Multi-port Neuroendoscope for Robotic Intraventricular Procedures

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INTRODUCTION

About 20% of brain surgeries are performed to remove lesions located inside or adjacent to the brain's ventricles [**1**]. Using endoscopes, neurosurgeons can navigate their instruments through the ventricles to reach these lesions with less damage to healthy brain tissue than occurs in open surgery. Current endoscopes, however, are restricted by several factors. First, the tools emerge parallel to the endoscope, precluding many of the two-handed surgical techniques of open surgery that are used to dissect tissue and stop bleeding. Second, most neurosurgeons use straight rigid endoscopes that can only image and deploy tools from their tips and so cannot negotiate around corners without causing significant brain retraction injury. While a few neurosurgeons have mastered flexible endoscopes, these instruments typically provide only a single instrument channel. A recently proposed solution to the first problem deploys concentric tube robots from the endoscope working channels to enable dexterous bimanual manipulation (**Fig. 1**) **[2, 3]** The contribution of this paper is to provide a solution to the second problem by introducing the concept of multiple imaging/tool ports on a single endoscope. In this approach, imaging ports can be positioned not only at the instrument tip, but also anywhere and at any angle along the endoscope body. If the imaging and illumination is accomplished using chip cameras and LED's, many imaging ports can be supported in a given diameter instrument while also producing an instrument that is much lighter and easier to manipulate than a standard rigid endoscope.

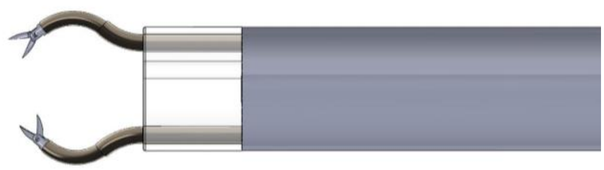

Fig 1. Continuum robots deployed from a neuroendscope.

MATERIALS AND METHODS

As an initial step toward a robotic system, we developed the multi-port concept in the context of an MR-compatible, hand tool for colloid cyst resection combined with septostomy. By developing the device MR-compatible, the benefits of stereoataxy together with a real-time continuous imaging are also provided.

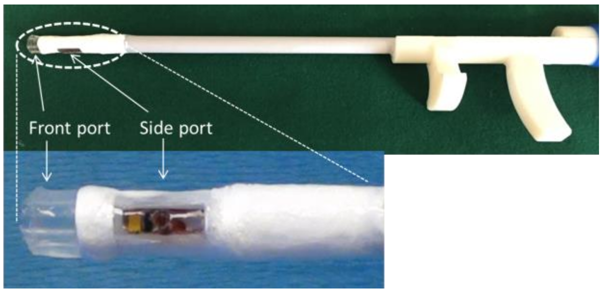

Fig. 2 Novel neuroendoscope prototype.

The neuroendoscope (**Fig. 2**) was designed with two imaging ports enabling tissue resection at the tip port and electrocautery at the lateral port. The device has a total weight of 50 grams, which adds up to less than 150 grams including its camera processor, making it a light-weight neuroendoscope without any torque at the proximal end.

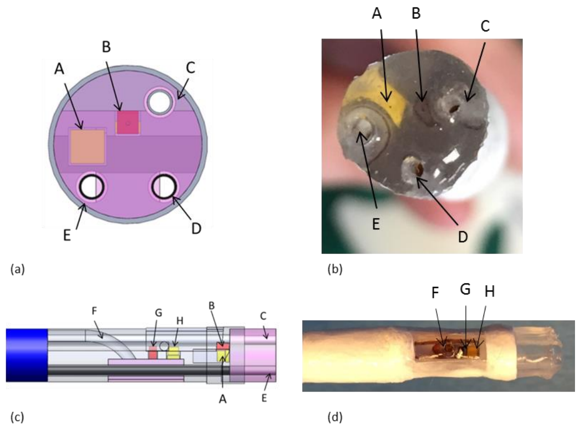

Fig. 3 Imaging ports. (a) CAD model of tip port. (b) Tip port. (c) CAD model of lateral port. (d) Lateral port.
A = Front LED, B = Front camera, C = Front working channel, D = Flush channel, E = Suction channel, F = Side working channel, G = Side camera, H = Side LED.

The novel neuroendoscope has an instrument body (7 mm outer diameter, OD) consisting of a straight 150mm long plastic tube with a proximal ergonomic handle. The tip and lateral imaging ports (**Fig. 3**) each contain a 1x1x1mm CMOS video camera (250x250 pixels, NanEye, Awaiba, Inc.) and an LED for illumination (1.6x1.6x**Q,** Cree Inc, Durham NC). The tip port contains three 1mm channels positioned in the corners of the camera image. These can be used for tools, irrigation and aspiration. The lateral port contains a single 1mm channel with a 7mm radius of curvature, which is sized to deliver a Bugbee wire to perform monopolar cautery for fenestration of the septum pellucidum. All channels are lined by 1.2mm OD polyimide tubes. Each imaging port is molded from optically clear silicone (QSil 218, Quantum Silicones LLC), which serves to encapsulate the camera and LED. While the optical window of the lateral port is ~2mm thick and molded to be flush with the instrument's cylindrical surface, the window of the tip port has been designed with a thickness of ~6mm.

While a much thinner window can be substituted, this thickness was used to enable (1) visualization of inserted tools before they extend from the tip of the endoscope, and (2) safe tissue contact with concurrent imaging.

RESULTS

MRI compatibilty was evaluated in a 3T scanner by inserting the endoscope into the brain of a freshly sacrificed adult Yorkshire pig. Both video cameras were observed to operate inside the scanner with no change in image quality. Furthermore, MR images using standard brain imaging sequences revealed that the imaging artifact (void) matched the dimensions of the device itself (**Fig. 4**).

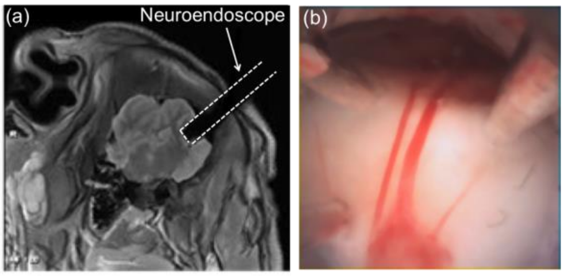

Fig. 4 (a) MR image of porcine brain with endoscope inserted (b) Endoscopic view of porcine ex-vivo ventricle.

Image quality was also evaluated using the USAF 3-bar Resolving Power Test target [**4**]. **Fig. 5** compares images obtained from both imaging ports with that of a clinical rigid endoscope. As shown in Fig. 5a, there are three instrument channels at the tip. As a safety feature, the channels are clear making it is possible to see instruments before they extend from the device. The single instruments channel of the lateral port is visible in Fig. 5b. An image from a clinical endoscope is shown in Fig. 5c for comparison. Image quality is better owing to the use of multiple larger lenses compared to a chip camera. Note that the image from a flexible clinical neuroendoscope, not shown, is likely to be worse than the dual-port prototype owing to fewer image pixels.

DISCUSSION

Despite progress in neuroendoscopy, there are many procedures such as resection of paraventricular lesions, that are still not amenable to a transventricular endoscopic approach. By replacing straight-shafted instruments with needle-sized continuum robots, the dexterity of open microsurgery can be reproduced with an endoscope. The multi-port concept introduced in this paper is a passive, inexpensive alternative to a steerable robotic wrist for enabling reorientation of imaging and tool deployment.

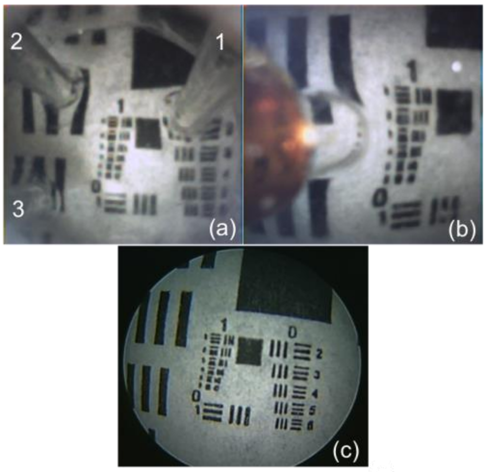

Fig. 5 Endoscope images. (a) Prototype tip port. Instrument channels are numbered, (b) Prototype lateral port. Orange polyamide tube and transparent working channel are visible. (c) Commercial 6mm rigid neuroendoscope. To achieve similar magnification, standoff distance was 10mm for prototype and 15mm for commercial system.

It is made possible by chip camera technology. The CMOS camera used in our prototype, at 1mm on a side, is among the smallest currently available and provides an image size of 250x250=62,500 pixels. For comparison, a fiber bundle of comparable cross section contains only 20,000 fibers / pixels. **[5]** This places the image quality of our endoscope between that of existing rigid and flexible neuroendoscopes.

The prototype shown here was designed for performing colloid cyst resection combined with septostomy with minimal pivoting of the instrument shaft about the center of the burr hole. Pilot ex-vivo tests in human cadaver and phantom brain are underway to achieve further validation.

This particular design choice could also be used in lieu of a steerable endoscope for treating multiloculated hydrocephalus, where the sideport enable the lysis of intraventricular adhesions that could not be fenestrated easily by the tip port alone. Many design variations are possible since the port number, location, orientation and working channels can be tailored to address specific procedures or classes of intraventricular procedures.

REFERENCES

[1] Souweidane M. M., Endoscopic surgery for intraventricular brain tumors in patients without hydrocephalus,. Neurosurgery, 57(4), 2005.
[2] https://www.youtube.com/watch?v=Zs_-G8pD2Jw.
[3] https://www.youtube.com/watch?v=WOIDAc4YtYQ.
[4] Bedard N, Tkaczyk TS. Snapshot spectrally encoded fluorescence imaging through a fiber bundle. J Biomed 17(8), 2012
[5] Friedman G. N., Grannan B. L., Nahed B. V., Codd P. J. Initial Experience with High-Definition Camera-On-a-Chip Flexible Endoscopy for Intraventricular Neurosurgery. World Neurosurg. 84(6), 2015.