosurgery, and the way in which this platform could be utilized for complex, non-linear navigation within the intracranial space.

References

Anor et al. 2011 IEEE ICRA, May 9-13, Shanghai, China

Bergeles C, Vasilyev NV, Codd PJ et al.. International Journal of Robotics Research. 2013