Towards the robotic approach for Endoscopic Lumbar Discectomy (ELD) surgery: design of a mechanism for the manual actuation of the gripper for holding the endoscope.

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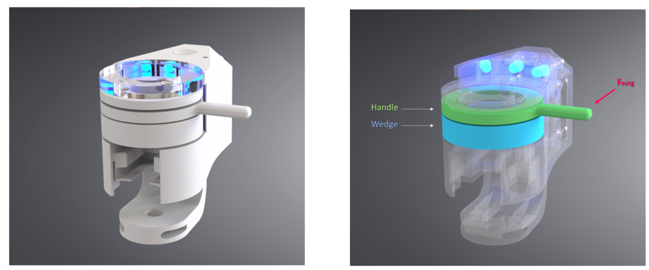
I. INTRODUCTION

Endoscopic Lumbar Discectomy (ELD) is a minimally invasive surgical procedure to remove the herniated material of a disc in the lumbar spine [1]. In the traditional approach, the surgeon holds the endoscope and inserts the instruments into its lumen to reach the surgical window and perform the discectomy. Some steps, such as opening of the ligamentum flavum, require the help of an assistant to hold the endoscope while the surgeon is occupied handling other tools: this operation results in an inevitable waste of time. To overcome this and other drawbacks of the traditional procedure, a robotic approach has been investigated, which involves the use of a collaborative robot to hold the endoscope throughout the procedure. In this context, the gripper and its actuation system must be safe, reliable and lightweight. The following paper describes a novel mechanism for manual actuation of the gripper responsible for holding the endoscope, specifically designed to allow the surgeon to have full control over the gripping force applied.

II. MATERIALS AND METHOD

The design of the mechanical actuator revolves around the flexible gripper used to grasp the endoscope, which has already been implemented in the manipulation of surgical catheters [2]: by pulling apart the two collars at the ends of a cylindrical flexible sleeve along its axis, the internal diameter of the sleeve is reduced. The presence of the endoscope tube inside the sleeve constitutes a constraint that allows the generation of a force that restricts the movement of the endoscope.

In this new design, the collars are pulled apart by exploiting the surgeon's input force, which is converted from tangential to axial by the mechanism shown in Fig. 1.



(a) (b)

Fig. 1. Graphic representation of the end-effector (a). Handle and wedge cam of the mechanical actuator highlighted in the end-effector design.

For the purpose of clarity, the cylindrical mechanism shown in Fig. 1 is represented in a planar configuration in Fig. 2.

After inserting the endoscope tube into the sleeve, the surgeon rotates the handle, applying the tangential force F_{surg} to the rotating handle. Inside the handle is a compliant mechanism that transmits the force to a wedge cam, which converts it into an axial force on the basis of the wedge cam angle α and of the coefficient of friction μ in the contact area and thus pushes the lower sleeve apart from the upper sleeve attached to the end effector frame.

As the handle is rotated and the sleeve is stretched, an increasing bending force is applied to the compliant mechanism until the displacement at the tip is sufficient to lift the tip completely out of its slot on the wedge cam, thus disengaging it from the handle. This causes the force transmission to stop once a maximum force value is reached, which depends on the structural characteristics of the compliant mechanism. The angle of the wedge cam is chosen to nullify the efficiency of the retrograde movement, allowing the surgeon to apply any force between null and maximum to

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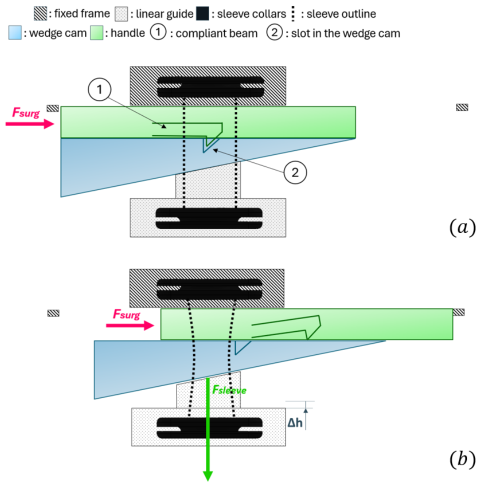

Fig. 2. Planar representation of the mechanism with the same color pattern as in Fig.1. Mechanism at null force configuration (a) and at Maximum force configuration with compliant mechanism fully detached and handle at the end of its stroke (b).

limit the movement of the endoscope. The maximum value of the wedge angle is the one that nullifies the efficiency in Eq. 1.

$$\eta = \frac{\tan(\alpha - \arctan(\mu))}{\tan(\alpha)} \quad (1)$$

The compliant mechanism is designed as a beam that follows the curve of the handle and has a chamfered tip. Twelve handles with beams of different sizes were manufactured to assess the capabilities of the actuation system. For dimensional reasons, the width was kept constant at 6mm, while the width and length were varied. The entire mechanism was made in PLA using FDM additive manufacturing. Performance was assessed by attaching the end-effector to a frame, inserting the endoscope, activating the mechanism to maximum force, and using a digital dynamometer to measure the maximum axial force required to overcome static friction between the endoscope and the gripper. For each handle configuration, the test was repeated five times.

III. RESULTS AND DISCUSSION

Results are shown in Fig. 3. All the configurations tested apart from the thinnest and longest one, were capable of providing a force higher than the minimum force required to lock the endoscope both in the axial and the rotational degrees of freedom. A peak force of

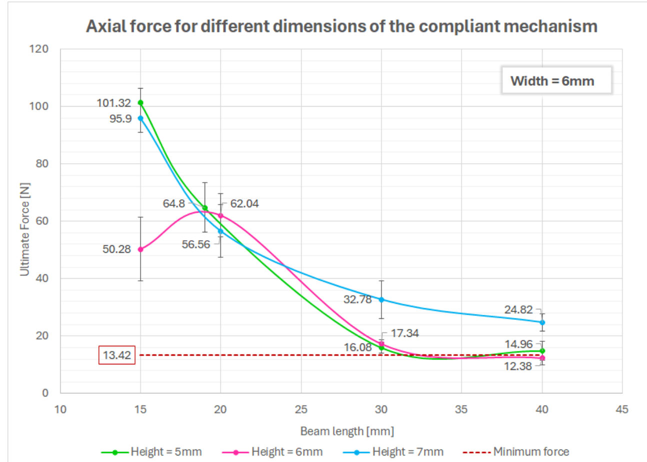

Fig. 3. Axial grasping force provided by the system to the endoscope for different dimensions of the compliant mechanism.

101N was measured. The overall mass of the actuator was 80g.

The end-effector and the actuator system for the gripper were validated by the orthopedic surgeon Dr. Christoph Laux in a functionality test conducted at Balgrist University in April 2023 (Fig. 4).

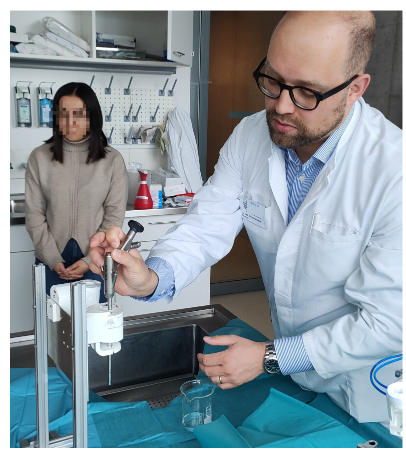

Fig. 4. Surgeon Dr. Christoph Laux testing the functionalities of the end-effector and of the actuator system during the functionality test.

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