Design of a Meso-Scale Grasper for Robotic Pediatric Neuroendoscope Tool

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INTRODUCTION

Endoscopic third ventriculostomy (ETV) is a procedure to relieve intracranial pressure by creating a hole at the bottom of the third ventricle, allowing cerebrospinal fluid (CSF) to drain [1]. Many neurosurgical procedures, such as ETV, make use of surgical graspers to collect biopsy samples [2]. Grasping forces exerted by neurosurgical tools on brain tissue have been indicated to range from 0 – 0.3 N for 70% of neurosurgical procedures [3]. Perforating the bottom of the third ventricle in ETV has even been measured to require less than 0.01 N [4].

This paper focuses on the design and evaluation of a meso-scale surgical grasper to be integrated within our previously developed neurosurgical continuum robot [5]. Fig. 1(a) shows the schematic of the proposed integration of the grasper with the continuum robot. The grasper developed was machined using a multi-axis CNC mill (CNC Mini-Mill/GX, Minitech Machinery Corp., GA, United States) and a femtosecond laser (WS-FlexUltra-Short Pulse Laser Workstation, Optec, Frameries, Belgium) and was actuated with a single cable to allow for compatibility with most flexible surgical robots. With the use of micro-machining processes and a tendon-actuated mechanism, the meso-scale neurosurgical grasper had a 1.93 mm OD, appropriate for high-precision neurosurgical procedures and to be introduced through the working channel of commercially available endoscopic tools.

MATERIALS AND METHODS

The proposed grasper design differentiated from recently developed surgical graspers by size, which remained in the 3-4 mm OD range [6], [7]. The grasper consisted of a scissor linkage system with a compression spring encapsulating the input linkage as shown in Fig. 1(a)(inset). This allowed for the grasper to be actuated exclusively by the tension of a nitinol (NiTi) tendon, making it compatible for tendon-driven endoscopic tools as compared to commercially available rigid graspers and forceps.

Each grasper (Fig. 1(b-1)) was machined from 1.5 mm thick 316L stainless steel sheets using a 5-axis CNC micro-mill. The steel sheets were fixed to a Delrin block using high strength adhesives and machined using micro end mills with diameters of 0.3-1.0 mm at spindle speeds ranging from 10k-55k rpm. Each grasper component was then finalized on a femtosecond laser where its final features were refined.

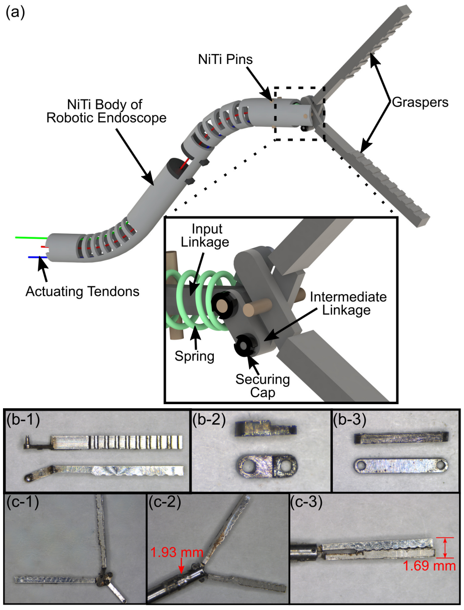

Fig. 1 The (a) proposed robotic endoscope and grasper design with (inset) details of the grasper linkage system shown. Images of the (b-1) machined graspers, (b-2) intermediate links, and (b-3) input linkage. The images of (c-1) the assembled linkage system, (c-2) the linkage system inside of its 1.93mm tube sheath, and (c-3) the closed grasper.

The graspers contained a 0.4 mm extrusion in which intermediate linkages (Fig. 1(b-2)) were placed over and secured using a stainless steel cap, each machined using a femtosecond laser. The intermediate linkages had a length, width, and thickness of 1.6 mm, 0.6 mm, and 0.4 mm respectively and contained a step on the side that interfaces with the input linkage (Fig. 1(b-3)) to ensure all faces mated properly. The intermediate linkages were then constrained to one end of the input linkage using NiTi tubes (OD 0.3 mm) with NiTi caps to hold the assembly together. The input link, machined from 0.4 mm stainless steel on the femtosecond laser, had a length and width of 3 mm and 0.6 mm, respectively. Holes were machined on each side to allow for assembly with the intermediate linkages and for securing a tendon for actuation.

Assembly of the graspers consisted of sliding each

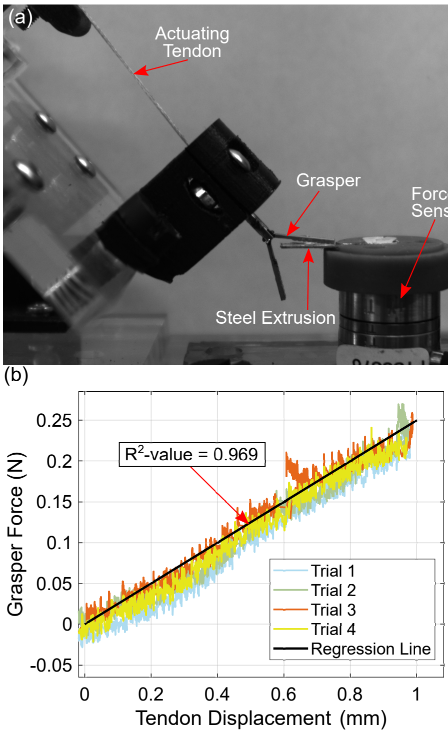

Fig. 2 (a) Image of the grasper force evaluation setup and (b) the results of grasping forces as a function of the tendon displacement.

linkage on its respective shaft and securing it laterally through the use of the machined securing caps. The caps were attached with stainless steel and NiTi flux to keep respective metal components secured. The assembled linkage system, shown in Fig. 1(c-1), was then placed into a 1.93 mm OD NiTi tube. NiTi tubes of 0.3 mm OD were placed inside the said tube, acting as a wall for the spring to compress against. The input linkage and tendon were routed through the spring and pins. The compression spring provided a force for opening the graspers when the tendon was released from tension. The final grasper assembly is shown in Fig. 1(c-2) and Fig. 1(c-3) in its open and closed configurations respectively, where the closed configuration is measured to have an OD of 1.69 mm.

To evaluate the grasping force capabilities, one interior face of the graspers was placed against a steel beam extruding outward from a 6-axis force sensor (ATI Industrial Automation, NC, USA). The force acting downward throughout actuation was taken to be the applied grasping force. The input link was linearly translated using a Kevlar tendon secured to a lead-screw assembly actuated by a brushed DC motor (Maxon Precision Motors, MA, United States). The experimental assembly, shown in Fig. 2(a), was observed using a CMOS camera (ZeluxTM1.6 MP, Thorlabs Inc., NJ, United States) throughout each experimental trial.

RESULTS

The motor was commanded to move the initially slacked tendon from 0-1 mm at a rate of 0.016 mm/s followed by a 30 second rest period. The recorded grasping forces for four trials of motion are shown in Fig. 2(b) where the applied force is shown to be linear with respect to tendon stroke with an R^2-value of 0.969. The average maximum force was recorded to be 0.246 N, which falls in the range of forces required for a large number of neurosurgical interventions [3].

While conducting tests, the grasper was observed to lack the ability to fully return to its open configuration with the aid of the compression spring. This is hypothesized to be due to friction and interstitial spacing introduced by assembly errors. Reducing friction, improving securing methods, and refining the assembly procedure are ongoing work.

DISCUSSION

The development of a meso-scale grasper for use in a neurosurgical robotic endoscope tool was presented in this work. This significantly smaller grasper used actuation strategies compatible with those of current tendon-driven continuum surgical tools and can provide forces in the range of existing clinical graspers. Future works will focus on the improvement of the mechanical design, integration into existing steerable robotic endoscopic tools, and incorporation of grasper force estimation for force feedback.

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