Transparent Surgical Device Tips with Fiber Optic Delivery for Laser-Based Tissue Sealing and Cutting

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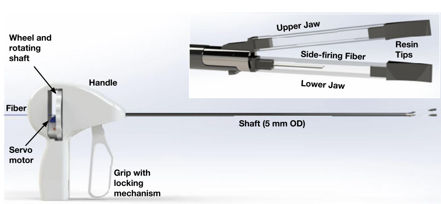
Introduction

- Laparoscopic surgery involves small incisions and specialized instruments to perform procedures on internal organs, offering reduced risks and faster recovery times than conventional open surgery.
- 80% of ~15 million laparoscopic procedures performed globally each year use energy based, radiofrequency (RF) and ultrasonic (US) devices.
- RF and US instruments are commonly used as an alternative to sutures and scalpel blades for rapid hemostatic closure of vascular tissues for laparoscopic surgery.

LigaSureTM, radiofrequency (RF) bipolar electrosurgical device, with frequency of 473 kHz (Medtronic)

Harmonic Focus Shears, ultrasonic (US) technology with frequency up to 55 kHz (Johnson & Johnson)

- We present an alternative infrared (IR) laser based transparent laparoscopic surgical device for vessel sealing and cutting, which should enhance surgical field-of-view.



Concept of IR laser vessel sealing device with inset showing bottom fixed transparent jaw housing optical fiber and top hinged transparent jaw for tissue compression.

Objectives

- Design a fixed lower jaw to house a side-firing optical fiber that delivers laser energy at 90° and reshapes the beam into a uniform linear profile.
- Engineer a hinged upper jaw to apply sufficient tissue compression for effective vessel sealing.
- Ensure rotational stability of the optical fiber within confined device dimensions.
- Prototype and evaluate the complete device for feasibility in minimally invasive surgical applications.
- Maximize transparency of the device to improve the surgeon's field of view.

Methods

Design

1. **Ensure Fiber Stability:** Prevent rotation of the fiber while linear translation occurs.
2. **Device Tip Functionality:** Cater to surgeon preference for curved end tip.
3. **Motor Housing and Manual Rotation:** Allow for rotation of device and house motor used to translate fiber.
4. **Upper Jaw for Tissue Compression:** Ensure sufficient applied pressure utilizing a spring hinge system.
5. **Handle and Component Housing:** A compact handle houses all components ergonomically.

Assembly

1. **Build A Prototype:** Prove a prototype can be assembled and provide advantages over conventional US and RF devices.

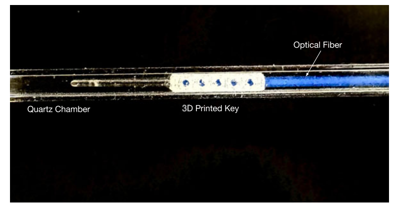
Testing

1. **Performance:** Characterize mechanical, thermal, & optical properties of prototype.

Results

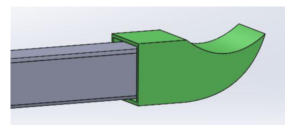
Fiber Stability

- Rotational stability of optical fiber was achieved utilizing CAD and 3D-printed key to match bottom chamber quartz geometry.



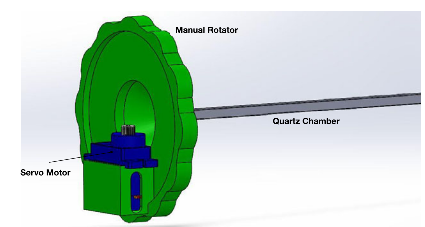
Distal Tip Functionality

- Curved tip was designed and 3D-printed to fit based on surgeon preferences.



Rotation and Housing

- Housing of motor enabling linear translation and rotation of stem was 3D-printed.



Comparative Performance of Major Commercial Energy Based Vessel Sealing Devices

Device	Energy Source	Seal Time (s)	Burst Strength (mmHg)	Thermal Spread (mm)
Prototype	*IR Laser*	*2.0*	*1305*	*0.94*
Harmonic Scalpel™	US	3.3 - 14.3	204 - 921	1 - 1.9
Gyrus PK™	RF	4.0 - 11.1	290 - 648	
EnSeal™	RF	4.1 - 19.2	255 - 928	1.1
LigaSure™	RF	3.0 - 10.0	380 - 885	2.2 - 4

Discussion

Why use an IR Laser at λ = 1470 nm?

- Soft tissues are mostly water (60-80%) and water is main absorber at 1470 nm.
- IR light at 1470 nm penetrates 0.4 mm, matching compressed vessel thickness.
- Compact, inexpensive, high-power diode lasers commercially available at 1470 nm.

Next Steps

- Spring-loaded hinge for the upper jaw utilizing a 0.5 mm thick sapphire window.
- Exploring smaller, more reliable motors.
- Maximize transparency of whole device.
- Testing of prototype on vessels.

Challenges

- Size constraints of typical 5 mm OD port.
- Advancements in conventional devices.
- Mechanical, thermal, optical & biocompatible properties of device.

Conclusion

This novel IR laser-based laparoscopic device offers safer, faster, and more precise sealing of blood vessels. Using IR laser energy and a transparent tip improves visibility, reduces thermal damage, and may outperform conventional RF and US tools, thus paving the way for improved surgical outcomes.

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References