Original Research

Study of laparoscopic monopolar devices and its thermal effects

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Objective: Energy devices are frequently used in minimally invasive surgeries (MIS). For MIS involving gynecologic malignancies, energy devices should be used cautiously to prevent thermal injuries to nearby organs. We evaluated monopolar electrosurgery devices and measured increases in temperature in the tissue and device. *Methods*: Briefly, the surface of a porcine tissue was incised using short and long activation times. Subsequently, the maximum temperature at the tip of the monopolar device, the cooling time required to reach a temperature of 60 °C, and the maximum tissue temperature were recorded. *Results*: Longer activation time was correlated with a higher tip temperature. With all activation times, there was an increase in the tip temperature that exceeded 100 °C. The cooling time to reach 60 °C was faster with the short activation times than with the long activation times. Even with the same output, the temperature decreased faster in the coagulation mode, suggesting that the cooling times were shorter with lower outputs. The tissue temperature dropped to 60 °C or less within 1 s in the cut mode but required approximately 2 s in the coagulation mode at 40 W. The temperature of the dissected tissue increased to 60 °C or higher; the cooling time was longer with high output and in the coagulation mode. *Conclusions*: We revealed that the activation of the monopolar device under routine use conditions exceeded a temperature of 100 °C. Additionally, the temperatures of the tip and tissue were significantly higher in proportion to the output and time. For MIS involving gynecologic malignancies, careful attention is necessary to avoid thermal injury.

Keywords

Minimally invasive surgery; Monopolar device; Thermal injury

1. Introduction

Energy devices are frequently used for minimally invasive surgeries (MIS) such as laparoscopic and robotic surgeries. MIS can be performed using either monopolar or bipolar devices in conjunction with a specialized instrument. Each device requires specific instruments and has its own distinct advantages. Monopolar devices can be used for several modalities including cutting and fulguration. When using a pencil instrument, the active electrode is placed at the entry site, and it can be used for both tissue cutting and coagulate bleeding. Bipolar devices require a lower voltage waveform to achieve hemostasis, allowing for the prevention of nearby organ damage. However, one disadvantage of bipolar devices over monopolar devices is the increase in operation time due to the low power setting needed for coagulation. Although these devices are associated with a shorter operation time and minimal blood loss, the incidence of inadvertent injury reportedly ranges from 0.6 to 5 per 1,000 [1–4]. Thermal injury is one of the most common causes of inadvertent injury. With MIS for gynecologic malignancies or extensive dissection, such as that required in endometriosis surgery, energy devices should be used cautiously to prevent unintended thermal injury to nearby organs and structures that are sensitive to heat, such as the ureters, intestine, blood vessels, and nerves. To avoid thermal injury, it is necessary to monitor the peak temperature and residual heat at the tip of the instrument and target tissue. Therefore, this study aimed to evaluate monopolar electrosurgical devices and to measure the increase in the temperature of the device and target tissue.

2. Materials and methods

We used the Opti4^{TM} (Medtronic plc., Dublin, Ireland) monopolar electrosurgical device powered by the Valleylab^{TM} FT10 energy platform that was classified in wattage-based units (Medtronic plc., Dublin, Ireland). The shape of the tip was a curved spatula. Thermography was performed using an R500EX-Pro camera (Nippon Avionics Co., Ltd., Yokohama, Japan) with an InfReC Analyzer NS9500 Standard software (Nippon Avionics Co., Ltd., Yokohama, Japan). The study was performed using a porcine tissue. The output of the monopolar device was set to 20 W and 40 W for the cut mode (pure cut mode: peak voltage 1287 V, duty cycle 100%) and coagulation mode (fulguration mode: peak voltage 3448 V, duty cycle 6.25%), respectively.

The porcine tissue surface was incised using a short activation time (1 s, 3 times per s) and long activation time (3 s, 5 s). Additionally, the maximum temperature at the tip of the monopolar device, the cooling time required to reach a temperature of 60 °C, and the maximum tissue temperature were recorded. We repeated five experiments for each condition.

This was an *ex vivo* animal study. The experiments were performed under the guidelines set forth by the Helsinki Dec-

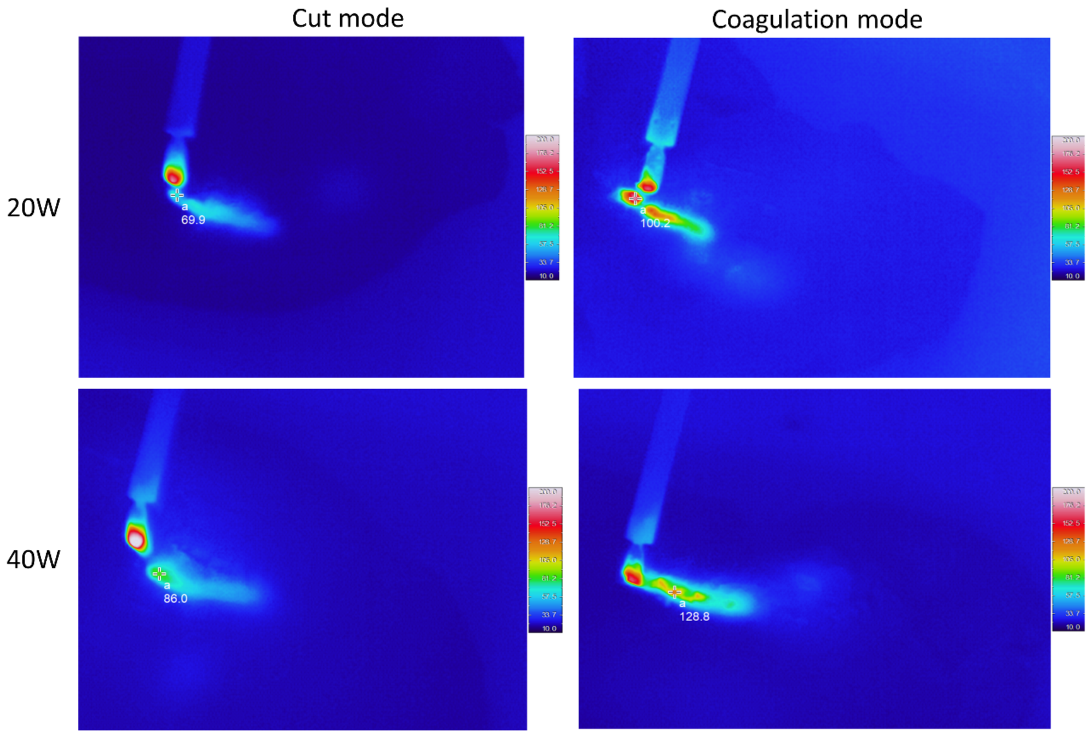

Fig. 1. Thermography of the porcine tissue and tip. The temperature of the tissue increased the most in the coagulation mode (40 W) and the least in the cut mode (20 W).

Table 1. Maximum temperature of the tip when activated for 1 to 5 s

Type of activation time	Duration of activation	Tip temperature (°C)	*P*-value
Short activation time	1 s	139.5 ± 5.9	0.004877
	1 s × 3 times	148.6 ± 34.7	
Long activation time	3 s	197.7 ± 46.6	
	5 s	231.5 ± 36.0	

laration of 1975, as revised in 2000. Approval from the institutional review board was not needed.

Statistical analysis was performed using analysis of variance with multiple comparisons. The results are reported as mean ± standard deviation. Significance was set at P-value < 0.05.

3. Results

Table 1 shows the maximum instrument tip temperatures measured immediately after the four activation cycles. The monopolar device output was set to 20 W for the cut mode. Longer activation time was significantly correlated with higher tip temperatures; with all activation times, there was an increase in the temperature that exceeded 100 °C (P = 0.004877).

The output was performed under the same conditions. The time required for cooling to a temperature of 60 °C was measured (Table 2). The temperature decreased significantly faster with the short activation time (1 s, 1 s, 3 times) than with the long activation time (3 s, 5 s, P = 0.000552). In the cut mode, at a constant output of 20 W, longer activation time was correlated with higher tip temperatures, which exceeded 100 °C at all activation times.

The output of the monopolar device was set to 20 W and 40 W in the cut mode and coagulation mode, respectively, and the cooling time required for the tip to reach a temperature of 60 °C was measured (Table 3). Even for the same power output, the temperature was found to decrease faster in the coagulation mode, demonstrating that both lower output and coagulation mode were associated with a shorter cooling time.

Next, the increase in temperature and cooling time for the target tissue were measured in the two modes (Fig. 1). We observed that the temperature increased the most in the coagulation mode (40 W) and the least in the cut mode (20 W) (Table 4). The target tissue temperature decreased to 60 °C or less within 1 s in the cut mode but required approximately 2 s in the coagulation mode at 40 W (Table 5).

4. Discussion

In this study, we revealed that the activation of the monopolar device under routine use conditions exceeded

Table 2. Decrease in the device tip cooling time to 60 °C when activated for 1 to 5 s

Type of activation time	Duration of activation	Time (s)	*P*-value
Short activation time	1 s	2.0 ± 1.1	0.000552
	1 s × 3 times	4.4 ± 3.0	
Long activation time	3 s	12.0 ± 7.2	
	5 s	19.8 ± 6.3	

Table 3. Decrease in the device tip cooling time to 60 °C when activated for 3 s

		Output (W)		
		20	40	
Mode	Cut	12.0 ± 7.2	19.3 ± 8.1	*P* = 0.21309
	Coagulation	5.1 ± 4.0	12.5 ± 6.0	*P* = 0.092062
		P = 0.13458	*P* = 0.226449	

Table 4. Maximum temperature of the tissue when activated for 3 s (°C)

		Output (W)		
		20	40	
Mode	Cut	66.9 ± 9.0	84.5 ± 7.3	*P* = 0.009492
	Coagulation	96.3 ± 8.3	116.7 ± 24.0	*P* = 0.109442
		P = 0.000672	*P* = 0.020784	

Table 5. Decrease in the tissue cooling time to 60 °C when activated for 3 s

		Output (W)		
		20	40	
Mode	Cut	0.09 ± 0.08	0.55 ± 0.16	*P* = 0.00038
	Coagulation	1.40 ± 0.59	2.21 ± 1.07	*P* = 0.180306
		P = 0.00121	*P* = 0.009271	

temperatures of 100 °C. The tip and tissue temperatures were significantly higher in proportion to the output and time. Ureteral injury remains a major complication of radical hysterectomy or extensive dissection, such as that required for endometriosis surgery. In radical hysterectomy, ureter injuries usually occur during dissection of the periureteral tissue, which is performed to confirm ureter passage and find the uterine artery. Laparoscopic radical hysterectomy is associated with a significantly higher risk of intraoperative and postoperative urologic complications than abdominal radical hysterectomy [5]. Hwang and Kim (2020) reported that the odds ratio of the risk of intraoperative urologic complications with laparoscopic radical hysterectomy compared to that with abdominal radical hysterectomy was 1.40 [95% confidence interval 1.05-1.87]. As energy devices are often used in laparoscopic surgery, the risk of a ureter injury may be high. Thermal injury is one of the most important causes of a ureter injury in laparoscopic surgery. The use of monopolar devices may cause thermal injuries in MIS for gynecologic malignancies and must therefore be used with caution.

Although a momentary temperature increase occurs at the tip of the device in the cut mode, the tissue temperature does not increase sharply. In contrast, in the coagulation mode, the tissue temperature increases sharply even when the temperature of the tip does not increase. During surgery, however, the temperature at the tip of the monopolar device would not increase in the same manner as it did in this experiment when the loose binding tissue is cut off. However, when dissecting a hard tissue, such as an adhesion or endometriotic tissue, it is necessary to carefully select the output time and incision mode.

The clinical impact of increased tissue temperature depends on both the maximum temperature and the period of time the tissue is exposed to elevated temperatures. Denaturation of tissue proteins and thermal damage occur at temperatures exceeding 40 °C [6]. The critical temperature to cause nerve injury has been reported to be 60 °C [7]. In this experiment, the tissue temperature exceeded 60 °C even in the low-output cut mode; therefore, organ damage is highly probable.

In MIS for gynecologic malignancies or extensive dissection, such as that performed in endometriosis surgery, the residual heat at the tip becomes a problem when using an ultrasound device. The tip of the ultrasound device continues to increase the tissue temperature even after the final activation is completed. In this study, the temperature of the ultrasound device tips increased up to 100 °C or more and remained at that temperature for up to 8 s after completing the dissection [8]. Residual heat is not a major concern when using a vessel-sealing device; however, when the tissue is sealed, subsequent dissection becomes difficult. A monopolar electrosurgical device is a fast and sophisticated cutting tool. Therefore, it is commonly used in gynecologic malignancy surgeries. However, high tissue temperature changes during and after monopolar cutting are associated with emission of surgical smoke [9, 10]. Excessive surgical smoke impairs visibility in MIS and interferes with safe surgery. Therefore, to suppress surgical smoke, it is also important for surgeons to be cognizant of the type of monopolar mode being used.

This study has some limitations. First, this was an experimental study using porcine tissue; therefore, the conditions were different from those present during surgery on the human body. For this study, for example, the porcine tissue was separated from the body, and the temperature in the room during the experiment was 25 °C, which is much lower than that of the human body. Blood flow also carries heat away from the target tissue in the human body. Additionally, the temperature increase and tissue resistance (Ω) in the closed abdominal cavity are different from those during experiments in a large room. Moreover, the increase in temperature of the monopolar device depends on the current density. For example, the current density is determined by the type and thickness of the tissue to be dissected (e.g., how to touch the area), the shape of the tip of the monopolar device, output setting, output time, and strength of the counter traction. Therefore, these outcomes cannot be generalized to all surgical situations. Nonetheless, we believe that this study is important since it demonstrated the temperature of the dissected tissue and at each tip using thermography, allowing for a better understanding of potential thermal injury to human organs during surgery.

5. Conclusions

In MIS such as laparoscopic and robotic surgeries, it should be noted that temperature increases at the tip of the energy devices may cause damage to nearby organs. A device such as the FT10 monitors for changes in tissue impedance and adjusts the energy output to deliver the appropriate amount of power for the desired tissue effect. Additionally, these devices adjust the current and voltage to maintain a consistent surgical effect across a wide range of patient tissue resistance/impedance. As shown in this experiment, the temperature of the dissected tissue increased to 60 °C or higher, and the time required for cooling was longer with high output and in the coagulation mode. In gynecologic malignancy surgery or extensive dissection, such as that performed in endometriosis surgery, gynecological oncologists often use monopolar devices near the ureters, nerves, intestines, and blood vessels. Therefore, careful attention is essential to minimize thermal injury.

Author contributions

All authors conceived and designed the experiments. MM performed the experiments and analyzed the data. MM and MT wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The experiments were performed under the guidelines set forth by the Helsinki Declaration of 1975, as revised in 2000. Approval from the institutional review board was not needed.

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Conflict of interest

Motoki Matsuura and Masato Tamate have received honoraria from Medtronic for teaching laparoscopic surgery. Other authors have no conflicts of interest or financial ties to disclose.

Consent to participate

Not applicable.

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