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Improving anti-adhesion performance of electrosurgical electrode assisted with ultrasonic vibration

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ABSTRACT

The electrosurgical electrode currently stands out as one of the most commonly used tools in minimally invasive surgery. In order to facilitate tissue cutting and accelerate wound healing, tissue adhesion to the electrosurgical electrode is considered as an extremely urgent problem to be solved. In this paper, a novel ultrasonic vibration assisted (UV-A) electrosurgical electrode is firstly proposed to overcome the problem of tissue sticking. The anti-adhesion effects were evaluated by measuring the adhesion force and the weight of tissue adhesion using the electrosurgical electrode with and without UV-A comparatively. Experimental results show that the average adhesion force and the tissue adhesion mass with UV-A were decreased by approximately 60% and 70% respectively, accompanied by smaller thermal injury area compared with that without UV-A. Moreover, the underlying mechanism of anti-adhesion effect with UV-A was revealed by investigating the influence of ultrasonic vibration on electric current, tissue removal and spark discharge. This research suggests that UV-A is a promising and practical method for improving the anti-adhesion performance of electrosurgical electrode.

1. Introduction

Nowadays, the electrosurgical electrode is widely used to dissect and coagulate tissue in laparoscopic surgery with the benefits, including decreasing the amount of blood loss, rapidly separating tissue and reducing the risk of surgeons [1–4]. Therefore, the electrosurgical electrode has become one of the most welcome surgical tools over the past few decades [5]. However, tissue adhesion to the electrode (tissue sticking) may hamper energy delivery and tear adjacent tissue, which will damage the adjacent tissue and cause the failure of hemostasis. Therefore, it's risky to use this technique since there exists the potential in the possibility of poor wound healing associated with increased postoperative adhesions [6]. In the past few years, numerous investigations have been conducted to decrease the sticking of tissue, such as anti-adhesion coating technology [7–15], optimizing the electrode shape [16,17], spraying cooling liquid [18] and modifying the electrode surface [19,20]. Most solutions to this problem are focused on anti-adhesion coating technology and modifying the electrode surfaces. Coating technologies, including sputtering gold and silver [7,8], employing synthetic polymer films and metal-polymer composite films [9–12], spraying an insulating porous ceramic material [13], and sputtering with hydrogenated Cu-incorporated diamond-like carbon (DLC-Cu) film [14,15] can effectively enhance the anti-adhesion performance of electrosurgical electrode and decrease tissue sticking. However, these coatings may cause many other negative effects, such as the release of toxic gases and increased costs, limiting their clinical application. In addition, some other studies have attempted to modify the hydrophobicity of electrosurgical electrode surface by engraving a spider web micro-stripes [19], using femtosecond laser pulses to modify micro/nanostructured surface [20], etching the periodic distribution of micro-nano-particles and liquid-infused texture on electrosurgical electrode [21,22] to reduce the adhesion of soft tissue to electrode and improve surgical efficiency. However, these modified surfaces are susceptible to be destroyed by high-speed burn tissue and impair the anti-adhesion stability of electrosurgical electrode.

As for anti-adhesion of soft tissue, many studies have demonstrated that ultrasonic scalpel can dissect soft tissue without tissue sticking, but its application in clinical surgery is limited due to the high cost for a single-use device compared with electrosurgical electrode [23–25]. Inspiration from the excellent anti-adhesion performance of ultrasonic scalpel gives new insights into the design of a novel electrosurgical electrode to minimize tissue adhesion. However, up to now, no attempt has been made to combine electrosurgical electrode with ultrasonic vibration to overcome this problem and no publications are available on the underlying

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mechanism of the UV-A electrosurgical electrode. Under this condition, we innovatively integrated electrosurgical electrode with ultrasonic vibration to prevent tissue sticking efficiently and continuously. This study aims to investigate the anti-adhesion performance and stability of UV-A electrosurgical electrode by comparing the adhesion force and tissue adhesion with and without UV-A. Besides, both of the adhesion strength of tissue adhesion and thermal injury to adjacent tissue with and without UV-A were evaluated. Finally, the underlying anti-adhesion mechanism with UV-A was analyzed.

2. Experimental setup and methods

2.1. UV-A electrosurgical electrode unit

Fig. 1(a) shows one UV-A electrosurgical electrode unit, which consists of an electrosurgical power supply and a self-designed ultrasonic transducer. The electrosurgical power is supplied to back cylinder and the ultrasonic power is supplied to piezoelectric plates (PZT's). Two rubber sheets that located between cylinders and copper sheets are used for insulating electrical circuit and ultrasonic circuit to avoid electrical interference. Fig. 1(b) shows the sectional view of the UV-A electrosurgical electrode, wherein the ultrasonic transducer is mechanically combined with a surgical electrode (made of titanium alloy). The longitudinal mode vibration of the electrode end is excited by two oppositely-polarized PZT's. The dimensions of PZT's correspond to that of surgical ultrasonic scalpel. By adjusting the length of electrode, the vibrational frequency can be controlled at 42 kHz. The vibrational amplitude for this experiment is set to be 51 μm, by changing the output power of ultrasonic power supply. In this experiment, only changing the moving velocity, other parameters remained unchanged.

2.2. Force measurement

The electrosurgical electrode was clamped and controlled by one XY-translation stage, so as to achieve the stepless regulation of moving velocity. One two-dimensional (2D) force transducer was used to measure adhesion force and cutting force, as shown in Fig. 2(a). The maximum measurable values of adhesion force and cutting force are both 10,000 mN and the resolution of measurable force is 0.01 mN. To measure adhesion force and cutting force, a piece of fresh chicken breast tissue was fixed on the substrate. The measurement method for adhesion force is shown in Fig. 2(b), where the electrode was loaded on the tissue under a certain pressure and then lifted at a velocity of 0.5 mm/s. The adhesion force under different loads (20 mN, 40 mN, 60 mN 100 mN, 200 mN) was measured by the force transducer. Fig. 1(c) shows the measurement method for cutting force, where the electrode cut tissue along vertical direction at five velocities (0.1 mm/s, 0.2 mm/s, 0.5 mm/s, 1 mm/s and 2 mm/s). Each force value was measured five times. The whole cutting process in soft tissue was recorded using a high-speed camera (I-velocity LT, Olympus, Japan) with a recording speed of 200 frames per second.

2.3. Measurement of the weight of tissue adhesion

The weight of electrode was measured by a precision balance (BSM220.4, 220 g/0.0001 g), the weight of tissue adhesion was calculated as the weight of electrode after-cutting minus the weight of electrode pre-cutting.

2.4. Measurement of electric current across soft tissue

Fig. 3 shows the measurement circuit for the electric current across soft tissue, in which R_1 is the electric resistance of UV-A electrosurgical electrode, $R_2 = 10\ \Omega$ is an external resistor, and R_3 is the electric resistance of soft tissue, usually thousands of ohms. So the external resistor has little effect on the measurement circuit. The voltage U_2 across R_2 was measured using an oscilloscope. According to Ohm's law $I_2 = U_2/R_2$, the current across soft tissue was obtained.

3. Results and discussion

3.1. Influence of ultrasonic vibration on tissue anti-adhesion

3.1.1. Influence of ultrasonic vibration on adhesion force

In order to study the influence of ultrasonic vibration on tissue anti-adhesion of electrosurgical electrode, the adhesion force test on soft tissue was performed. The output mode and power of electrosurgical electrode were set to "cut" mode and 40 W

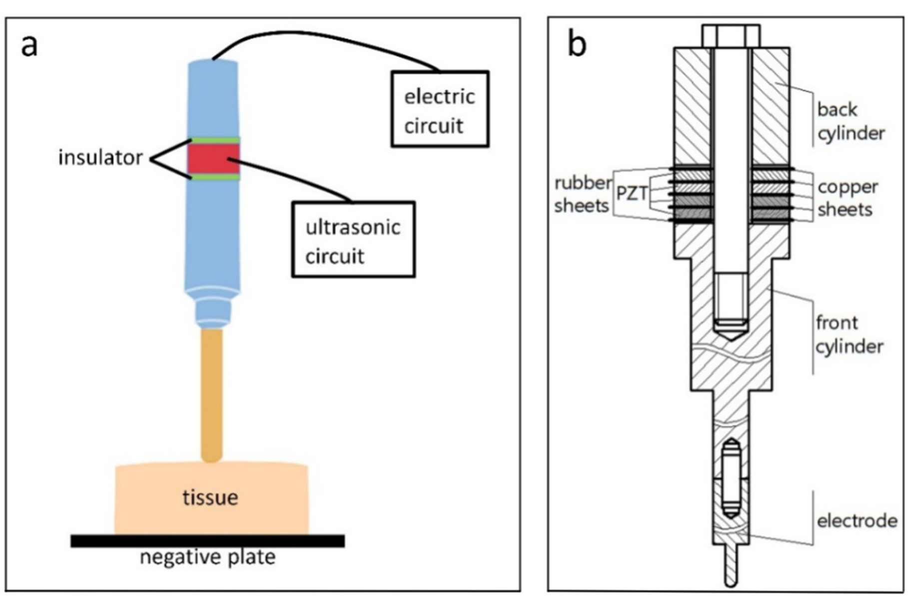

Fig. 1. (a) Structural schematic of the UV-A electrosurgical electrode unit; (b) Sectional view of the UV-A electrosurgical electrode.