Development of a surgical instrument using an elastic vibration wing mechanism

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Abstract. In the field of surgery the ability to handle organs and their associated systems in a stable yet delicate manner is of paramount importance for both the patient and the surgeon to ensure operation efficacy. This paper focuses on the development of flexible tipped surgical forceps. The mechanism is based on a previously developed "elastic vibration wing" which is biomimicry of the propulsion mechanism of a typical fish. The flexible forceps distributes pressure through a network of articulated linkages in order to softly envelop the object to be held. This mechanism was specifically designed for use in endoscopic surgery, however it could also be used in robotics where gentle grasp of an object is required at the end of a robotic arm. The mechanism was designed in 3D-CAD and conceptually prototyped using a 3D printer.

Keyword: Elastic Vibration wing[1], Surgical forceps[2], 3D-printer[3], CAD simulation[4], Pressure relief[5]

1. INTRODUCTION

Recently, there has been an increasing need for surgical instruments that can hold organs delicately yet stably. Such an instrument increases the efficacy of surgical operations by decreasing the physical and mental strain on both surgeons and patients. New bio-mechanism based surgical instruments based in part on the anatomical structure of a fish provide soft handling forceps. The maneuvering mechanism of robotic fish technology in particular has been applied to medical mechatronics. Aquatic animals like fish can swim very fast using minimal power. In regard to prototyping the mechanism the authors have used a seamless design and prototyping process. This process has been used to prototype biologically based mechanisms using 3D-CAD and a 3D-printer. Specifically, this fish based mechanism which produces an elastic oscillating fin combined with the use of a shark skin like surface which effectively reduces hydrodynamic resistance have been found to be effective in creating superior surgical instruments. Classical surgical instruments which exert a large amount of force on a limited number of points on organs are stressful for both surgeons and patients. Furthermore classical instrument's ergonomics often do not consider the surgeon and are often awkward and thus stressful to use.

The purpose of this research is to develop user-friendly surgical instruments that enable more efficient surgery. This process is effectively facilitated by using a more seamless design through to the prototyping process using 3D-CAD and a 3D-printer. The Fig.1 shows the 3D printer used. The basic steps of the system design and prototyping are shown in Fig.2.

Fig.1 3D-Printer

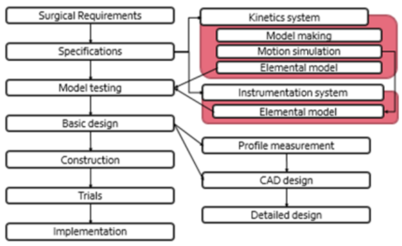

Fig.2 Basic steps of design

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2. Elastic vibration wing forceps

(1) Problems with conventional forceps

Firstly, we outline some of the problems with conventional endoscopic forceps, based on conversations with a number of surgeons. There are three main problems. The first point is about contact, because pressure is focused at two contact points. The second point is about slip, because organs are coated in body fluids. The third point is about the angle of usage, because awkward wrist adjustments need to be made. These problems make operations difficult for doctors and negatively impact patients. So, we have improved the design as follows.

a) Contact points

Firstly regarding the contact points, with a standard set of forceps the points of contact are focused at two points resulting in a high contact pressure. As mentioned earlier by applying the elastic vibration wing of the fish robot mechanism (Fig.3) the pressure is reduced because the contact area is better distributed (Fig.4).

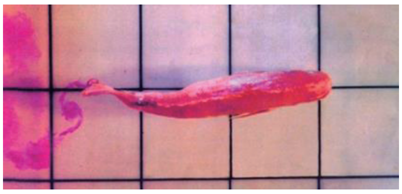

Fig.3 Robotic fish

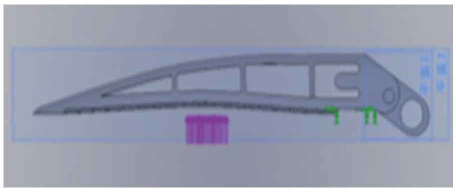

Fig.4 Forceps elasticity shape

b) **Contact surface slip**

Next, regarding contact surface slip. Particularly in the case of endoscopic surgery, as body organs are often coated in body fluids they are very slippery to handle. To deal with this, we have applied a design that is biomimicry of shark skin. Shark skin reduces fluid resistance in one direction but increases it in the opposite direction because of its inherent structure shown in Fig.5. This mechanism has been proven to be effective in reducing slip on the forceps tips. The use of this mechanism has become increasingly used in the medical industry.

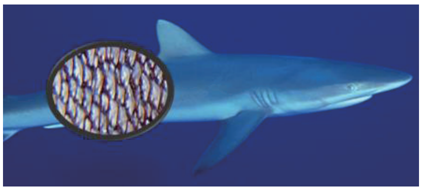

Fig.5 Shark skin

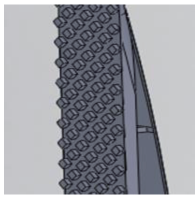

Fig.6 Shark skin surface based flexible forceps

c) **Angle of usage**

Finally, regarding the angle of usage. In any kind of surgery the angle of operation of the forceps needs to be adapted as required, the required angle is often awkward therefore we designed the forceps to make transformation of the operating angle possible. Rotation of the forceps angle can easily be carried out with one hand including lock and release of the angle. The forceps are opened and closed by pulling the trigger shown in Fig. 7. The rotation and rotation lock and release are thumb operated.

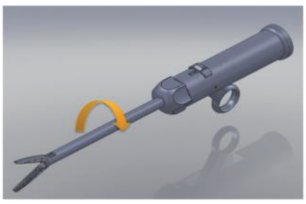

Fig.7 Rotation function

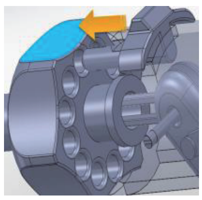

Fig.8 Rotation lock function

3. Modeling by 3D-Printer

After checking the operational functionality, a concept prototype was made using a 3D printer. These are the parts that make up the forceps (Fig.9, Fig.10). Table 1 shows the specifications, the values within the blue frames were specified by the medical staff.

Fig.9 Parts of the Elastic vibration wing forceps

Fig.10 Elastic vibration wing forceps (3D-Printed)

Table 1 Specification of forceps

Description	Size
Total length	360mm
Hand grasp section length	150mm
Tip length	45mm
Tip thickness	7mm
Overall thickness closed	12mm
Opening angle (max)	90°

4. Pressure analysis of forceps

Finally, we conducted an experiment in order to confirm whether the elastic vibration wing forceps reduces the contact pressure. This section explains the method and equipment used to carry out the test.

The experiment was carried out as follows: Firstly, 5 newtons of pressure was applied to the trigger, a plastic hose was used to simulate an organ. This resulted in deformation of the hose. A pressure measuring sheet (PMS) was inserted between the forceps jaw and the hose to obtain a reading of the pressure (Fig.11). This was repeated at 5mm intervals from the tip (Fig.12). The PMS data was then input with a scanner and analyzed by special software (FPD-8010J). The pressure measurement sheet provides a proportional display of pressure exerted.

Fig.13 shows the pressure distribution using regular (solid) forceps and Fig.14 shows the resulting improved pressure distribution using the flexible forceps. The regular forceps were made from the same resin material for comparison. Comparing them, the pressure contact area of the elastic vibration wing forceps is clearly better distributed. So, it was shown that the elastic vibration wing mechanism is effective.

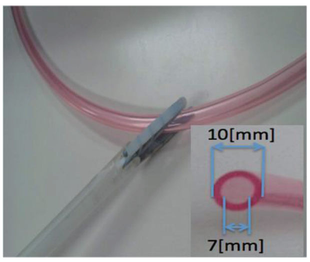

Fig.11 Experimental situation

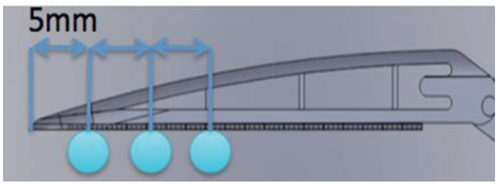

Fig.12 Analysis points

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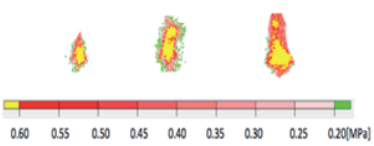

Fig.13 Regular forceps grip

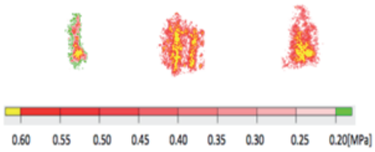

Fig.14 Flexible forceps grip

5. Conclusion

Although these forceps are still under development, the elastic vibration wing forceps concept has potential in a wide variety of situations. We are in the process of designing an actual scale working prototype of the forceps in metal in preparation for the next stage which will be animal testing.

We succeeded in developing a prototype of an endoscopic surgical instrument based on the operating requirements using 3D-CAD and a 3D printer. The motion was simulation in 3D-CAD and a prototype created using a 3D printer confirmed the functionality. This rapid prototype process allows medical personnel to provide feedback regarding user friendliness at an early stage. It is possible to obtain operational evaluation by medical professionals at the design stage, thus it is possible to improve development efficiency of the surgical instrument.

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