Design of a Stiff Steerable Grasper for Sinus Surgery[1]

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1 Background

With the advent of endoscopic sinus surgery in the late 1980's [1], a completely new surgical field was born. The endoscope, passed through the natural orifice of the nose, allowed for much more precise visualization of the operative field and enabled a new understanding of the function of the sinuses. Today, functional endoscopic sinus surgery (FESS) is commonly used to improve the sinuses' natural drainage pathways in patients with chronic sinusitis, to remove pathologies such as nasal polyps and tumors, and even to access the skull base to remove brain tumors.

Commonly used angled endoscopes allow for visualization of nearly every portion of the sinus cavities and skull base. However, traditional tools have not enabled adequate surgical access to all of these areas. This is because the current surgical method requires a nearly direct line of access from the opening of the nose to the surgical target. Due to anatomical obstacles, not all areas visible to the endoscope can be directly accessed in this way. As a result, procedures have been developed to remove anatomical structures in order to clear a direct line of access to hard-to-reach targets. However, removal of these structures comes at a cost, with complications including vascular, nerve and soft tissue damage that can result in pain or numbness in the mouth and face.

Current technique requires one hand to hold the surgical instrument, while the other hand is typically occupied holding the endoscope, as shown in Fig. 1. Generally, these tools are supported entirely by the surgeon's hands, in contrast with other types of laparoscopic surgery in which a trocar provides additional support. As a result, tools must be lightweight and comfortable to hold. These tools have traditionally been designed to be rigid (so as to be easily controlled with one hand), though not necessarily straight. In an attempt to reach around corners and avoid obstacles in the anatomy, some devices incorporate curved tool shafts. However, these are limited in their maneuverability, since the curved shape is fixed during surgery. These rigid tools have been adequate for the majority of surgeries, but as techniques have

Fig. 1 Placement of an endoscope and a traditional rigid grasper tool during endonasal surgery. One hand (not pictured) holds the endoscope, while the other (pictured) holds the rigid grasper.

advanced, surgeons have reached the limits of what they can accomplish with these tools. In order to avoid the need to remove tissue in order to access hard-to-reach sites, new tools must be developed which are capable of navigating through angled pathways in the nasal cavities. A new approach to this problem involving a stiff yet elastic steerable tool tip is presented in this paper. This approach uses a continuum structure. For a review of prior uses of continuum structures in robotic tools, see Ref. [2].

2 Methods

Our objective was to develop a stiff, yet bendable manual grasper with controllable curvature, allowing the surgeon to easily steer the tip of the tool within the sinuses. The device was required to be relatively stiff to effectively accomplish surgical tasks such as grasping and cutting; yet we also required the tool shaft to have the ability to bend locally near tool tip. The goal was to access a larger set of potential targets in the sinus cavities, without the need for a clear line of access between the opening of the nostril and the target site.

User control represented an additional design challenge. We sought a design in which a single hand could comfortably and intuitively control gross tool manipulation, bending of the tool shaft, and gripper opening and closing. We targeted a shaft diameter of 4 mm or less, such that the device could fit through a nostril, and a shaft length and handle width comparable to those of currently available sinus surgery tools (approximately 80 mm and 5 mm, respectively). The CAD model and physical prototype we developed are shown in Fig. 2.

To allow for tool shaft bending, we implemented a "multibackbone" continuum mechanism [3] at the distal end of the shaft, shown in detail in Fig. 3. It consists of a set of 4 superelastic nitinol wires passed through a series of small plastic support disks, which hold them in a desired configuration. These wires are stiff enough to create a structure that can apply reasonable forces to the anatomy during surgery (an open research question is optimizing wire diameters based on exact surgical force requirements), yet are capable of bending significantly without

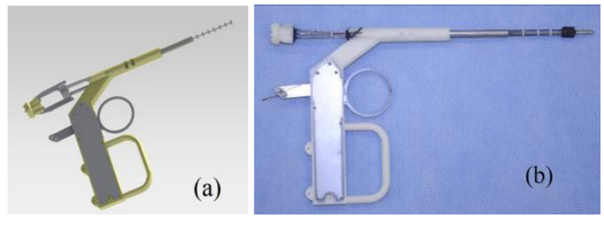

Fig. 2 (*a*) CAD model of tool design, and (*b*) prototype of tool

[1]Accepted and presented at the Design of Medical Devices Conference (DMD2014), Minneapolis, MN, April 7-10, 2014.

DOI: 10.1115/1.4027036

Manuscript received February 21, 2014; final manuscript received March 3, 2014; published online July 21, 2014. Editor: Arthur G. Erdman.

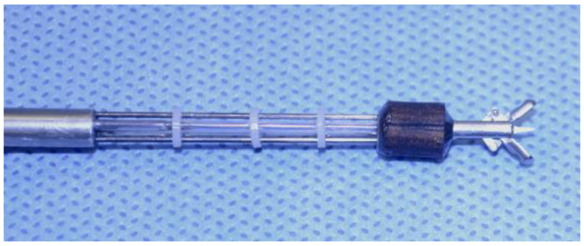

Fig. 3 Multi-backbone bending mechanism with grasper

experiencing plastic deformation. The spacing between the support disks was maintained by placing flexible PTFE tube sections around the wire segments between disks, to serve as spacers. A thumb-activated joystick at the rear of the handle enables the surgeon to control tool shaft bending. As the joystick is deflected, the nitinol wires on one side are pushed forward, while those on the other side are pulled back. As a result, these wires bend, causing the tool shaft to deflect in the direction opposite joystick motion. This deflection is achievable in any direction. This design was inspired by the continuously flexible manipulators featured in some surgical robots [2], and to our knowledge, this tool represents the first time such a multi-backbone mechanism has been used in a manual surgical tool.

A grasper is attached to the tip of the tool. It is actuated by a flexible push-pull wire, which is fed through the center of the hollow tool shaft and into the handle. There, it is affixed to a trigger mechanism, which the user actuates with his or her index finger at the front of the handle. The ergonomics of the device were designed to be similar to those of current endoscopic sinus surgery tools, with the addition of the joystick to control shaft bending. It is hoped that this will facilitate rapid adoption of the new instrument, since surgeons are expected to feel comfortable using it, due to its similarity to devices they already use.

3 Results

Our goal in constructing the prototype described above was to determine the feasibility of constructing the proposed device and to obtain qualitative feedback from surgeons. The intent was to determine whether any modifications or improvements were necessary. In our initial qualitative tests of the tool, we found that surgeons were able to easily use the joystick to deflect the flexible tool shaft in any direction, as shown in Fig. 4, as well as to effectively open and close the grasper tool using the trigger on the front of the handle.

Fig. 4 Prototype deflecting upward under hand control

4 Discussion and Future Work

The results described in this paper are early stage prototyping and design efforts. There remains much research to be done before this tool becomes a commercial product, and even before the merits of our new tool concept can be fully evaluated. First, to provide a clear and obvious advantage with respect to existing tools, we must find ways to increase the achievable curvature. Currently, we are exploring adding mechanisms to the thumb control to amplify the distance the rods are pushed and pulled in response to a given handle deflection. This would permit higher tip curvatures for the same joystick curvature.

Next, we must choose a specific set of sinus surgeries and evaluate their requirements in detail. In particular, the force application requirements and workspace requirements must be determined. This will enable us to size the push-pull rods appropriately to satisfy the force requirements, and also to choose the length and maximum curvature of the bending section appropriately based on the areas it must reach.

Lastly, we will pursue substantial user testing on the benchtop and then in cadaveric specimens. These experiments will be designed to ensure that surgeons are able to effectively use the device to perform the intended surgical procedures.

5 Conclusion

In this paper, we have presented a new tool design for endonasal sinus and skull-base surgery. The tool features a multi-backbone continuously bending mechanism that enables the surgeon to change the curvature of the tool tip. This enables the surgeon to actively steer the grasper within the surgical field during the procedure. The grasper itself is opened and closed by a trigger on the handle.

While this design concept appears promising, much work remains to be done before one can conclusively say that this device will provide valuable benefits to the surgeon. However, it does appear to hold the potential to enhance surgical dexterity in endonasal procedures. In so doing, it is our hope that working in concert with angled endoscopes, it may eliminate the need to remove anatomical features in order to clear a straight line of access to the target in some procedures. If it is effective in doing so, this will make sinus surgeries less invasive and may lead to reductions in complication rates.

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