Toward Bipolar Electrosurgery with Concentric Tube Robots

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INTRODUCTION

Some of the earliest clinical motivations for concentric tube robots (CTRs) involved procedures which are often accomplished via electrosurgery [1], [2]. However, the development of electrosurgery in physical prototypes was initially left to future work, as early research focused on mechanics-based models and model-based control methods [3], [4]. In recent years, monopolar electrosurgery has been delivered through CTRs in physical prototypes [5], [6]. Since the ground is attached elsewhere on the patient's body, monopolar tools typically simply require an exposed metal tip to cut.

Bipolar tools, in contrast, carry two electrodes, are traditionally made in the shape of a forceps with each jaw containing one of the electrodes. Bipolar electrosurgery has several general advantages over monopolar, in applications where it can be used, including more localized heating and lower voltages, which lead to a lower risk of injury to the patient [7]. Motivated by these advantages, a bipolar electrosurgery forceps has been designed for delivery through for CTRs [8].

In this paper we propose an alternate approach in which the CTR itself acts as one of the active electrodes, with the other delivered through the CTR's central lumen. We demonstrate teleoperated tissue cutting using a concentric tube robot equipped with this approach to electrosurgery.

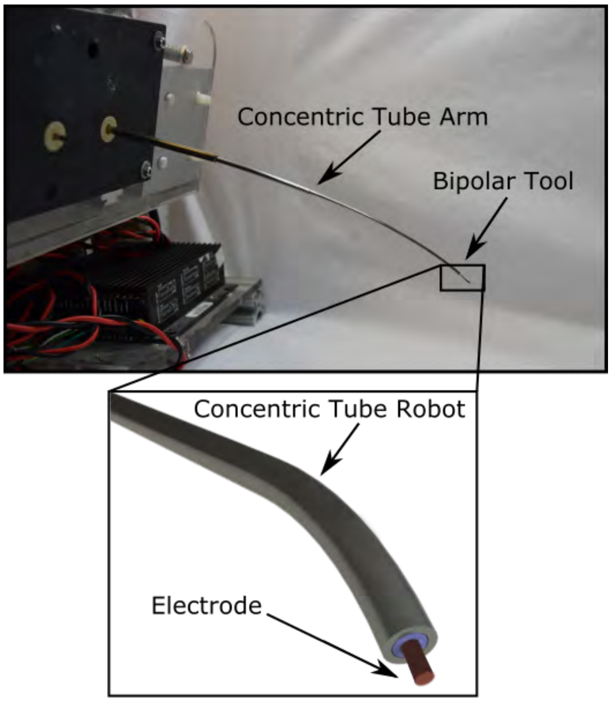

Fig. 1 (Top) Image of the electrosurgery tool mounted to the bimanual robot (Bottom) Close up model of the electrosurgery tool in which a wire passing through the concentric tubes acts as the active electrode to bring power to the tip of the tool and the nitinol tube itself functions as the return path for the current.

MATERIALS AND METHODS

While typical bipolar electrosurgery tools include two electrodes, incorporating two of these down the central lumen of a CTR with appropriate insulation either limits the diameters of the electrodes, or requires relatively larger-diameter concentric tube robots than may otherwise be desirable. Fortunately though, the CTR itself is made of conductive metal (a nickel-titanium alloy called Nitinol) and can function as one of the electrodes. This leaves the entire internal lumen for the other electrode. The following describes our preliminary tests in developing this prototype bipolar tool.

A. Design of the Electrosurgery Tool

We chose 30 AWG wire to function as our active electrode, as it is rated for a high level of current while being small enough (1.2 mm diameter with insulation) to fit within the inner tube of the existing tube set on the robot. We further selected wire with a silicone insulation that was capable of withstanding temperatures of 200°C, so that the wire would not melt during use. The wire was passed through the central lumen of our CTR prototype, and a cable was soldered to the inner tube to attach to an electrosurgical unit (ESU). For our ESU we used an RF Cautery generator (Basco India, Chennai, India). A small section of exposed wire protruded from the tip of the tube, enabling current to flow between this active section and CTR itself when in contact with tissue or in a saline solution. A model of the system is shown in Figure 1. Our ESU is capable of producing 100 W on a 100 ohm load for bipolar cutting, at frequencies of 2MHz. We selected the ESU intensity setting of 1.5 for cutting tissue. We also used a thermal imaging camera to estimate the heat produced by the tool while operational.

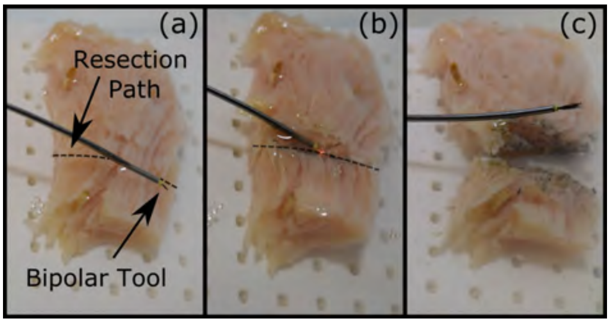

Fig. 2 The experimental results of resection with the robotically operated electrosurgery tool in which chicken breast was cut along the dotted line; shown before (left), during (middle) and after (right) the experiment.

TABLE I Tube Parameters used in CTR

Tube	OD (mm)	ID (mm)	Curvature (m^{-1})
Inner	1.68	1.34	4.5
Middle	2.32	1.87	2.1
Outer	3.80	2.75	0

B. Teleoperated Electrosurgical Tissue Cutting

The robot we used for testing was previously developed in [9], which uses a three tube manipulator and can be teleoperated via a Phantom Omni haptic device (3D Systems, Rock Hill, South Carolina, USA). The tube set, with parameters shown in Table I, consisted of a straight outer tube and curved middle and inner tubes.

To validate the performance of the electrosurgery tool, we sought to emulate the resection of a tumorous portion of tissue by using the bipolar tool to cut apart a portion of chicken breast tissue. A piece of tissue was secured to a 3D printed platform and submerged in a bowl of saline solution. We then teleoperated the robot with our bipolar tool attached to manually resect the desired portion of tissue.

RESULTS

We were successfully able to teleoperate the robot with the electrosurgery tool to resect a portion of chicken breast tissue. The results of this experimental resection are shown in Figure 2. A thermal image of the tool in operation is show in Figure 3.

DISCUSSION

This paper describes our initial work toward integrating bipolar electrosurgery into a concentric tube robot. With minimal cost and effort, we were able to successfully create a concentric tube robot capable of cutting chicken breast. Much future work remains to be done to optimize electrosurgical cutting, including in-depth evaluation of all materials choices, tool tip geometry as it relates to not only cutting but also coagulation, and electrical voltages and power levels used. Ideally bipolar electrosurgery involves the generation of local plasma at the cutting tip, which requires an ESU capable of sophisticated closed-loop control of the cutting process based on electrical feedback. The ESU we used in this paper, while inexpensive, is not designed to facilitate plasma-based cutting. Furthermore, integration of our electrosurgry concept into a complete system suitable for deployment in a practical operating room will also be needed before these results can be clinically deployed.

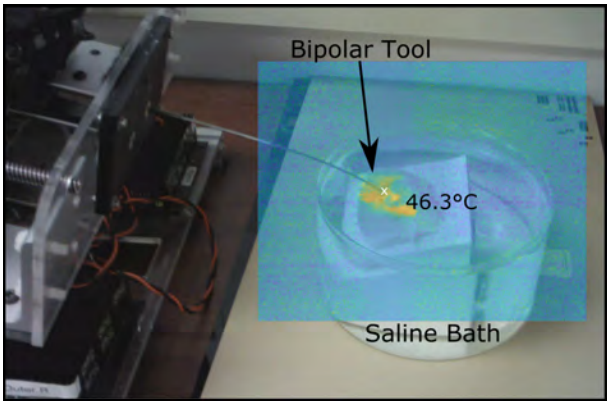

Fig. 3 Thermal image of bipolar tool cutting chicken breast along a path overlaid on the optical image. The maximum temperature in this instance was measured to be 43.6°.

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